Geological and field control and diagnostics of treatment efficiency of a wellbore zone within carbonate reservoirs

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Abstract. It is established that geologic parameters of deposits have a significant impact on HAT efficiency, followed by parameters reflecting the technological features of wells and deposits, and technological parameters of the treatment. The set of informative parameters that determine the most effective treatment is different in the conditions of different groups of low-productive objects of carbonate reservoirs. Field and statistical models to assess and forecast the HAT efficiency according to the parameter reflecting various indicators in complex are proposed. The models can be used to select wells for treatment and to define the approximate treatment parameters.

1. Introduction

The efficiency analysis of hydrochloric acid treatment of wells in low-productive oil deposits of carbonate reservoirs indicates significant influence of geological features on the effect expressed by various parameters. These features make it possible to reasonably select wells for bottomhole zone treatment and to define the approximate parameters of treatment [1-8].

For the conditions of various groups of objects in carbonate reservoirs (characteristics of groups are given in the work [9]), the complex effect on the efficiency of hydrochloric acid treatments (HAT), parameters reflecting the geological features of deposits, technological features of wells and deposits, processing technology was studied. Simple HAT and HAT under pressure were considered. The efficiency was characterized by the following indicators: total gain of oil production ($T_3$), which was determined taking into account the production decline; absolute average flowrate gain ($T_2$) over treatment time; relative average flowrate gain ($T_1$) over treatment time.

2. Materials and methods

The parameters reflecting geological, physical and physicochemical properties of formations and their saturating fluids, as well as initial formation conditions were considered as variables influencing the HAT efficiency – well productivity coefficient ($C_{ef}$), effective net oil thickness ($N_{e}$), average thickness of oil-saturated sublayers ($N_s$) and their amount ($n$), oil saturation factor ($F_{os}$), viscosity ($\mu_o$), relative viscosity ($\mu_r$), density ($\rho_o$) of formation oil, gas content ($G$), saturation pressure ($P_{sat}$) of formation oil, formation depth ($N_{dep}$), initial formation pressure ($P_{for}$) and temperature ($t_{for}$); parameters characterizing technological peculiarities of wells and formations – time from the moment of well operation commencement to the moment of HAT performance ($t$), maximum flowrate prior to HAT.
(\(Q_{\text{max}}\)), well flowrate (\(Q_1\)), water encroachment (\(B_1\)), accumulated oil production (\(Q_{\text{acc}}\)), current formation pressure (\(P_{\text{for cur}}\)) at the time of HAT, recoverable oil reserves in a well (\(Q_{\text{rec}}\)) (estimated by statistical methods), degree of reserve recovery (\(Q_{\text{acc}}/Q_{\text{rec}}\)), relative formation pressure decline at the time of HAT (\(P_{\text{for cur}}/P_{\text{for}}\)), HAT frequency (\(N\)); parameters characterizing HAT technology – injection pressure (\(P_{\text{inj}}\)), volume of pumped acid (\(V_l\)), concentration (\(C\)) and relative volume of pumped acid (\(N_e/V_a\)) [10-14].

A comprehensive estimate of efficiency and the study of the degree and nature of the influence of geological and technological parameters were implemented through the construction and analysis of statistical models using the canonical correlation method. The models were built as follows:

\[
a_1T_1 + a_2T_2 + a_3T_3 = b_1X_1 + b_2X_2 + \ldots + b_nX_n,
\]

where \(a_1, a_2, a_3, b_1, b_2, \ldots, b_n\) – constant empirical coefficients of the equation; \(X_1, X_2, \ldots, X_n\) – considered variables that affect HAT efficiency.

The value of performance indicators (left part of the equation – the first set of variables) and the parameters that affect it (right part of the equation – the second set of variables) were thus standardized, which made it possible to determine the most significant parameters from the values of empirical coefficients. The models were built separately for the wells of ten groups of objects, each of which has specific geological structure.

