Differential impact on wellbore zone based on hydrochloric-acid simulation

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Abstract. On the basis of geologic and statistical modeling in high-viscosity oil deposits of the Tournaisian stage and using the obtained models the paper proposes to carry out forecasting, selection of wells, control and regulation of the impact process in order to reduce the number of inefficient operations and increase technical and economic indicators of fuel and energy complex enterprises.

1. Introduction
When carrying out, controlling and regulating the hydrochloric acid effect in the wellbore zone of the formation, it is important to know the forecast efficiency of this measure reflected by various criteria [1-8].

To solve this problem, in the conditions of high-viscosity oil deposits in carbonate reservoirs of the North-Western part of Bashkortostan, a generalization of the experience of conducting HAT was carried out with the construction of geological and statistical models using various volumes of field data.

2. Materials and methods
The following were used as independent variables: net oil thickness \(H_2\), average thickness of oil-saturated sublayers \(H_n\) and their number \(n\), porosity factor \(M_p\), share of reservoir rocks in the total reservoir thickness \(K_d\), time from the beginning of well operation to the HAT \(t\), maximum well flow rate before HAT \(Q_{H_{max}}\), flow rate \(Q_{H1}\), watercut \(f_1\), accumulated oil production \(Q_{nak}\) of a well at the time of HAT, volume \(V_k\) and maximum pressure \(P_{nak}\) of acid injection into the formation. The following performance criteria were used as response functions: absolute \(\mathcal{E}_1\) and relative \(\mathcal{E}_2\) gain of oil flowrate; absolute \(\mathcal{E}_3\) and relative \(\mathcal{E}_4\) water production reduction; total gain of oil production during HAT \(\mathcal{E}_5\); relative increase of well productivity coefficient \(\mathcal{E}_6\).

This large number of performance criteria and different amounts of data is caused by the need to solve the tasks at various stages of development and in conditions of limited information on deposits (due to insufficient volumes of field studies due to organizational and financial reasons), as well as by...
the cases of changing the tactics and strategy of the enterprise in market conditions. This will allow a flexible response to changes in internal and external operating conditions [9-14].

3. Results and Discussion
The models were built using the step regression analysis.

Using the full amount of information (option 1), the following models were obtained:

\[
\begin{align*}
\mathcal{E}_1 &= 468 - 0.38r + 0.21Q_{H_{max}} - 0.76Q_{H_{11}} - 40.0f_1 + 8.18 \times 10^{-5}Q_{w_{max}} + 15.6H_3 - 71.4H_2 - 6.64M_f - 81\ln + 7.03V_k; \\
\mathcal{E}_2 &= 2254.1 + 0.76t - 162Q_{H_{11}} + 38.8f_i + 0.001Q_{w_{max}} + 104.5H_3 - 407.4H_2 - 73.0M_f - 430.0n + + 19.3V_k/H_3 + 8.50P_w; \\
\mathcal{E}_3 &= -108.2 - 0.24r + 0.23Q_{H_{max}} - 0.35Q_{H_{11}} - 41.2f_1 - 3.54 \times 10^{-3}Q_{w_{max}} - 11.1H_3 + 20.1H_2 + 6.98M_f + + 36.6n - 4.06V_k; \\
\mathcal{E}_4 &= -5677.3 - 2.78s + 0.024Q_{H_{max}} + 2.57Q_{H_{11}} - 603.0f_1 - 0.013Q_{w_{max}} - 212.9H_3 + 658.2H_2 + + 206.9M_f + 886.7n - 15.9V_k - 10.8P_w + 1405.1K_p; \\
\mathcal{E}_5 &= 2184.2 - 2.09t + 0.79Q_{H_{max}} - 4.18Q_{H_{11}} - 225.5f_1 + 0.001Q_{w_{max}} + 67.8H_3 - 393.7H_2 + 6.01M_f - + 430.7n + 56.3V_k; \\
\mathcal{E}_6 &= 241 + 0.0001t + 0.23Q_{H_{max}} - 0.046Q_{H_{11}} + 5.31f_1 - 1.78 \times 10^{-3}Q_{w_{max}} + 1.79H_3 - 1.94H_2 - 2.12M_f - - 3.92n + 0.043V_k.
\end{align*}
\]

