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ON THE POSSIBILITY OF INTEGRATED REGULATION OF THE OPERATION OF WELLS OF THE OPERATIONAL FUND USING DYNAMIC REFERENCE MODELS (USING THE EXAMPLE OF THE RESULTS OF HYDROCHLORIC ACID TREATMENTS OF CARBONATE DEPOSITS OF THE PERM TERRITORY)

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A B S T R A C T

The work is devoted to a retrospective assessment of the possibility of using real-time diagnostic curves to solve problems of increasing the efficiency of hydrochloric acid treatments. The object of the study is the carbonate deposits of the Perm Region, characterized by a heterogeneous geological structure in combination with a different content of rock-forming components, their density and intensity of distribution in the context of the main deposits. The methodology of using artificial intelligence algorithms in calculating the fractal dimension of series is presented and the sequence of transition to the given coordinate systems is given to take into account the most important geological and technological indicators affecting the relevance of managerial decision-making. Based on the results of modeling, contradictions were revealed in the basic models for predicting permeability coefficients determined by various methods during field operations. Using the principal component method, hidden patterns were established and the most relevant dependence was selected, which can be successfully used as part of the transition from one coordinate system to another. During the detailed interpretation of the results obtained, it was found that when designing hydrochloric acid exposure, the most important aspect is the calculation of the true value of the Hurst index to characterize the initial data series and probabilistic assessment of the efficiency of cleaning the most permeable filtration channels. Conclusions are drawn about the features of the use of diagnostic curves in the planning of acid treatments and the relevance of their implementation in the real production process of field development and operation at the final stage.

Keywords: integrated well regulation; modeling; principal component method; dynamic reference dependencies; hydrochloric acid effect; cleaning of the bottomhole formation zone.

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Introduction

Acid injection into the reservoir is one of the most common methods of increasing well productivity and is based on the formation of highly permeable wormholes of various geometric sizes in combination with purification, as well as a slight expansion of existing filtration channels, which allows previously undrained areas of the reservoir to be involved in the development process [1-4]. For the first time, an acid composition for the treatment of oil-bearing horizons was used at the end of the eighteenth century by the Ohio Oil company, the effectiveness of which was ambiguous due to the creation of favorable conditions in the borehole-formation system for the manifestation and spread of corrosion foci on the surface of underground equipment. And only after more than a quarter of a century, acidic effects became widespread, including due to the discovery and development of large deposits in the Ural-Volga region, composed of limestones with different contents of dolomite components, the degree and density of their mineralization, as well as the concentration of iron and sulfate inclusions. Since that moment, various compositions based on acid-containing compositions have been actively used to this day in various geological and physical conditions of occurrence of productive formations, being an actual and proven way to maintain basic oil production volumes [5-7].

Over time, the applied technologies for the implementation of acid treatments have undergone a number of significant changes due to the need for selective exposure, the implementation of large wormholes and the widespread influence of geological and technological conditions on the success of acid exposure. As oil reserves were selected, the intensity of acid treatments increased significantly, which was reflected in the form of an increase in injection volumes, the use of multicomponent formulations, and the implementation of advanced combined injection technologies. This significantly complicated the procedures for designing, controlling and monitoring the effects, but at the same time allowed scientists to study in more detail the features of the reaction of acid compositions with rocks. Despite the fact that the mechanism of interaction of acid compositions with rocks

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of the carbonate group has been studied quite widely, as the frequency of treatments increases, their specific efficiency decreases exponentially [8-10].

Research and methods of solving the problem

An equally important reason for the decline in the effectiveness of acid treatments is the use of irrelevant algorithms for selecting candidate wells, methods of exposure and technological parameters of the process and, in general, methodological support from subsurface users, the essence of which is based only on a superficial analysis of the initial parameters without taking into account the specifics of certain processes at the micro- and macro-level of the organization of reservoir systems. In addition, the interest in improving the processes of implementing hydrochloric acid effects is due to changes in the structure of residual oil reserves and the reorientation of vectors of oil and gas production departments to the development of carbonate reservoir deposits, the variety of types of void space of which, together with the geological and technological features of their development, gives a powerful impetus to the search and improvement of technologies for influencing near-well and remote zones of the formation [11-15].