### 3. Results and discussion

The table shows the constant coefficients of canonical variables, the maximum canonical correlations at the same time vary from 0.581 to 0.934 (on average – 0.808), i.e. they are quite high and indicate the possibility of using the obtained models to solve the problems of assessing and forecasting the efficiency of hydrochloric acid treatments.

| Group of objects | \(T_1\) | \(T_2\) | \(T_3\) | \(C_{ef}\) | \(N_e\) | \(N_{\text{for}}\) | \(n\) | \(m\) | \(F_{\text{os}}\) | \(\mu_o\) | \(\mu_r\) |
|------------------|-------|-------|-------|---------|-------|---------|-----|-----|-------|-------|-------|
| 1, 2             | 0.264 | 0.702 | 0.703 | 0.104  | 0.236 | 0.086   | 0.158|      |       |       |       |
| 3                | 0.896 | 0.664 | 0.588 | 0.333  | 0.229 | 0.027   | 0.221| -0.102| -0.079|       |       |
| 4                | 0.945 | 0.737 | 0.728 | 0.207  | 0.218 | 0.018   |       | 0.375 | 0.106 | -0.028| -0.066|
| 5                | 0.069 | 0.982 | 0.957 | 0.316  | 0.079 | 0.134   | 0.311| -0.058| -0.053|       |       |
| 7                | 0.035 | 0.930 | 0.955 | 0.566  | 0.245 | 0.325   |       | -0.278| -0.247|       |       |
| 10               | 0.491 | 0.794 | 0.709 | 0.696  | 0.297 | 0.579   |       | -0.327|       |       |       |
| 11               | 0.052 | 0.972 | 0.966 | 0.504  | 0.305 | 0.443   | 0.530|       |       |       |       |
| 12               | 0.416 | 0.963 | 0.685 | 0.652  | 0.447 | 0.398   |       |       |       |       |       |
| 13               | 0.995 | 0.805 | 0.860 | 0.868  |       | 0.812   |       |       |       |       | -0.082|
| 14               | 0.092 | 0.292 | 0.209 | 0.733  | 0.933 | 0.514   |       |       |       |       | -0.501|
Table 2. Constant coefficients of canonical variables

| Group of objects | po | G | Ndep | Pert | t | Qmax | Qi | B1 | Qacc | Qrec |
|------------------|----|---|------|------|---|------|----|-----|------|------|
| 1, 2             | -0.197 | 0.161 | 0.176 | -0.398 | 0.065 |
| 3                | -0.199 | 0.277 | 0.744 | -0.318 | 0.278 |
| 4                | -0.199 | 0.277 | 0.744 | -0.318 | 0.278 |
| 5                | 0.157  | 0.157 | 0.157 | -0.081 | 0.169 |
| 7                | 0.158  | 0.158 | 0.158 | 0.318  | 0.158 |
| 10               | -0.251 | 0.516 | 0.505 | -0.086 | 0.688 |
| 11               | 0.533  | 0.358 | 0.358 | 0.040  | 0.532 |
| 12               | -0.397 | 0.302 | 0.302 | -0.548 | 0.331 |
| 13               | 0.516  | 0.505 | 0.505 | 0.350  | 0.688 |
| 14               | -0.167 | 0.179 | 0.179 | 0.350  | 0.688 |

Table 3. Constant coefficients of canonical variables

| Group of objects | Qacc/Qrec | Pert | Pert cur | Pert cur | N | C | Va | Pij | N/Va |
|------------------|-----------|------|----------|----------|---|---|----|-----|------|
| 1, 2             | -0.176    | 0.179 | 0.179    | 0.179    |   |   |    |     |      |
| 3                | -0.015    | 0.161 | 0.161    | 0.161    |   |   |    |     |      |
| 4                | -0.029    | 0.299 | 0.299    | 0.299    |   |   |    |     |      |
| 5                | -0.029    | 0.299 | 0.299    | 0.299    |   |   |    |     |      |
| 7                | -0.021    | 0.076 | 0.076    | 0.076    |   |   |    |     |      |
| 10               | -0.163    | 0.644 | 0.644    | 0.644    |   |   |    |     |      |
| 11               | -0.174    | 0.324 | 0.324    | 0.324    |   |   |    |     |      |
| 12               | -0.089    | 0.191 | 0.191    | 0.191    |   |   |    |     |      |
| 13               | -0.089    | 0.191 | 0.191    | 0.191    |   |   |    |     |      |
| 14               | -0.277    | 0.377 | 0.377    | 0.377    |   |   |    |     |      |

Positive empirical coefficients on the left side indicate that with the increase of any indicator reflecting efficiency, the remaining indicators also increase. The left part characterizes the efficiency of treatment taken as a whole, however, if in the conditions of the groups of objects 3, 4, 10, 12, 13, 14 the contribution of each indicator is approximately equal. This means that in the conditions of groups of objects 1, 2, 5, 7, 11, the complex parameter reflects mainly the increase of the flowrate and the total increase of oil production.

