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ELIMINATION OF UNCERTAINTIES IN THE SELECTION OF PARAMETERS FOR ASSESSING THE IMPACT ON THE BOTTOMHOLE ZONE

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A B S T R A C T

The article presents the results of geological and statistical modeling of the process of hydrochloric acid exposure using the method of canonical correlations - the main tool for information processing, which is based on the theory of the presence of linear combinations between the variables under consideration. Hydrochloric acid treatment is one of the most commonly used methods to increase productivity, in particular in wells that have exposed deposits of carbonate reservoirs. Despite the fact that the mechanisms of interaction between the injected composition and rocks have been studied in sufficient detail, the average effectiveness of measures remains at a low level, due to the influence of geological heterogeneity. Based on the modeling data, it is proposed to use a combination of various efficiency parameters when selecting impact objects in order to reduce uncertainty in making management decisions, determining the technological parameters of measures to intensify oil production, taking into account the peculiarities of the geological structure of objects, geological and physical properties of formations, technological parameters of wells and deposits. As part of the study, the obtained models allow for flexible response when making decisions to changes in the market situation, which has a positive effect on the technical and economic performance of enterprises in the energy sector and can significantly increase the effectiveness of the impact, reasonably select candidate wells. The interpretation of various dependencies made it possible to qualitatively identify hidden patterns between groups of objects of the Devonian and Carboniferous ages of the Ural-Volga region.

Keywords: bottom-hole formation zone; development of oil fields; hydrochloric acid exposure; selection of candidate wells; geological and technological parameters; impact efficiency.

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Introduction

When choosing wells to affect the bottom-hole zone using various models [1-4], by iterating through, options are possible in which wells will be ambiguously characterized by their planned efficiency. In other words, if a certain group of wells is selected based on the maximum values of the absolute increase in oil production, this does not mean that the planned total increase in oil production or the relative increase in production for them will also be maximum [5-7]. This fact creates uncertainties when making management decisions. It is obvious that the selection of wells in these conditions should be based on the user's goals for any one indicator of efficiency [8-12]. However, the choice of wells will be more objective if the treatment efficiency indicator includes all three parameters used, i.e. it will be comprehensive. In addition, the contribution of parameters determining the effectiveness of treatments and changes in the values of the complex efficiency indicator is of significant interest [13-15]. The solution of these problems was carried out by modeling using the method of canonical correlations. The essence of the canonical correlation method is as follows [16].

Let be in the output set $X^{(1)}$ contains P_1 features, and in the input set $X^{(2)}$ – P_2 signs ($P_1 \le P_2$). Combining the features of both sets, we get (P_1+P_2) – dimensional random vector $X=\{X^{(1)}, X^{(2)}\}$. The covariance matrix of the latter is divided into blocks with P_1 and P_2 rows and columns:

$$\mathrm{cov} = \begin{bmatrix} \sigma_1^2 & \mathrm{cov}(x_1, x_2) \\ \mathrm{cov}(x_2, x_1) & \sigma_2^2 \end{bmatrix} \quad (1)$$

Next, the transformation of the first is built P_1 coordinate axes and the transformation of the latter P_2 coordinate axes to the new one (P_1+P_2) – a dimensional coordinate system in which the mutual correlation between $X^{(1)}$ and $X^{(2)}$ it becomes the most visible. The result is P_1 independent pairs of linear combinations $U_i(X^{(1)})$ and $V_i(X_{(2)})$, such that each subsequent pair has a lower coefficient of mutual correlation than the previous one. The degree of interconnection of the two sets is characterized by the value of the maximum canonical correlation. A set of weighting coefficients of the

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multiple correlation vector makes it possible to rank input features according to the degree of connection with the output. The solution of the task was carried out for hydrochloric acid treatments – one of the most relevant methods for cleaning filtration channels and restoring reservoir permeability [17-24].

The accumulated information on the effects of hydrochloric acid compounds in various geological and physical conditions is characterized by ambiguous results, which indicates the need to implement a more detailed approach to improving the effectiveness of measures [25-27]. Based on a retrospective analysis of the data, the success rate of exposure to acidic compounds in many deposits varies from 25 to 90%, averaging 40%. This situation is explained by various reasons, both objective and subjective [28-32]:

- the developed treatment technology does not take into account all aspects of the mechanism of action of hydrochloric acid solutions on the carbonate reservoir due to their insufficient knowledge;
- work on the selection of objects (wells) for impact, on the development and observance of treatment technology in specific geological and physical conditions of formations is not carried out at the fields at the proper level.

