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# CONTROL AND REGULATION OF THE HYDROCHLORIC ACID TREATMENT OF THE BOTTOMHOLE ZONE BASED ON FIELD-GEOLOGICAL DATA

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The analysis results of the hydrochloric acid treatment of the bottomhole zone efficiency along the deposits of high-viscosity oil in the carbonate reservoirs of the Tournaisian stage are presented in the paper. Based on the use of the non-parametric Kulbak criterion, the most informative geological and technological parameters, which affect most the success of hydrochloric acid treatments, assessed by the criteria of increased oil production and reduced water cut, are revealed. The generalization of the hydrochloric acid treatments experience in the conditions of the high-viscosity oil reservoirs of the Tournaisian Stage allows for efficient forecasting, selection of wells, control and regulation of the treatment process to reduce the number of inefficient operations and improve the technical and economic parameters of fuel and energy enterprises at the investigated sites and the ones with similar field-geological characteristics.

***Key words*:** oil, carbonate reservoir, bottomhole zone, hydrochloric acid treatment, field-geological data

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**Introduction.** The treatment of the bottomhole formation zone with the hydrochloric acid solutions was and remains the main one in the development of oil deposits with carbonate reservoirs. However, numerous studies conducted both in our country and abroad show that the efficiency of this method is not always high enough, and sometimes characterized by negative values of the indicators [1, 8, 15, 18, 20]. The reasons for this are the following: the peculiarities of the deposits' geological structure, the inconsistency of the applied impacting technology to the specific geological conditions of the object in question, the lack of scientifically based methods of wells selection and treatment technologies, taking into account the technological traits of wells and deposits [5, 6, 9, 16, 19].

It should be noted that different researchers reflect the efficiency of carried out bottomhole zone treatments by means of various indicators. This makes it impossible to compare the results with each other and to provide a comprehensive evaluation of efficiency [3, 7, 12-14, 19]. In addition, it has been established that to date there are almost no studies devoted to the experience generalization of conducting hydrochloric acid treatments (HCAT) of the carbonate reservoirs in the Tournaisian stage containing high-viscosity oil (more than 20 mPa·s) and hard-to-recover reserves. The use of models and techniques obtained earlier [10, 11, 17] for the conditions of other deposits (with other geological and physic-chemical properties of the formations and fluids saturating them) can lead to not only large errors but also conflicting results.

**Statement of the problem.** In this regard, the experience generalization of the HCAT for deposits in the carbonate reservoirs of the Tournaisian stage containing high-viscosity oil in order to obtain a set of techniques that allow controlling and regulating the treatment process, as well as to perform scientifically based well selection and definition of treatment's technological parameters, is quite relevant.

**Methodology.** To solve the set tasks, the field-geological data of oil and gas producing enterprises was used for Tournaisian oil deposits that are located within the southeastern slope of the Russian platform and the Birskaya saddle and are layer-uplifted.

Reservoir rocks are of fracture-pore and pore-cavern types. The reservoirs' operation mode is elastic water drive with a weak pressure boost of marginal and plantar water due to the sealed deposits near the surface of the water-oil contact and to deposits of secondary calcite and viscous bitumen in a fractured porous medium.

Deposits are characterized by the following average values of geological parameters: reservoir pressure 13.3 MPa; depth of 1350 m; effective oil-saturated thickness 5.0 m; porosity 12.0 %; oil saturation 79 %; coefficient of permeability $5 \cdot 10^{-3}$ μm$^2$; the viscosity of the reservoir oil is 25 mPa·s.

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The drilling of the deposits began in the sixties of the twentieth century. The density of the well grid at the moment of analysis varies in different areas from 16 to 200 hectares/well. Oil production is mainly carried out using the natural energy of the reservoir's elastic forces and with weak pressure boost of the edge and plantar water. The current oil recovery in these conditions changes from 3 to 20 %, the forecasted final oil recovery factor will be approximately 15 %. The injection of water into the reservoir rarely gives positive results in the form of an increased oil production. Increasing the efficiency of development is associated with the concentration of the well grid and the organization of local flooding in separate high-productive areas with a high density of well grid.