Using parameters reflecting the geological and physical properties of the formation at the point of its penetration by the well and the exposure technology (option 2), the following models were obtained:

\[
\begin{align*}
\mathcal{E}_1 &= -80.7 + 9.91H_3 - 33.9H_2 - 3.74M_f - 13.9n + 212.6V_k + H_3; \\
\mathcal{E}_2 &= 1036.3 + 4.00H_3 - 63.3H_2 - 82.0M_f + 16.7n + 412.1V_k + H_3; \\
\mathcal{E}_3 &= -151.0 - 6.04H_3 + 21.3H_2 + 1.56M_f + 37.7n - 1.47V_k; \\
\mathcal{E}_4 &= -3837.5 - 79.7H_3 + 294.5H_2 + 200.3M_f + 358.8n - 37.3V_k; \\
\mathcal{E}_5 &= 492.5 + 9.61H_3 - 246.3H_2 + 27.0M_f - 152.8n + 101.8V_k; \\
\mathcal{E}_6 &= 0.035H_3 - 0.466H_2 + 0.058M_f - 0.264n + 0.616V_k; \\
\mathcal{E}_7 &= 11.54 + 0.12H_3 - 1.21H_2 - 0.37M_f - 1.470n + 0.62V_k; \\
\mathcal{E}_8 &= 0.056H_3 - 0.287H_2 - 0.100M_f - 0.317n + 0.469V_k.
\end{align*}
\]

When using parameters reflecting the technological features of wells and deposits, as well as the exposure technology (option 3), the following models were obtained:

\[
\begin{align*}
\mathcal{E}_1 &= 1.59 - 0.41r + 0.26Q_{H_{max}} - 0.84Q_{H_{11}} - 67.7f_i + 0.00001Q_{w_{max}} + 9.63V_k; \\
\mathcal{E}_2 &= 255.4 - 0.65r - 2.38Q_{H_{11}} - 405.1f_i + 34.7V_k; \\
\mathcal{E}_3 &= 39.9 - 0.21r - 0.08Q_{H_{11}} - 15.0f_i + 5.28V_k + 0.46Q_{H_{max}}; \\
\mathcal{E}_4 &= -42.7 - 104.3V_k - 1.70r + 1.30Q_{H_{max}} + 1.62Q_{H_{11}} + 414.6f_i; \\
\mathcal{E}_5 &= -132.7 + 69.0V_k - 1.81r + 1.28Q_{H_{max}} - 4.24Q_{H_{11}} - 249.7f_i; \\
\mathcal{E}_6 &= 2.95 + 0.189V_k - 0.017r + 0.015Q_{H_{max}} - 0.044Q_{H_{11}} - 2.91f_i.
\end{align*}
\]

The relative errors according to option 1 vary from 19.4 to 48.9%, averaging 31.7%. Using a limited amount of information, the errors were naturally slightly increased, averaging between 2 and 40.4 %, and between 3 and 37.2 %, i.e. the dependencies obtained are rather quantitative and qualitative. In other words, they can be used in the selection of wells for hydrochloric acid treatment by comparing them with the values of any performance indicator (criterion). The increase of flowrate (\(\mathcal{E}_1, \mathcal{E}_2\)) and production (\(\mathcal{E}_3, \mathcal{E}_4\)) of oil, reduction of watercut (\(\mathcal{E}_3, \mathcal{E}_4\)) and change of productivity coefficient (\(\mathcal{E}_5\)) for certain wells lead to significant errors, however, planning of these indicators by groups of wells (not less than 7-10) gives quite satisfactory results.
The analysis of the obtained models shows that in the vast majority (93%), the influence of geological and technological parameters on the treatment efficiency did not change using a limited amount of information.