One of the factors of effective well treatments using hydrochloric acid compositions is the detailed conduct of laboratory studies in conjunction with the use of advanced engineering approaches [33-35].

The identification of parameters that have a predominant effect on the effectiveness of treatments and the subsequent formalization of the process based on modeling make it possible to make a scientifically sound choice of wells and select the optimal exposure technology in order to increase the efficiency of hydrochloric acid treatments [36-38].

Research and methods of solving the problem

The conducted modeling using the method of canonical correlations, where the relative (E_1) and absolute (E_2) increases in well flow rates, as well as the total increase in oil production (E_3) as a result of the HAT, were used as the first set of variables, and as the second set – a full set of parameters reflecting the geological and technological conditions of treatments and impact parameters allowed us to obtain the following equations of canonical variables with maximum canonical correlations for objects of groups of deposits identified using differentiation and grouping procedures presented in [39-43]:

$$0.264E_1+0.702E_2+0.708E_3=-0.167N-0.197t+ \\ +0.161Q_{max}+0.776Q_1-0.162B_1+0.065Q_3+0.104K_1+ \\ +0.236H_1+0.086H_2+0.156n-0.121\frac{Q_2}{Q_3} \quad (2)$$

(for wells of objects of groups 1, 2);

$$0.89E_1+0.664E_2+0.588E_3=-0.336N-0.163t+0.398Q_2+ \\ +0.298Q_3+0.333K_1+0.229H_1+0.027H_2+0.221n- \\ -0.321P_1^1+0.421\frac{P_1^1}{P_2}+0.119V_1-0.096\frac{H_1}{V_1}+0.155P_3- \\ -0.102\mu_1-0.079\mu_2-0.090\rho_1-0.410\frac{Q_2}{Q_3} \quad (3)$$

(for wells of objects of group 3);

$$0.945E_1+0.737E_2+0.728E_3=-0.015N-0.157t-0.081Q_1+ \\ +0.169Q_3+0.207K_1+0.218H_1+0.185H_2+0.375m-0.029K+ \\ +0.163P_1^1+0.159\frac{P_1^1}{P_1}+0.161V_1-0.046\frac{H_1}{V_1}+0.299P_3- \\ -0.028\mu_1-0.066\mu_2+0.106K_2-0.447\frac{Q_2}{Q_3}-0.069H_3 \quad (4)$$

(for wells of objects of group 4);

$$0.069E_1+0.982E_2+0.957E_3=-0.199t+0.277Q_{max}+ \\ +0.744Q_1-0.318B_1+0.012Q_2+0.278Q_3+0.316K_1+ \\ +0.079H_1+0.134m+0.387n+0.350K+0.259V_1- \\ 0.258\frac{H_1}{V_1}+0.088P_3-0.058\mu_1-0.053\mu_2+0.131G+ \\ +0.311K_2-0.328\frac{Q_2}{Q_3}-0.466H_3+0.276t_1 \quad (5)$$

(for wells of objects of group 5);

$$0.035E_1+0.930E_2+0.955E_3=-0.096N-0.090t+ \\ +0.318Q_{max}-0.251B_1+0.296Q_3+0.566K_1+0.245H_1+ \\ +0.325H_2+0.021\mathrm{K}+0.076V_1-0.192P_3-0.278\mu_1- \\ -0.247\mu_2+0.271G+0.196H_3+0.234t_1 \quad (6)$$

(for wells of objects of group 7);

$$0.491E_1+0.794E_2+0.709E_3=-0.163N+0.516Q_{max}+ \\ +0.505Q_1-0.086B_1+0.688Q_3+0.696K_1+0.297H_1+ \\ +0.597H_2+0.644K+0.317P_1^1+0.275\frac{P_1^1}{P_2}+0.282V_1- \\ -0.148\frac{H_1}{V_1}-0.327\mu_1-0.312\frac{Q_2}{Q_3}+0.158H_3 \quad (7)$$

(for wells of objects of group 10);

$$0.052E_1+0.972E_2+0.966E_3=-0.174N+0.558Q_{max}+ \\ +0.358Q_1+0.040Q_2+0.592Q_3+0.504K_1+0.305H_1+ \\ +0.530m+0.443n+0.221K+0.323P_1^1+0.313\frac{P_1^1}{P_1}+ \\ +0.324V_1+0.142P_3-0.249\frac{Q_2}{Q_3} \quad (8)$$