During the investigation, the field data of more than 300 wells was taken into account, at which the usual HCAT and HCAT under pressure were performed.

The absolute and relative increase in oil production, the absolute and relative decrease in fluid water cut, the total increase in oil production during the effect period, and the relative increase in well productivity were used as efficiency criteria. As independent variables affecting the success and efficiency of the HCAT, the effective oil-saturated thickness, the average thickness of oil-saturated layers and their number, the porosity coefficient of the formation in the borehole, the proportion of reservoir rocks in the total thickness of the formations, the time from the beginning of the well operation to the moment of carrying out the HCAT, the maximum production rate of the well before the conduction of the HCAT; flow rate, water cut, accumulated oil production of the well at the time of the HCAT, volume and maximum injection pressure of the acid into the formation were reviewed.

**Discussion.** At the first stage, the influence of geological and technological parameters on the success of the treatment was studied using one of the diagnostic methods of pattern recognition – sequential Wald procedure. As a criterion of efficiency, the increase in oil production was used. The significance was calculated by the Kullback criterion [2, 4]. The obtained dependences allowed establishing the conditions for the most successful application of HCAT, as well as the required volumes and pumping pressures of acid into the formation. Dependencies are of a probabilistic nature.

To obtain a singlevalued answer to the question about the success for each well, the values of the total diagnostic coefficients in three variants are calculated:

1) using all the parameters that are significant by the Kullback criterion;

2) using the most significant parameters reflecting the geological and physical properties of the formation at the point of its drilling-in and the treatment technology;

3) using the most significant parameters, reflecting technological features of wells' operation and reservoirs, as well as treatment technology.

The received distributions allow:

• get singlevalued answer to the question of success;

• conduct at a qualitative level a choice of wells for carrying out the HCAT;

• by changing technological parameters of the treatment, transfer wells from zones with negative effect and zones of uncertainty to a zone with a positive effect;

• to diagnose and select wells at different volumes of field data and at different stages of development (after putting the well into operation, when reliable data on the technological parameters of the well are not available, option 2 may be used, in the absence of reliable data on the geological and physical properties of the formation, option 3).