The process of developing oil fields is closely associated with various difficulties arising from attempts by subsurface users to implement various software and hardware complexes for processing and analyzing geological and field data, which in turn leads to a high level of uncertainty and the risk of making ineffective design decisions. In this regard, one of the key tasks of the modern fuel and energy complex is to reduce the processing time of multicomponent information received in a dynamic mode. When considering the technological processes of oil production, it is important to note that existing approaches to the analysis, interpretation and processing of significant amounts of data are used only to structure the initial information. The search for hidden patterns between the main geological and technological parameters is complicated by their diversity and the use by researchers of «derived indicators» obtained as a result of calculating reference coefficients using formulas of mathematical statistics and algebraic analysis. As a result of these actions, with a superficial interpretation, contradictions are formed that affect the result of applied operations – the success of implementing a set of measures to improve the efficiency of oil production processes in the fields [16-20].

The concept of «integrated regulation» includes the possibility of interpretation without the use of auxiliary intelligent and digital systems to create conditions for uninterrupted monitoring of technological processes of oil production and the search for deviations, including using artificial intelligence systems. One of the advantages of using multicomponent data processing and the use of diagnostic curves is the high level of reliability of the results of rapid assessment of the effectiveness of various measures, including those aimed at cleaning the bottomhole formation zone from drilling and development products. An equally interesting aspect of the presented methodology of integrated regulation is the possibility of operational management decision-making [21-23].

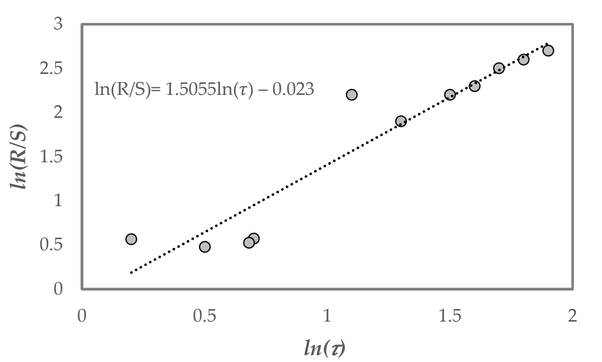

Fig. A reference model for evaluating the effectiveness of hydrochloric acid exposure

It should be noted that the position of the reference models in the axes of logarithmic coordinates *R*/*S* from *τ*, corresponding, for example, to the optimal operation of a producing well, in different geological and physical conditions of occurrence of deposits may differ, which makes it possible to reliably use adjacent information to take operational management actions, adjust models and reduce the overall level of uncertainty in complex nonlinear oil production systems. The proposed solution to the problem of operational data analysis is based on the theory of fractal dimension of series, characterized by the Hurst index. Depending on the amount of data, both the basic version of the calculation of reference models and a multi-level method are used, which includes several sequentially established boundary conditions, on the basis of which iterative processes are performed until the final result is obtained. For the basic version, the model that provides a relevant level of relationship between statistical indicators will look like this:

$$\frac{R}{S} = \left(aN\right)^{H}, \quad H = \ln\left(R/S\right)/\ln\left(a/N\right) \qquad (1)$$

where H – Hearst indicator; S – the value of the standard deviation of the base levels of the time series under study; R – the amount of accumulated deviation of values from the weighted average; N – the number of analyzed time periods; a – a constant value calculated on the basis of a small time series.

The object of the study is the deposits of carbonate reservoirs of the Ural oil and gas province. Figure shows a view of the diagnostic curve after conducting hydrochloric acid exposure at one of the wells of the field located within the territory of the Perm Territory. The model was built using dependence (1) and the methodology of processing geological and field data based on artificial intelligence systems. As can be seen from the graph, as a result of the injection of an acidic agent, the value of $\ln(R/S)$ it has increased by more than 1.5 times. Prior to exposure to acid composition, the inflow occurred unevenly, as indicated by the location of one of the points above the reference curve. After processing, the desired values are located along the model, based on which the restoration of the permeability of the bottomhole formation zone and the completion of its purification process is established.

