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Improving Methodological Approach to Measures Planning for Hydraulic Fracturing in Oil Fields

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Goal of the research is development of an integrated approach to the planning of hydraulic fracturing (HF) treatment taking into account geo-technical, hydrodynamic, technological and economic criteria for the selection of wells for inclusion in the programs of HF with increasing importance of economic criteria.

Stages of formation of the program for HF of the oil company are selected, systematized and analyzed. It is shown that high potential effectiveness of enhanced oil recovery method in fields with hard-to-recover reserves, on the one hand, and the complexity and high cost of application, on the other, determine the need to optimize the parameters of this business process at all stages of implementation and improve its planning methods. The priority directions for improving the hydraulic fracturing planning were justified: a clear definition of the criterion for the payback period of hydraulic fracturing activities, taking into account their technological features, improving the procedure for calculating the costs of implementing this technology and improving the reasonableness of selecting candidate wells for inclusion in the hydraulic fracturing program.

Feasibility of using an additional criterion in the formation of hydraulic fracturing programs – marginal minimum cost-effective wall capacity – has been shown and a method for calculating it has been developed. The use of this criterion will allow to take into account not only technological limitations, but also limits of economic efficiency of conducting hydraulic fracturing at each specific well and, at the preliminary selection of candidate wells, exclude a priori unprofitable measures.

It is advisable to take into account proposed directions for improving planning of hydraulic fracturing in the development of corporate regulatory documents, which will help to improve the quality of planning geological and technical measures, minimize investment risks, make more rational use of oil companies' resources for improving oil recovery, choosing the best management decision.

Key words: oil company; enhanced oil recovery; planning; geological and technical measures; hydraulic fracturing; debit; economic efficiency

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Introduction. Current stage of oil industry development in Russia is characterized by entry of the most high-yield fields into the late stage of development, accompanied by a decrease in oil production, an increase in the production water-cut of wells, an increase in the share of hard-to-recover reserves, and complex structure of productive strata. Since about 70 % of oil reserves in the industry belong to the category of hard-to-recover, for oil companies, along with increase in the volume of geological exploration for the purpose of reproducing reserves and entering new fields, problem of the most complete extraction of hydrocarbon reserves in the fields being in operation, increasing the period of their profitable development, is vital.

Economically and energy efficient secondary and tertiary methods of intensifying hydrocarbon crude extraction, technologies for extracting hard-to-recover oil, technical means of remote monitoring of reservoirs and wells state are priority technologies for the development of oil production.

As the world and national practice of oil field exploitation shows, one of the most effective methods for developing low-permeability sediments is hydraulic fracturing (HF). This method occupies a leading position among other geological and technical measures (GTM) both as a way to increase production and as a technology to increase oil recovery factor for deposits with hard-to-recover reserves. The use of hydraulic fracturing technologies as a component of the field development system ensures an increase in the rate of resource extraction, enhanced oil recovery due to the involvement in active development of poorly drained zones and seams and provides the possibility of placing in operation deposits with low potential flow rates and, therefore, transfer of part of out-balance reserves into industrial ones.

Advantages of the method ensured its wide application in the fields of many oil companies (PJSC Rosneft Oil Company, Gazprom Neft PJSC, Lukoil PJSC, Tat-Neft PJSC, etc.). At the same time, introduction of fracturing technologies for a long time was carried out in partnership with foreign oilfield services companies Weatherford International Plc, Schlumberger Ltd, Halliburton and others, and therefore the majority of high-tech equipment used in the hydraulic fracturing fleets was acquired abroad.

This circumstance, under the conditions of sanctions pressure on the Russian oil sector by the US and the EU, diversification of export deliveries, volatility of world oil prices, instability of exchange rates while maintaining a high level of dependence of hydraulic fracturing on imported equipment, technologies and services, underlines the urgent need for a solution technical and technological problems, such as optimization of applied methods, development of own resource-saving hydraulic fracturing technologies, production of domestic hydrofrac fleet, tooling-up for microseismic monitoring. At the same time, the role of rational methodical approaches to the planning of hydraulic fracturing, validity of management decisions is significantly increasing.