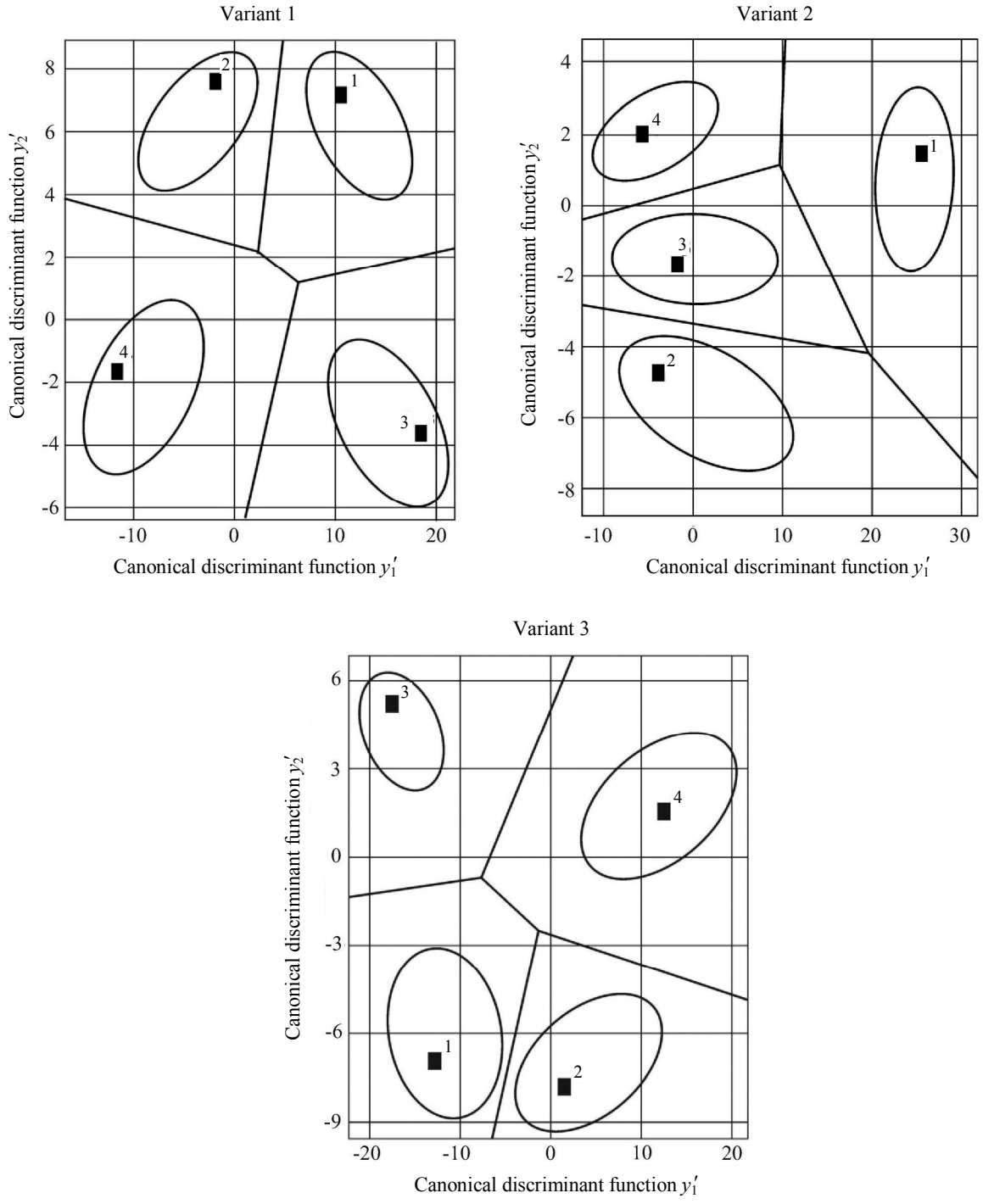
A similar range of problems was solved for the case where the reduction of water cut in well production was considered as an efficiency criterion.

Comparison of significant parameters value range in which the success of the treatment exceeded 50 % by the criteria of production increase and reduction of water cut showed the presence of common ranges. These common ranges explain the fact that in some wells, along with the increase in oil production, the water cut of the production has decreased. Simultaneous increase in production rate and water cut is explained by the absence of common ranges for individual parameters, i.e. in the pursuit of additional oil production with the increase in the volume of the injected acid, it is possible to obtain a significant increase in the water cut of the fluid.

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In order to simplify the calculations, reduce their labor input, monitor obtained results and separate the wells for both success criteria more clearly, the method of canonical discriminant functions was used. The calculations were also conducted in three variants. Four groups of wells were identified with the following characteristics:

1) increase in oil production and reduced water cut;
2) reduction of oil production and water cut;
3) reduction of oil production and increase in water cut;
4) increase in oil production and water cut.




Distribution of centroids and zones of wells group concentration in the axes of canonical discriminant functions at variants
1 – centroid, number and zones of wells group concentration; 2 – areas' bounds for determination of well belonging to a certain group

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In the axes of the canonical discriminant functions (see the figure), the wells clearly split and occupy a strictly defined area. None of the wells were within the boundaries of the other group.