The calculation of the fractal dimension using a well-known formula revealed that the studied series is characterized by «long-term memory», that is, achieving the maximum possible oil flow rate in current geological and technological conditions can be carried out quickly and during secondary and tertiary treatments due to a sufficiently high natural permeability and favorable location of interconnected cracks near intervals with established hydrodynamic coupling.

At the same time, this factor also has a negative impact on the productivity of the well, in particular, on the amount of operating time with stable technological indicators. A similar analysis was carried out for the remaining 20 wells that extract oil reserves from three different sites: central, vault and peripheral. According to the preliminary results of the construction of reference models, the relationship between the Hurst index, the time of wells reaching the maximum optimal flow rate and the duration of the effect of the impact has been established.

For wells located within the central part of the field, an increase in the indicator $\ln(R/S)$ in 1.1-1.4 times compared with the value calculated before injection of the acid composition, which leads to a decrease in the actual flow rate after treatment by 17-23 % compared with the predicted values with the shortest stable inflow time, equal to 43 to 52 days, respectively. This is due to the fact that during the organization of the reservoir pressure maintenance system and its intensive operation, the geological structure of the central part of the research object has significantly changed due to ineffective effects on the washed areas. For wells that have opened the layers of the arch and peripheral part of the deposits, similarities have been revealed in the change in the Hearst parameter when entering the regime. For a successful treatment option, the period of complete cleaning of the bottom-hole formation zone and stabilization of oil flows occurs within 75 days or more after the well is put into operation. Despite this, on average, after 234 days of their work, there is a primary colmation of the pore space and a decrease in productivity. As a rule, it is carried out according to a well-known scheme for deposits in this region: first of all, high permeability filtration channels and those located near the bottom-hole zone of the formation are subjected to the blockage process due to low reservoir pressures and the unstable process of oil displacement by water due to the high fragmentation of the formation.

It should be noted that the initial study made it possible to identify some difficulties in using diagnostic curves. Thus, the average permeability value for the sample of wells under consideration has a minimum standard deviation, which indicates the need for multifactorial analysis. To do this, we introduce the term «reduced coordinate system», which allows us to consider the basic algorithm for calculating the Hurst index, taking into account the main geological and technological indicators that affect the effectiveness of decision-making on planning treatments of the bottomhole formation zone. The empirical dependence that can be used to make the transition is presented below:

$$\ln\tau' = \frac{\ln\tau_1'}{\ln\tau_2'} + \xi\cdot 10^{-1} \qquad (2)$$

where $\ln\tau_1'$ – the average value of the operating time of the producing well at the maximum optimal flow rate; $\ln\tau_2'$ – the average value of the operating time of the producing wells of the field with the effective injection of acid composition identified by diagnostic curves; ξ – a parameter that takes into account the delay in the response time of the producing well to injection, determined by the generally accepted dependence (3):

$$\xi = \frac{\left(\dfrac{L}{0.038}\right)^2\cdot m\cdot\mu\cdot c_t}{k} \qquad (3)$$

where L – the average distance in the flooding element between the producing and injection wells, m; m – porosity, fractions of units.; μ – oil viscosity, MPa·s; total compressibility of the system, Pa^{-1}; k – reservoir permeability, m^2.

Discussion of the results

Based on calculations using formulas 2-3, a generalized model in the given coordinate system for the field in question in the Perm Region was obtained, which allows taking into account the main geological and technological parameters of well operation when evaluating the effectiveness of hydrochloric acid treatments:

$$\ln R/S' = 1.2456 + 1.09\,\ln\tau' \qquad (4)$$

As studies show, for the object under consideration, an increase in the level of uncertainty occurs when the parameter value increases (k), this may be due to the lack of consideration of rare cracks of small sizes, which are actively involved in the well drainage process. In the case of analyzing a model for another field belonging to the category of analogues, the difference between the permeability parameters varies unevenly, and with the current volume of geological and field data, it is impossible to reliably identify intervals in which the deviation value from a quantitative point of view assumes a value similar to the baseline indicator. Let's consider five types of basic models that can be used to establish the relationship between permeability indicators determined by hydrodynamic data (k') and geophysical (k) well surveys of the research object (table). The sample is based on data from more than 100 wells for various purposes, where measures were taken to inject hydrochloric acid compounds.