(for wells of objects of group 11);

$$0.416E_1+0.963E_2+0.685E_3=-0.089N-0.194t+ \\ +0.268Q_{max}+0.302Q_1-0.397B_1-0.056Q_2+0.648Q_3+ \\ +0.652K_1+0.447H_1+0.398H_2+0.005K+0.508\frac{P_1^1}{P_2}+ \\ +0.191V_1+0.328P_3-0.535\frac{Q_2}{Q_3} \quad (9)$$

(for wells of objects of group 12);

$$0.995E_1+0.805E_2+0.860E_3=-0.577t+0.201Q_1- \\ -0.548Q_2+0.331Q_3+0.868H_2+0.568K+0.221V_1- \\ -0.524\frac{H_1}{V_1}+0.326P_3-0.082\mu_1+0.812K_2-0.620\frac{Q_2}{Q_3} \quad (10)$$

(for wells of objects of group 13);

$$0.092E_1+0.292E_2+0.209E_3=-0.277N-0.448t- \\ -0.159Q_2+0.733H_1+0.514m+0.377K+0.184V_1+ \\ +0.232P_3-0.501\mu_1-0.305\frac{Q_2}{Q_3} \quad (11)$$

(for wells of objects of group 14);

where K_1 initial well productivity coefficient, t/day MPa;

H_1 – effective oil-saturated thickness of the formation in the well, m;

H_2 – the average thickness of oil-saturated layers in the well, m;

n – the number of oil-saturated layers in the well;

m – the weighted average value of the reservoir porosity coefficient in the well according to geophysical research data, %;

K_2 – oil saturation coefficient;

μ_1 – viscosity of reservoir oil, MPa·s;

μ_2 – relative viscosity of oil;

ρ_1 – density of reservoir oil, kg/m^3;

G – formation gas factor, m^3/t;

P_1 – oil saturation pressure with gas, MPa;

H_3 – depth of the productive formation, m;

P_2 – initial reservoir pressure, MPa;

t_1 – the time from the beginning of the well operation to the time of the HAT, a year;

Q_{max} – the maximum flow rate of the well before the HAT, t/month;

Q_1 – well flow rate at the time of the HAT, t/month;

B_1 – the water content of the well's production at the time of the HAT, %;

Q_2 – accumulated oil production at the time of the HAT, t;

Q_3 – recoverable oil reserves by well, thousand tons;

Q_2/Q_3 – the ratio of accumulated oil production to recoverable reserves (the degree of reserves development);

P_1^1 – reservoir pressure during hydrochloric acid treatment, MPa;

P_1^1/P_2 – change in reservoir pressure during hydrochloric acid treatment;

N – the frequency of the HAT;

K – hydrochloric acid concentration, %;

V_1 – volume of injected acid, m^3;

P_3 – acid injection pressure, MPa;

H_1/V_1 – effective oil-saturated thickness, processed one cubic meter of acid, m/m^3.

The values of the parameters of the models (2) – (11) are standardized based on the expression:

$$x_1 = \frac{X_2 - x_i}{\sigma_X} \tag{12}$$

where X_2 – the average value of the parameter;

x_i – the true value of the parameter for a specific well;

σ_X – the standard deviation of the parameter.

Discussion of the results

For groups of objects 6, 8, 9, the absence of models is due to the insufficient volume of relevant geological and commercial information. Groups of objects 1-14 are confined to deposits in carbonate reservoirs of the Devonian and Carboniferous ages of the Ural-Volga region. The values of the canonical correlations of the obtained models vary from 0.581 to 0.934 (on average – 0.808), i.e. they are quite high and indicate the possibility of using them to solve problems of evaluating and predicting the effectiveness of hydrochloric acid treatments [44-47]. In addition, to assess the quality of the initial data, standardization is carried out beforehand, after which the indicators are analyzed for significant deviations from the established boundaries of change, which minimizes the risk of making ineffective management decisions.

The analysis of the values of the constant coefficients of canonical variables and the ranking of the parameters included in them made it possible to give a physical interpretation and identify the main parameters determining the effectiveness of hydrochloric acid treatments. The positive values of the empirical coefficients on the left side of the equations indicate that with an increase in any indicator reflecting efficiency, the remaining indicators also grow. The left part characterizes the effectiveness of treatments in the complex, however, if in the conditions of wells of groups of objects 3, 4, 10, 12, 13, 14 the contribution of each indicator is approximately equal, then in the conditions of groups of objects 1, 2, 5, 7, 11, the complex parameter mainly reflects the absolute increase in flow rate and the total increase oil production.