Equations of canonical discriminant functions have the following form: according to variant 1

$$y_1' = -4.52 - 0.36t - 0.10Q_{\text{n max}} + 0.13Q_{\text{n1}} - 65.46f_1 + 0.001Q_{\text{tot}} + 1.45V_{\text{ac}} + 0.20t/V_{\text{ac}} + \\ + 1.05Q_{\text{n max}}/V_{\text{ac}} - 1.67Q_{\text{n1}}/V_{\text{ac}} + 0.99H_{\text{e}} + 18.34V_{\text{ac}}/H_{\text{e}}; \quad (1)$$

$$y_2' = -1.18 - 0.13t - 0.03Q_{\text{n max}} + 0.04Q_{\text{n1}} - 21.06f_1 + 0.0004Q_{\text{tot}} + 0.41V_{\text{ac}} + 0.07t/V_{\text{ac}} + \\ + 0.34Q_{\text{n max}}/V_{\text{ac}} - 0.57Q_{\text{n1}}/V_{\text{ac}} + 0.32H_{\text{e}} + 6.34V_{\text{ac}}/H_{\text{e}}; \quad (2)$$

according to variant 2

$$y_1' = 15.34 - 12.19H_{\text{e}} + 6.44H_1 - 0.16M_{\text{g}} + 1.02n + 14.14V_{\text{ac}} - 105.09V_{\text{ac}}/H_{\text{e}} + \\ + 17.75K_1 + 31.70H_{\text{e}}/V_{\text{ac}} - 20.52H_1/V_{\text{ac}}; \quad (3)$$

$$y_2' = -1.27 - 0.44H_{\text{e}} - 3.00H_1 + 0.09M_{\text{g}} - 1.01n + 1.84V_{\text{ac}} - 8.12V_{\text{ac}}/H_{\text{e}} + 6.94K_1 + \\ + 1.95H_e/V_{\text{ac}} + 4.01H_1/V_{\text{ac}}; \quad (4)$$

according to variant 3

$$y_1' = -7.48 + 0{,}37t + 0.07Q_{\text{n max}} - 0.07Q_{\text{n1}} + 56.13f_1 - 0.0001Q_{\text{tot}} - 2.73V_{\text{ac}} - 0.36t/V_{\text{ac}} - \\ - 0.83Q_{\text{n max}}/V_{\text{ac}} + 1.25Q_{\text{n1}}/V_{\text{ac}}; \quad (5)$$

$$y_2' = 8.36 - 0.22t + 0.007Q_{n\,\text{max}} - 0.024Q_{\text{n1}} - 2.52f_1 + 0.0001Q_{\text{tot}} + 0.93V_{\text{ac}} + 0.57t/V_{\text{ac}} - \\ - 0.06Q_{\text{n max}}/V_{\text{ac}} + 0.18Q_{\text{n1}}/V_{\text{ac}}, \quad (6)$$

where $t$ – time from the beginning of the operation of the well to the moment of carrying out the HCAT, months; $Q_{\text{n max}}$ – maximal oil well flow rate before HCAT, t/mon.; $Q_{\text{n1}}$ – well flow rate in time of performing HCAT, t/mon.; $f_1$ – water cut of the well fluid in time of performing HCAT, %; $Q_{\text{tot}}$ – total oil production in time of performing HCAT, ton; $V_{\text{ac}}$ – volume of injected acid, m$^3$; $H_{\text{e}}$ – efficient oil-saturated formation thickness in the wellbore, m; $H_1$ – average thickness of oil-saturated layers in the wellbore, m; $M_{\text{g}}$ – average weighted value of the porosity coefficient of the formation in the borehole according to geophysical survey data, %; $n$ – number of oil-saturated layers in the wellbore; $K_1$ – the share of reservoir rocks in the total thickness of the formations, units.

The obtained distributions and dependences (1)-(6) allow quick solving the issue of assessing the success of the treatment on some criterion, and also to select wells for conducting the HCAT depending on the user's desire.

When monitoring and regulating the parameters of hydrochloric acid treatment, it is important to know not only the success of this operation implementation, but also its effectiveness, expressed through various efficiency criteria. This problem was solved by generalizing the experience of carrying out the HCAT with the construction of geological and statistical models for various volumes of field information. The simulation was carried out using step regression analysis. A significant number of options and performance criteria for various volumes of information is caused by the need to address the tasks at different stages of development and in the context of limited data on deposits. The latter is explained by the insufficient amount of field research due to organizational and financial reasons, as well as changes in the tactics and strategy of the enterprise in market conditions. Geological and statistical models give the opportunity to respond flexibly to changes in internal and external conditions of functioning.