The highest value of the coefficient of determination is set for the model number 8. The appearance of this curve suggests that the relationship between the permeability parameters is heterogeneous. This is also due to the geological features of the structure of carbonate reservoirs in the Ural oil and gas province. The spatial location of the filtration channels in the bottom-hole zone of the formation affects the amount of increase in oil production after exposure. The choice of one or another dependence for calculating the permeability coefficient and, consequently, the transition to the given coordinate system, we will make on the basis of the

Table

Dependencies with different levels of reliability of forecasting indicators

Type of model / Coefficient of determination	N	Number
$k' = 0.0433e^{1.4k}$ / 0.118	110	(5)
$k' = 0.165k + 0.037$ / 0.204		(6)
$k' = 0.01\ln k + 0.5$ / 0.23		(7)
$k' = 4.1937k^2 + 1.4235k - 2.279$ / 0.343		(8)
$k' = 0.157k^{0.22}$ / 0.198		(9)

principal component method, the essence of which is based on the representation of the initial data in new axes, which are meaningful and can be interpreted taking into account the specifics of the oil field development processes.

At the initial stage, the initial sample is represented by hydrodynamic and geophysical permeability data, as well as parameters that can be reliably determined at the initial stage of drilling an object, namely: H_1 – the average depth of the formation, m; P_1 – reservoir pressure, MPa; P_2 – oil saturation pressure with gas, MPa; ρ_1 – oil density, t/m^3; ρ_2 – water density, t/m^3; G – gas factor, m^3/m^3. With the help of a special hardware and software complex, models are calculated for the first two main components, which usually provide more than 70% of the total variance of the parameters. Taking into account the fact that the data sample size is more than 100 wells, the level of reliability of the models can be estimated based on the highest value of the statistical value [24-27]. As a constant parameter of permeability, an indicator calculated after the implementation of hydrodynamic studies will be used due to the availability of sufficient results of operations and their relevance at the date of the study. Regression dependencies are constructed alternately using models (5)-(9). They have the following form:

$$Z_1^5 = 0.19H_1 + 0.01P_1 + 0.4P_2 - 0.05\rho_1 + 0.12\rho_2 - \\ - 0.004G + 0.954\mu - 0.2m - 0.17k + 0.14k'; \quad (10)$$

$$Z_2^5 = 0.02H_1 + 0.017P_1 + 0.05P_2 - 0.11\rho_1 + 0.32\rho_2 - \\ - 0.024G - 0.92\mu - 0.08m - 0.37k - 0.019k' \quad (11)$$

where Z_j^i – the value of the main component (i – the cipher of the model (see the table); j – component number).

Of the 10 main components, the first four components have the highest percentage of parameter variance, equal to 89.7%. Each of the presented components defines a different set of parameters, which are quite simple to identify using load analysis (F). The highest value F=34.7% it is established for the parameters characterizing the conditions of occurrence of productive formations and the fluids saturating them (H_1, P_1, P_2). Note that for the studied parameters k and k' the magnitude of the load differs both in magnitude and direction, which indicates the possibility of forming a high level of uncertainty when using these indicators as part of the implementation of various stages of modeling.