Fundamental research and scientific publications of domestic and foreign automobiles provide an opportunity to solve one of the key planning tasks for applying this method – substantiating the technological feasibility of its implementation in each particular case. Another key task of hydraulic fracturing planning is to justify economic feasibility of hydraulic fracturing at wells selected for this purpose according to technological criteria, economic optimization of hydraulic fracturing plans, reducing the likelihood of including a priori ineffective and unprofitable measures. The most problematic and insufficiently studied aspect of the formation of hydraulic fracturing programs for oil companies, which largely determines their performance, is improvement of the principles of selection from both technological and economic positions of the most promising wells for implementing measures.

Improving the planning methodology at the well selection stage, ensuring that oil companies include not only technologically feasible but also economically viable activities in the hydraulic fracturing programs, creates the necessary conditions for improving scientific validity of the plans, adequate interpretation of the measures effectiveness, contributes to the rational use of investment resources and improved measures of efficiency for oil companies.

The subject of scientific interest of the authors is the problem of improving the methodological techniques for planning hydraulic fracturing process through an integrated approach to substantiating the parameters of each well – a candidate for conducting hydraulic fracturing according to geological, technological and economic criteria with increasing importance of economic criteria.

Formulation of the problem. In the modern scientific literature there are widely presented studies describing technical aspects of the problem of using hydraulic fracturing in oil fields as the main method of enhanced oil recovery, increase in oil recovery factor, and well productivity growth.

In the works of foreign authors J. Clark [22], M.Ekonomidis, K.Nolt [24], P.Valko [34], B.Haymson [28], A.Mathura, H.Nina, R.Marsineva [29], R.Nordgren [31], E.Simonson [32], P.Varenburg [27], L.Britt, M.Smith [26] and domestic researchers S.A.Khristianovich, Yu.P.Zheltova, G.I.Barenblatt [15] the possibility of formation of large vertical and horizontal cracks during hydraulic fracturing of the oil reservoir is scientifically substantiated, understanding of the mechanism of hydraulic fracturing formation is generalized, nature of the behavior of cracks and their impact on the results of the method is studied, mathematical model of the process is developed, methodical aspects of calculations increase in oil production during fracturing are described.

Experience in the use of HF, improvement of technology, use of HF in horizontal wells and sidetracks, introduction of multi-stage HF, selection of proppant, improvement of perforation works and other technical problems of the studied method are highlighted by S.I. Kudryashov, S.I.Bachin [3], I.G.Fattakhov, P.M.Malyshev [5], A.G.Pasynkov, A.R.Latypov [8], T.S.Usmanov, I.Z.Mullagalin, I.S.Afanasyev [2], M.M.Hasanov [14].

In the studies of M.Kaichs [21], Al.F.Shakurova, I.F.Shakurova [16], P.Martins [33], C.Atkinson [18] as the main indicators that need to be taken into account when optimizing the technology of HF, the geometry (length, width, height) and the residual permeability of HF crack, its conductivity, the role of the skin effect in determining the productivity of wells are considered.

M.Ekonomidis, R.Olaini, P.Valko [25], H.Meng [30] proposed a unified method of hydraulic fracturing design, justified the logical design sequence, basic principles of a unified HF design for all oil and gas reservoirs.

HF planning is a complex, multi-step and multi-criteria process, during which a significant amount of heterogeneous geological and technical information is processed and systematized, HF parameters are optimized and the list of wells included in the work program is optimized. In domestic and foreign practice, as a rule, economic efficiency of planned activities for HF is estimated by standard methods of project analysis based on the generally accepted system of indicators: net profit (NP), net present value (NPV), profitability index (PI), internal rate of return (IRR), payback period. In accordance with corporate regulations, wells and estimated performance indicators, which meet all the listed criteria or several of them, are selected for HF. In order to make a final decision on the inclusion of activities in the program of work, additional criteria can be used, for example, reflecting environmental or industrial safety. The most common criteria for the selection of measures when planning HF is the positive value of the NPV and the non-excess of the payback period of the established level of costs.