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The errors of the obtained models make it possible to consider them as more quantitative and qualitative, although in the calculations for 7-10 wells the forecast is quite satisfactory.

The analysis of the obtained results showed that it is necessary to create a complex technological efficiency criterion that would reflect the efficiency criteria and various aspects of the hydrochloric acid treatment, and was also a compromise solution between the increase in the productivity coefficient, the increase in oil production rate and the increase in production water cut. This criterion considerably simplifies the procedure for diagnosing, selecting wells and optimizing technological parameters of the HCAT.

As such complex efficiency criterion, it is suggested to use a combination of parameters in the following form

$$\mathrm{E} = \frac{Q_{\mathrm{n}2}}{Q_{\mathrm{n}1}} \frac{f_1}{f_2} \tau, \qquad (7)$$

where $Q_{\mathrm{n}2}$, $Q_{\mathrm{n}1}$ – monthly flow rate of the well before and after the treatment, ton; $f_2$, $f_1$ – water cut in the production before and after the treatment, %; $\tau$ – effect duration, months.

From the physical point of view, this efficiency criterion characterizes the resource of oil well production capabilities.

**Conclusion.** Conducted research allowed acquiring following results:

• Based on the use of the nonparametric Kulbak criterion, the most informative geological and technological parameters that have a prevailing effect on the success of the HCAT, assessed by the criteria for increasing oil production and reducing water cut in the production, are identified. The conditions for the most successful treatment process are established. A physical interpretation of the results is given. It is established that when using certain efficiency criteria, the highest success rates are in different ranges of geological and technological parameters, which should be taken into account when choosing wells for treatment and determining the technological parameters of the HCAT.

• Common ranges of changes in the values of significant geological and technological parameters are established, in which the success of the treatment by the criterion of oil production rate and by the criterion of water cut of the fluid is more than 50%. It is shown that there is no common interval of changes in volumes and specific volumes of injected acid. This indicates that in the pursuit of additional oil production due to the increase in the volumes of injected acid, it is possible to obtain a significant increase in water cut of the fluid. In this case, the choice of wells and treatment technology is recommended to be implemented after carrying out technical and economic calculations.

• Based on the use of the canonical discriminant functions equations, a technique is obtained that allows determining, according to the values of geological and technological parameters, to which group the well belongs:

– to the group where the increase in oil production and reduction of water cut was obtained;
– to the group where the reduction in oil production and water cut was obtained;
– to the group, where a reduction in oil production and an increase in water cut was obtained;
– to the group where an increase in oil production and water cut was obtained.

• The technique allows for the use of various volumes of information to promptly make a management decision, use the experience of conducted treatment of the group, to which a specific well belongs, to adapt the technology of treatment to specific geological conditions, and to implement directed treatment of the bottomhole zone. To solve these problems effectively, in the axes of the two canonical discriminant functions, centroids and zones of well groups' concentration are established, as well as the boundaries of the regions to determine whether the well belongs to a group.

• A comprehensive efficiency criterion is proposed that allows solving the problems of forecasting and selection of wells by a single criterion. The criterion characterizes the unused resource of the oil wells' production capabilities and allows eliminating the contradiction between the increase in production rates and the increase in water cut, as well as the facts of progressive flooding with the use of large volumes of acid to obtain a significant increase in oil production.

• Generalization of the experience of hydrochloric acid treatments in the conditions of the reservoirs of high-viscosity oil from the Tournaisian stage and obtained results allow efficient carrying out of the forecast, selection of wells, control and regulation of the treatment process with the aim of reducing the number of inefficient operations and improving the technical and economic performance of fuel and energy enterprises at the investigated facilities and the ones with similar geological and field characteristics.

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