The second main component describes to a greater extent the properties of the fluids saturating the reservoir (ρ_1, ρ_2, G) and to a lesser extent the capacitance characteristics of the deposit (m). It is important to note that the total percentage of the generated load by four parameters is 59.4%, of which the indicator m It accounts for less than 5%. The highest load value is set for the parameter ρ_1. Comparing the results of the interpretation of the first two main components, the pattern of load changes can be clearly traced depending on the decrease in the contribution of each of them to the total percentage of variance of the ten parameters. Thus, when selecting homogeneous groups in spatial coordinates, the density of the distribution of objects in which seven previously established parameters affect, the distance between the centroids of neighboring clusters varies from 0.79 to 1.78 units. The highest load values for the parameters k and k' the fifth and seventh components were registered in the interpretation, whose contribution to the total percentage of variance is 2.3% and 1.9%, respectively. Based on this, it can be said that the use of these parameters in the implementation of modeling entails the occurrence of various noises and uncertainties [28-34].

At the next stage, we will calculate the permeability values based on the data of geophysical studies using the model (6) and consider the trend of the distribution of objects in the axes of the main components. Equations describing the degree and nature of the relationship between geological and physical parameters in spatial coordinates can be calculated using formulas (12), (13):

$$Z_1^6 = 0.04H_1 - 0.23P_1 + 0.14P_2 - 0.002\rho_1 + 0.3\rho_2 - \\ - 0.21G - 0.8\mu - 0.17m + 0.32k - 0.54k'; \quad (12)$$

$$Z_2^6 = 0.11H_1 + 0.042P_1 + 0.1P_2 - 0.29\rho_1 + 0.12\rho_2 - \\ - 0.44G - 0.12\mu - 0.3m - 0.45k - 0.023k' \quad (13)$$

The first three main components of the nine provide 93.2% of the parameter variance. It should be noted that the recalculation of one of the dependent indicators made it possible to reduce the total number of main components as a whole, on the basis of which the loads of the parameters changed significantly. The first main component reflects the filtration and capacitance properties of productive formations and accounts for 55% of the load from the parameters m, k and k', but between the last two indicators of permeability, the value of F has a different direction. The second main component characterizes the intensity of liquid filtration to a lesser extent (m and k') and it reflects the conditions of occurrence of deposits by more than 50%. When analyzing the remaining components, it was found that the change in the load value of the parameter k' it occurs more evenly compared to the indicator k. A high level of variability of the latter is also indicated by a change in the sign before the parameter in models (12)-(13).

Let's consider the case when the model (7) with the highest coefficient of determination compared to the dependence (6) was used to calculate permeability according to geophysical research data. As in the previous case, the total number of components was 9 units, but in this variant, to ensure a percentage of dispersion of at least 93.2%, it is necessary to use twice as much There are six main components, namely. The first main component is represented by parameters reflecting the physico-chemical properties of the extracted liquid at a total load of 41.1%. The second main component characterizes the conditions of occurrence of productive formations by a quarter and describes to a greater extent the capacitive properties of reservoir rocks, in connection with which for the parameter m the maximum load value is set.

The contribution of the studied indicators k and k' the total percentage of variance of the parameters is observed only when analyzing and interpreting the sixth and other components, and their trend direction of change differs from each other. When selecting relatively homogeneous groups of objects, the calculated average distances between their centroids (R) it allowed us to establish the dynamics of changes in this indicator depending on the total percentage of the total variance of the parameters that provide certain main components. So, after using the model (7) to implement permeability calculations based on data from geophysical studies of parameters R it has increased significantly, and its decrease is observed only with an increase in the magnitude of the loads of indicators k and k'. Based on this, the permeability parameters obtained from the model (6) are more relevant and preferable for use in modeling, despite the fact that the coefficient of determination of this dependence is lower compared to this indicator for equation (7) [35-38]. This discrepancy with classical decision-making algorithms in conditions of uncertainty and disequilibrium of geological and field data when The use of basic models may be due to the high level of heterogeneity of various properties of productive formations and their constituent carbonate reservoirs. When using models (8) and (9) in the framework of the implementation of the principal component method, the following results were obtained: their application contributes to an increase in the uncertainty zone represented by the average distance between objects that can be combined into a single cluster [39-43]. With this in mind, we will recalculate the models in the given coordinate system based on the use of dependence (6):

$$\ln R / S' = 1.154 + 1.17 \ln \tau' \quad (14)$$

It should be noted that the obtained dependence (14) differs significantly from the model (4), especially when analyzing the time intervals corresponding to the period after hydrochloric acid treatments, when the bottom-hole zone of the formation is cleaned and wells exit to the steady state. A preliminary comparison of the results obtained with the accumulated experience in the development of deposits in the Ural oil and gas province confirms the high relevance of dependence and the possibility of its application with a limited amount of geological and field data.