It should be noted that standard methods used to assess the measures effectiveness do not always allow to adequately take into account the specifics of HF and the risks arising from its implementation.

In the studies of domestic and foreign authors V.I.Grajfer, V.A.Galustyants, M.M.Vinnitsky, V.S.Sheinbaum [13], V.D.Lysenko [7], A.G.Zagurenko [6], R.Balena, H. Mens, M.Ekonomidis [19], R.Agarval [17], L.Britt [20], B.Styuart, M.Mullen, R.Ellis, U.Norman, U.Miller [23], the need to improve the approaches to HF planning is considered, and recommendations for assessing economic efficiency of this method from the standpoint of choosing the optimal proppant mass to achieve maximum well productivity, project oil recovery factor and provide predictable technological indicators, are made.

The need to take into account strategic priorities to ensure a balance between reproduction and extraction of oil reserves in the planning of geological and technical measures was justified by V.V.Traise, A.V.Shalahmetova, M.S.Yumsunov [12]. These authors proposed a comprehensive criteria for evaluating measures in selecting for inclusion in the geological and engineering program, aggregating traditional indicators of the economic efficiency of investments (net present value, profitability index, payback period) and indicators of technical and economic performance of their implementation (oil recovery factor, growth rate, unit costs). In order to improve the methodology for economic justification of measures included in the programs of geological and engineering measures of oil companies, the options for substantiating the net present value indicator with regard to specific risks for GTM have been investigated.

D.N.Ramazanov developed a model for the formation of a GTM portfolio with an acceptable level of risk, taking into account strategic priorities and restrictions of the oil company's activities when applying methods of enhanced oil recovery [9].

A solution to the problem of information and algorithmic support for planning processes for GTM by creating an automated decision support system for planning geological and technical measures was proposed by V.A.Silich, A.O.Savelyev [10]. The authors of this work have taken the payback period of the event as a criterion of efficiency, calculated on the basis of planned indicators of production growth and total cost of the geological and technical measures.

Despite the directions for improvement presented in the scientific literature and stipulated in a number of corporate standards, a serious disadvantage of the current system of HF planning in oil companies is the fact that cost-effectiveness calculations are performed or aggregated by the type of GTM and not individually for each well or generally are not performed, but are carried out after taking measures on the basis of actual results, and not planned indicators. Often, the reason for selecting candidate wells for HF is the results of activities at other wells without taking into account the difference in their flow rates and other operational properties.

Insufficient consideration of economic criteria in the selection of wells for inclusion in the program of HF, lack of assessment of calculation reliability of the initial technological and economic data used in the formation of the program of HF, incorrectly performed substantiation of the effectiveness of this method application may result in failure to comply with the planned indicators for oil production, inefficient use of funds allocated by the oil company to carry out GTM [1, 4].

It should be noted that in both domestic and foreign studies, the flow rate (for oil and for fluid) obtained after carrying out hydraulic fracturing is considered as a key parameter that ensures the effectiveness of HF. The baseline data for calculating well production after HF is based on monthly average oil and fluid flow rates on the date the well was shut down before the HF and the rate of change of base oil and liquid flow rates prior to HF, calculated on the basis of statistics of the corresponding indicators for the previous period. This approach is reflected in the corporate regulations for the selection of wells for HF used by oil companies.

Methodology. Along with general methods of scientific analysis (abstract-logical and comparative), we used an integrated approach, models and methods of system analysis, object-oriented design methodology for complex systems (Object Model for System Design – OMSD), methods of economic and mathematical modeling, simulation modeling were applied.

The use of abstract-logical method and models provided the opportunity to develop hypotheses about the shortcomings of the methodological support of HF planning and their impact on the efficiency of carrying out the work and performance of oil companies. A comparative analysis revealed a commonality of approaches to evaluating the effectiveness of GTM and insufficient consideration of specific features of hydraulic fracturing measures.

An integrated approach to the study of the problem, used by the authors of this work, allowed to take into account the variety of factors determining the success of planning and implementation of HF, identify trends and features of HF planning within the strategic and tactical management of the oil resource potential of the oil company, identify and systematize stages formation of HF programs, to justify the need to focus on strategic priorities in their development.