The analysis of constant coefficients and their ranking showed that under the conditions of the groups of objects 4, 5, 7, 10, 13, 14 geological parameters have the main influence on the efficiency of treatment, followed by the parameters reflecting the peculiarities of wells and deposits. The groups of objects 1, 2, 3, 11, 12 demonstrate the inverse scenario. The third group, which includes parameters reflecting processing technology, has less influence compared to these two groups of parameters.

The features of the groups of objects determine different set of geological parameters, which determine the efficiency of treatment within each group.

The following geological parameters (in the descending order of their contribution) affect the HAT efficiency to the greatest extent: Ne, n, Ce (under conditions of the groups of objects 1, 2); Ce, Ne, n (3); m, Ne, Ce (4); Ndep, n, Ce (5); Ce, Ne, n (7, 10); m, Ce, n (11); Ce, Ne, Ni (12); Ne, Fos, μ (13); Ne, Ne, m (14).

Among the process parameters that most affect the efficiency of treatment are the following: Qi, Qacc/Qrec, Qacc, t (1, 2); Pfor cur/Pfor, Qacc/Qrec, Qacc (3); Qacc/Qrec, Qrec, Pfor cur (4); Qi, Qacc/Qrec, B1 (5); Qmax, Qrec, Q1 (11); Qacc/Qrec, Pfor cur/Pfor (12); Qacc/Qrec, t, Qacc/Qrec (13); t, Qacc/Qrec (14).

The treatment parameters affect the efficiency in the following order: Pij, Va, N/Va (3, 4); C, Va, N/Va (5); Pij, Va, C (7, 12); C, Va, N/Va (10); Va, C, Pij (11); C, N/Va, Pij (13); C, Pij, Va (14).

In general, for all groups of objects there is approximately equal influence of geological parameters reflecting the technological characteristics of wells and deposits on the treatment efficiency. However,
many of the process parameters ($Q_{rec}$, $Q_{max}$, $Q_{acc}/Q_{rec}$, $Q_{acc}$ and others) are largely determined by the geological features of the objects. Among the geological parameters, the most informative are the productivity coefficient, the average thickness of oil-saturated sublayers and the effective net oil thickness. Among the parameters reflecting technological features of wells and deposits, the greatest contribution to treatment efficiency is made by the ratio of accumulated oil production to recoverable reserves, recoverable reserves, time from the moment of well operation before HAT, treatment frequency. A slightly smaller contribution to the efficiency compared to these two groups of parameters is made by parameters characterizing the exposure technology. Among them, the volume of injected acid is the most informative, followed by the injection pressure and the concentration of the acid solution.

Under field conditions, for various reasons, not all parameters can be obtained or defined, for example: $Q_{rec}$, $Q_{acc}/Q_{rec}$, $C_{ef}$, $P_{for \; cur}/P_{for \; ini}$, $P_{for \; cur}$. Therefore, simulations were carried out without these parameters. The value of canonical correlations of the obtained equations was 0.417-0.840 (average – 0.665). In other words, the assessment of HAT efficiency when using these models will be quite approximate compared to the above models. The qualitative analysis of the influence of various parameters on the efficiency of hydrochloric acid treatment and the comparison of the above canonical correlations show that the productivity coefficient, recoverable reserves, current formation pressure are rather informative parameters. The absence of them allows assessing the efficiency, selecting wells for treatment and parameters of treatment with less cost of field study. However, the accuracy of the assessment is lower. Thus, for example, in general, for all objects using a complete set of information, the models can take into account 65% of the total variability in the efficiency for three indicators, while the models built on a limited amount of data explain only 44% of this variability.

4. Conclusion

Based on the studies, the following conclusions can be made:
- it is established that geologic parameters of deposits have a significant impact on HAT efficiency, followed by parameters reflecting the technological features of wells and deposits, and technological parameters of the treatment. The set of informative parameters that determine the most effective treatment is different in the conditions of different groups of low-productive objects of carbonate reservoirs;
- field and statistical models to assess and forecast the HAT efficiency according to the parameter reflecting various indicators in complex are proposed. The models can be used to select wells for treatment and to define the approximate treatment parameters.

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