Conclusions

Based on the conducted studies aimed at assessing the prospects for the application of the methodology of integrated regulation of producing wells on the example of the results of hydrochloric acid exposure, the following conclusions were obtained:

1. Dynamic reference models allow, under conditions of uncertainty, to produce a qualitative interpretation of the data processing of the bottomhole formation zone and to establish hidden patterns between various geological and technological parameters of well operation;
2. Combining methods of geological and statistical modeling helps to reduce the risks of making ineffective management decisions when monitoring macro- and micro-processes of field development in the Ural oil and gas province;
3. A number of contradictions have been identified for carbonate reservoirs in the Perm Territory and ways to prevent and eliminate them have been established based on the construction of multidimensional regression models using the principal component method and calculation of basic dependencies between permeability indicators determined by various field methods.
4. The diagnostic curves in the given coordinate system take into account the list of the most important indicators that affect the effectiveness of the design and implementation of measures to clean filtration channels and reduce the skin factor in the field of hydrodynamic communication between the borehole-formation system.

References

1. Guo, B. Er., Xiao, N., Martyushev, D., Zhao, Zh. (2024). Deep learning-based pore network generation: Numerical insights into pore geometry effects on microstructural fluid flow behaviors of unconventional resources. *Energy*, 294, 130990.

2. Batyrshin, E. S., Nikolaev, A. A., Nikolaeva, D. R., et al. (2024). New information on the kinetics of the hydrochloric acid - carbonate rock reaction in the presence of impurities of sepiolite/palygorskite, *Oil Industry*, 8, 42-47.

3. Meshcheryakov, A. A., Galiev, N. A., Folomeev, A. E., et al. (2023). Substantiation of the optimal formulation of the acid composition and parameters of acid exposure using physical and mathematical modeling. *Oil Industry*, 8, 104-109.

4. Khuzin, R. R., Andreev, V. E., Mukhametshin, V. V., et al. (2021). Influence of hydraulic compression on porosity and permeability properties of reservoirs. *Journal of Mining Institute*, 251(3), 688-697.

5. Gilyazetdinov, R. A., Kuleshova, L. S., Mukhametshin, V. V. (2024). An experimental approach to estimating the current oil recovery coefficient using a complex of stochastic and numerical computer modeling methods. *SOCAR Proceedings*, SI1, 47-52.

6. Gilyazetdinov, R. A., Mukhametshin, V. Sh., Gizzatullina, A. A., et al. (2024). Development and adaptation of hybrid algorithms for assessing the degree of well interaction. *SOCAR Proceedings*, 1, 70-75.

7. Dmitrieva, A. Yu., Baturin, N. I., Lutfullin, A. A., et al. (2024). An integrated approach to forecasting colmatant deposits in the near-well zone of the formation. *Oil Industry*, 7, 26-31.

8. Dmitrieva, A. Yu., Baturin, N. I., Lutfullin, A. A., et al. (2024). Investigation of optimal options for thermal acid treatment of carbonate reservoirs. *Oil Industry*, 7, 39-43.

9. Buravtsov, A. S., Vernigora, D. E., Olender, O. V., et al. (2023). Organic clay acid composition as an alternative to mineral acids in the treatment of terrigenous reservoirs in Western Siberia. *Oil Industry*, 9, 123-127.