In terms of groups of objects 4, 5, 7, 10, 13, 14 The main influence on the effectiveness of treatments is provided by geological parameters, followed by parameters reflecting the technological features of wells and deposits. The reverse pattern is observed within the groups of objects 1, 2, 3, 11, 12. The third group, which includes parameters reflecting the processing technology, has a lesser impact on the effectiveness of treatments compared to these two groups of parameters.

The features of the selected groups of objects determine a different set of geological parameters that determine the effectiveness of the impact within each group. The following geological parameters (in order of decreasing their contribution) have the greatest impact on the efficiency of the HAT system: effective oil-saturated thickness, number of layers in the well, productivity coefficient (in the conditions of wells of object groups 1, 2); productivity coefficient, effective oil-saturated thickness, number of layers in the well (group 3); porosity coefficient, effective oil-saturated thickness, productivity coefficient (group 5); productivity coefficient, average thickness of oil-saturated layers, viscosity of reservoir oil (groups 7, 10); porosity coefficient, productivity coefficient, number of layers in the well (group 11); productivity coefficient, effective oil-saturated thickness, average thickness of oil-saturated layers (group 12); average thickness of oil-saturated layers, oil saturation coefficient, relative viscosity of oil (group 13); average thickness of oil-saturated interlayers, effective oil-saturated thickness, porosity coefficient (group 14).

Among the technological parameters that most affect the effectiveness of treatments, the following are distinguished (also in descending order): oil flow rate at the time of processing, the ratio of accumulated oil production at the time of processing to recoverable reserves, the time from the start of well operation to the time of the HAT (groups 1, 2); the ratio of current reservoir pressure at the time of processing to the initial, the ratio of accumulated oil production to recoverable reserves, accumulated oil production (group 3); the ratio of accumulated oil production to recoverable reserves, recoverable reserves, current reservoir pressure (group 4); oil flow rate at the time of the HAT operation, the ratio of accumulated oil production to recoverable reserves, water content of products at the time of the HAT operation (group 5); maximum oil flow rate before the HAT operation, recoverable reserves, water content of products at the time of the HAT (group 7); recoverable oil reserves, maximum flow rate before HAT, flow rate at the time of COEX (group 10); maximum oil flow rate before HAT, recoverable reserves, flow rate at the time of HAT (group 11); recoverable reserves, the ratio of accumulated oil production to recoverable reserves, the ratio of current reservoir pressure to initial pressure (group 12); the ratio of accumulated oil production to recoverable reserves, the time from the start of well operation to the time of the HAT, accumulated oil production (group 13); the time from the start of well operation to the time of the HAT, the ratio of accumulated oil production to recoverable reserves, the frequency of processing (group 14).

The significant influence of these parameters on the effectiveness of treatments places increased demands on the accuracy of their determination.

The technological parameters of the treatments affect the efficiency in the following order: injection pressure, volume of injected acid, ratio of effective oil-saturated thickness to acid volume (group 3, 4); acid concentration, acid volume, ratio of effective oil-saturated thickness to acid volume (group 5); injection pressure, acid volume, acid concentration (group 7, 12); concentration, volume of acid, ratio of effective oil-saturated thickness to volume of acid (group 10); volume of acid, concentration, injection pressure (group 11); acid concentration, ratio of effective oil-saturated thickness to acid volume, injection pressure (group 13); acid concentration, injection pressure, acid volume (group 14).

In general, for all groups of objects, there is an approximately equal effect on the efficiency of treatments of geological parameters reflecting the technological features of wells and deposits. Among the geological parameters, the most informative are the productivity coefficient, the average thickness of oil-saturated layers and the effective oil-saturated thickness. Of the parameters reflecting the technological features of wells and deposits, the ratio of accumulated production to recoverable reserves, recoverable reserves, the time from the start of well operation to the time of the HAT operation, the multiplicity of treatments make the greatest contribution to the efficiency of treatments.

The parameters characterizing the exposure technology make a slightly smaller contribution to efficiency compared to these two groups of parameters. Among them, the most informative is the volume of the injected acid, followed by the injection pressure and the concentration of the acid solution.

Conclusions

Thus, the conducted modeling and the results obtained allow:

1. Flexibly respond to changes in the external conditions of oil production enterprises by making adequate management decisions differentially for different groups of objects in carbonate reservoirs during hydrochloric acid well treatments.
2. To create universal algorithms for processing geological and commercial information at different densities.
3. To reduce the error of forecasting models of various geological and technological indicators.

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