With the increase of net oil thickness and decrease of the average thickness of oil-saturated sublayers, their number and porosity, the gain of oil flowrate and production, as well as productivity coefficients increase. At the same time, there is the increase of water cutting of well production.

In almost all parameters, the treatment efficiency decreases (with the exception of $\mathcal{E}_h$) with an increase in time from the moment of well commissioning to the moment of HAT. This fact is caused by the depletion of reservoir energy reserves and the decrease in the production reserve as oil reserves are developed.

With watercut increase (with the exception of $\mathcal{E}_h$), the treatment efficiency also decreases, which confirms the results of other researchers. With the increase of the maximum production rate of the well before HAT and the decrease of the oil production rate at the moment of impact, the efficiency of treatment increases.

It is particularly noteworthy that over time, as the water production increases, hydrochloric acid treatment leads to a greater increase in productivity. However, this does not indicate efficiency in terms of increasing production rates and additional oil production and reduction of water production. With the increase of well operation time and with the increase of watercut, the increase of oil production and watercut per unit of productivity coefficient change decreases.

With the increase of accumulated oil production at the time of impact, the increase in production rates and oil production increases, but at the same time the watercut also increases.

The increase in the amount of injected acid also leads to an increase in production rates, additional oil production and productivity ratio, but also the increase of water production.

The reduction of the maximum pressure of acid injection reduces the relative gain of oil flowrate, but also decreases the relative gain of water production. Based on the above, the selection of process impact indicators should take into account the fact that excessive acid injection and high injection pressure can lead to progressive watercut and the negative economic effect.

The analysis of the obtained results shows that a complex technological criterion of efficiency is needed, which would not only reflect the above efficiency criteria and various aspects of the hydrochloric acid effect, but also a compromise between the increase in the productivity coefficient, the gain in oil flowrates and production with the gain in water production. This criterion greatly simplifies the procedure for diagnosing, selecting wells and optimal process parameters of HAT.

As such a complex performance criterion, it is proposed to use the parameter $\mathcal{E}_7$ that is written in the form:

$$\mathcal{E}_7 = \frac{Q_{H2}}{Q_{H1}} \cdot f_1 \cdot \tau,$$

where $Q_{H1}$, $Q_{H2}$ – well flowrate before and after HAT, t/month; $f_1$, $f_2$ – water cutting of well production before and after HAT, %; $\tau$ – treatment, month.

The treatment duration was determined by the time during which the oil flowrate after treatment decreases to the oil flowrate before treatment. From a physical point of view, the efficiency criterion $\mathcal{E}_7$ characterizes the resource of oil production capacity of wells.

Using this complex performance criterion, the following models were obtained:

- option 1:
  $$\mathcal{E}_1 = -3.85 - 0.06t - 0.02Q_{H_{max}} - 0.04Q_{H1} + 15.21f_1 + 0.0001Q_{H_{max}} - 6.89H_2 +$$
  $$+ 11.2H_2 - 1.33M_r + 2183n + 0.64V_k,$$

- option 2:
  $$\mathcal{E}_2 = -55.2 - 6.11H_2 + 15.4H_2 - 1.39M_r + 28.0n + 4.29V_k,$$

- option 3:
\[ \varphi = 16.8 - 0.02V - 0.05t - 0.008Q_{max} - 0.05Q_{min} + 8.61f_i. \]

The multiple correlation coefficients respectively make 0.895; 0.743; 0.820, and the relative errors – 20.6; 30.4; 26.0 %.

4. Conclusion

Thus, the performed geological and statistical modeling allows performing forecasting, selection of wells, control and regulation of the impact process in high-viscosity oil deposits of the Tournaisian stage in order to reduce the number of inefficient operations and increase technical and economic indicators of enterprises of the fuel and energy complex.

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