10. Folomeev, A. E., Magadiev, A. F., Khatmullin, A. R., et al. (2020). Acidizing combined with heat generating system in low-temperature dolomitized wax damaged carbonates. SPE-202069-MS. In: *SPE Russian Petroleum Technology Conference, Virtual.*

11. Bulgakova, G. T., Kharisov, R. Ya., Sharifullin, A. R., Pestrikov, A.V. (2013). Optimization of acid treatments of horizontal wells in carbonate reservoirs. *Oil Industry*, 6, 102-105.

12. Akhmetov, R. T., Mukhametshin, V. V., Kuleshova, L. S., Grezina, O. A. (2021). Production facilities grouping based on the parameters of the capillary pressure curves generalized model on the example of Western Siberia oil fields. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 332(11), 89–97.

13. Kuleshova, L. S. (2024). Reducing the risks of making erroneous decisions when managing the development of deposits in carbonate reservoirs. *SOCAR Proceedings*, 2, 3-12.

14. Novikov, V. A., Martyushev, D. A., Li, Y., Yang, Y. (2022). A new approach for the demonstration of acidizing parameters of carbonates: Experimental and field studies. *Journal of Petroleum Science and Engineering*, 213, 110363.

15. Folomeev, A. E., Taipov, I. A., Skvortsov, A. M., et al. (2023). Experience in acid treatment of a high-temperature carbonate reservoir using a high-tech layout. *Oil Industry*, 6, 54-59.

16. Yurin, A. V., Ryabokon, E. P. (2024). Methodology for determining the optimal reagent volume for acid treatments of carbonate reservoirs based on the pressure recovery curve method. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 335(8), 215-226.

17. Lutfullin, A. A., Abusalimov, E. M., Sharifullin, A. R., et al. (2023). Adaptation of mathematical models for the formation of acidic dissolution channels based on the results of studies of carbonate reservoirs. *Oil Industry*, 6, 49-53.

18. Lutfullin, A. A., Abusalimov, E. M., Sharifullin, A. R., et al. (2022). Investigations of the physico-chemical properties of process fluids for modeling acid treatment of the downhole zone of a carbonate formation. *Oil Industry*, 7, 43-47.

19. Guo, A., Tang, X., Qiao, J., et al. (2023). Three-dimensional simulation of the acidizing process under different influencing factors in fractured carbonate reservoirs. *Energy Science & Engineering*, 11(9), 3102-3118.

20. Nasr-El-Din, H. A., Al-Mohammad, A. M., Al-Shurei, A. A., et al. (2006). Restoring the injectivity of water disposal wells using a viscoelastic surfactant-based acid. *Journal of Petroleum Science and Engineering*, 54(1-2), 10-24.

21. Sayed, M. A., Nasr-El-Din, H. A., Zhou, J., et al. (2012, February). A new emulsified acid to stimulate deep wells in carbonate reservoirs. SPE-151061-MS. In: *SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, USA.*

22. Kuleshova, L. S. (2024). Modeling of the oil recovery process for managing the development of deposits using artificial intelligence. *SOCAR Proceedings*, SI1, 22-25.

23. Mukhametshin, V. V., Gilyazetdinov, R. A., Kuleshova, L. S., et al. (2024). On the depth of identification of objects in the study of the influence of the density of the grid of wells on the degree of production of oil reserves. *SOCAR Proceedings*, SI1, 26-31.

24. Mukhametshin, V. Sh., Kuleshova, L. S., Safiullina, A. R. (2021). Grouping and determining oil reservoirs in carbonate reservoirs by their productivity at the stage of geological exploration. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 332(12), 43–51.

25. Sergeev, V. V., Belenkova, N. G., Zeigman, Yu. V., Mukhametshin, V. Sh. (2017). Physical properties of emulsion systems with SiO_2 nanoparticles. *Nanotechnologies in Construction*, 9(6), 37–64.

26. Grishchenko, V. A., Mukhametshin, V. Sh., Rabaev, R. U. (2022). Geological structure features of carbonate formations and their impact on the efficiency of developing hydrocarbon deposits. *Energies*, 15(23), 9002.

27. Mukhametshin, V. V., Kuleshova, L. S. (2023). An algorithm for justifying the selection of facilities for the introduction of innovative oil production technologies in the conditions of the Lower Cretaceous deposits of Western Siberia. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 334(10), 179-186.

28. Gilyazetdinov, R. A. (2024). Digital support and evaluation of the effectiveness of geological and technical measures based on artificial intelligence systems. *E3S Web of Conferences*, 524, 03038.

29. Gilyazetdinov, R. A. (2024). Prospects for the use of advanced computer modeling systems in planning geological and technical activities. *E3S Web of Conferences*, 524, 03042.

30. Sayed, M., Cairns, A. J., Aldakkan, B. S., et al. (2018, April). A low-viscosity retarded acid system for stimulation of high-temperature deep wells. OTC-28838-MS. In: *Offshore Technology Conference, Houston, Texas, USA.*

31. Adewunmi, A. A., Solling, T., Sultan, A. S., Saikia, T. (2022). Emulsified acid systems for oil well stimulation: A review. *Journal of Petroleum Science and Engineering*, 208, 109569.

32. Furui, K., Burton, R. C., Burkhead, D. W., et al. (2012). A comprehensive model of high-rate matrix-acid stimulation for long horizontal wells in carbonate reservoirs: Part II—Wellbore/reservoir coupled-flow modeling and field application. *SPE Journal*, 17(01), 280-291.

33. Mogensen, K., Hansen, J. H. (2007, November). A dynamic model for high-rate acid stimulation of very long horizontal wells. SPE-110135-MS. In: *SPE Annual Technical Conference and Exhibition, Anaheim, California, USA.*

34. Ali, M. T., Ezzat, A. A., Nasr-El-Din, H. A. (2020). A model to simulate matrix-acid stimulation for wells in dolomite reservoirs with vugs and natural fractures. *SPE Journal*, 25(02), 609-631.

35. Jafarpour, H., Moghadasi, J., Khormali, A., et al. (2019). Increasing the stimulation efficiency of heterogeneous carbonate reservoirs by developing a multi-bached acid system. *Journal of Petroleum Science and Engineering*, 172, 50-59.

36. Alameedy, U., Alhaleem, A. A., Isah, A., et al. (2022). Effect of acid treatment on the geomechanical properties of rocks: an experimental investigation in Ahdeb oil field. *Journal of Petroleum Exploration and Production Technology*, 12(12), 3425-3441.

37. Martyushev, D. A., Govindarajan, S. K., Li, Y., Yang, Y. (2022). Experimental study of the influence of the content of calcite and dolomite in the rock on the efficiency of acid treatment. *Journal of Petroleum Science and Engineering*, 208, 109770.

38. Wang, X., Qu, Q., Berry, S., Cutler, J. (2013, June). Iron sulfide removal: a nonacidic alternative to hydrochloric acid treatment. SPE-165199-MS. In: *SPE European Formation Damage Conference & Exhibition, Noordwijk, The Netherlands.*

39. Suleimanov, B. A., Guseynova, N. I., Rzayeva, S. C., Tuleshova, G. D. (2018). Results of acidizing injection wells on the Zhetybai field (Kazakhstan). *Petroleum Science and Technology*, 36(3), 193-199.

40. Suleimanov, B. A., Rzayeva, S. C., Akberova, A. F., Akhmedova, U. T. (2022). Self-foamed biosystem for deep reservoir conformance control. *Petroleum Science and Technology*, 40(20), 2450-2467.

41. Suleimanov, B. A., Rzayeva, S. C., Akhmedova, U. T. (2021). Self-gasified biosystems for enhanced oil recovery. *International Journal of Modern Physics B*, 35(27), 2150274.

42. Vishnyakov, V. V., Suleimanov, B. A., Salmanov, A. V., Zeynalov, E. B. (2019). Primer on enhanced oil recovery. *Gulf Professional Publishing*.

43. Suleimanov, B. A., Veliyev, E. F., Vishnyakov, V. V. (2022). Nanocolloids for petroleum engineering: Fundamentals and practices. *John Wiley & Sons*.