The use of models and methods of system analysis provided a methodological opportunity, without changing the current sequence of calculating the predicted increase in oil production, to develop an additional criterion for selecting wells for inclusion in the HF program – the minimum cost-effective flow rate and propose a model for its calculation based on break-even methodology. Application of this model, slightly increasing the volume of calculations, creates the possibility of a more detailed preliminary substantiation of the expected performance indicators for each particular well, reduces the likelihood of errors in forecasting results and provides conditions for making more informed investment decisions. Such an object-oriented approach creates conditions for reducing the number of low-efficienct HF.

In order to increase reliability of the research results and validity of recommendations, methods of economic-mathematical and simulation modeling are used in the work.

Discussion. Planning of geological and technical measures, including measures for hydraulic fracturing, is based on strategic priorities of oil companies and is being carried out in order to form an optimal set of measures ensuring the planned increase in oil production, based on requirements of acceptable risk, technical feasibility, and economic efficiency in conditions of limited financial resources.

The main factors determining the success of HF and ensuring optimal plans for their implementation are the rationale for selection of production facility for operations, perfection of fracturing technology, optimal selection of wells for these measures in these specific conditions.

Currently, planning and evaluating the effectiveness of HF are carried out on the basis of corporate regulations, methods and other regulatory documents developed by oil companies.

Selection of candidate wells and formation of proposals in the program of work on hydraulic fracturing are carried out on the basis of geological field analysis of the development of reserves, experience in the use of HF at the impact site and generalized criteria.

As part of this study, a planning algorithm was developed for the stages of HF process (Fig.1). Considering the fact that HF is a technology of radical impact on the reservoir, when forming a work program, it is advisable to take into account that any intervention of this kind in the well operation process that is not justified by reliable calculations can lead to geological, technological, environmental problems, as well as economic losses, which consist not only in unjustified costs of the measures, but also in the non-fulfillment of the oil companies' plans for oil production and profits [11].

The author's position is such that when choosing options for operating a reservoir of low-debit wells, a more critical approach to selecting wells is required for conducting HF, which involves performing a more detailed assessment of the activities included in the plans, based not only on the magnitude of technological effect, but also on optimizing HF planning, taking into account factors determining this value according to economic criteria, taking into consideration economic constraints (Fig.2).

High potential effectiveness of this method of increasing oil recovery and growth of oil recovery index at fields with hard-to-recover reserves, on the one hand, and complexity and high cost of use, on the other hand, necessitate optimization of this business process parameters at all stages of its implementation.

Optimization by technological criteria, taking into account geological and technological constraints, involves selecting and optimizing the mass of the proppant, fracture fluid and its injection rate to create the necessary fracture parameters and minimizing the skin factor, taking into account a set of parameters: permeability, depth, productive part of the oil reservoir , reservoir pressure, etc.

Optimization by economic criteria is based on optimal technological criteria, taking into account strategic objectives of the oil company and economic constraints. The result of such an integrated approach is development of an optimal design of HF, based on maximum economic efficiency with existing geological and technological constraints.

In our opinion, the priority areas for improving HF planning are as follows: clearly defining the criterion for the payback periods of HF activities, taking into account their technological features, improving the procedure for calculating costs for implementing this technology and increasing the reasonableness of selecting and including selected wells in the HF program.

In oil companies, regardless of obvious technological features of each type of GTM, as a rule, a unified procedure for assessing their economic efficiency is applied. The uniformity of the approach to justify economic efficiency of GTM is implemented by using a single algorithm, common technological and economic sources of information for calculations and the same selection criteria for all GTM: measure is considered effective if the value of net present value for the estimated period is above zero and payback period does not exceed the set value. At the same time, in corporate documents there is no uniformity of requirements for the cost recovery criterion when conducting HF on the basis of the regulations for the selection of wells for HF oil and gas production – no more than the period of obtaining the technological effect. It should be noted that when HF planning, the company's average production period is often used, while for each particular case it is individual and ranges from 24 to 60 months. To eliminate inconsistencies in estimates when using different payback period criteria, taking into account complex of factors determining the HF effectiveness, in

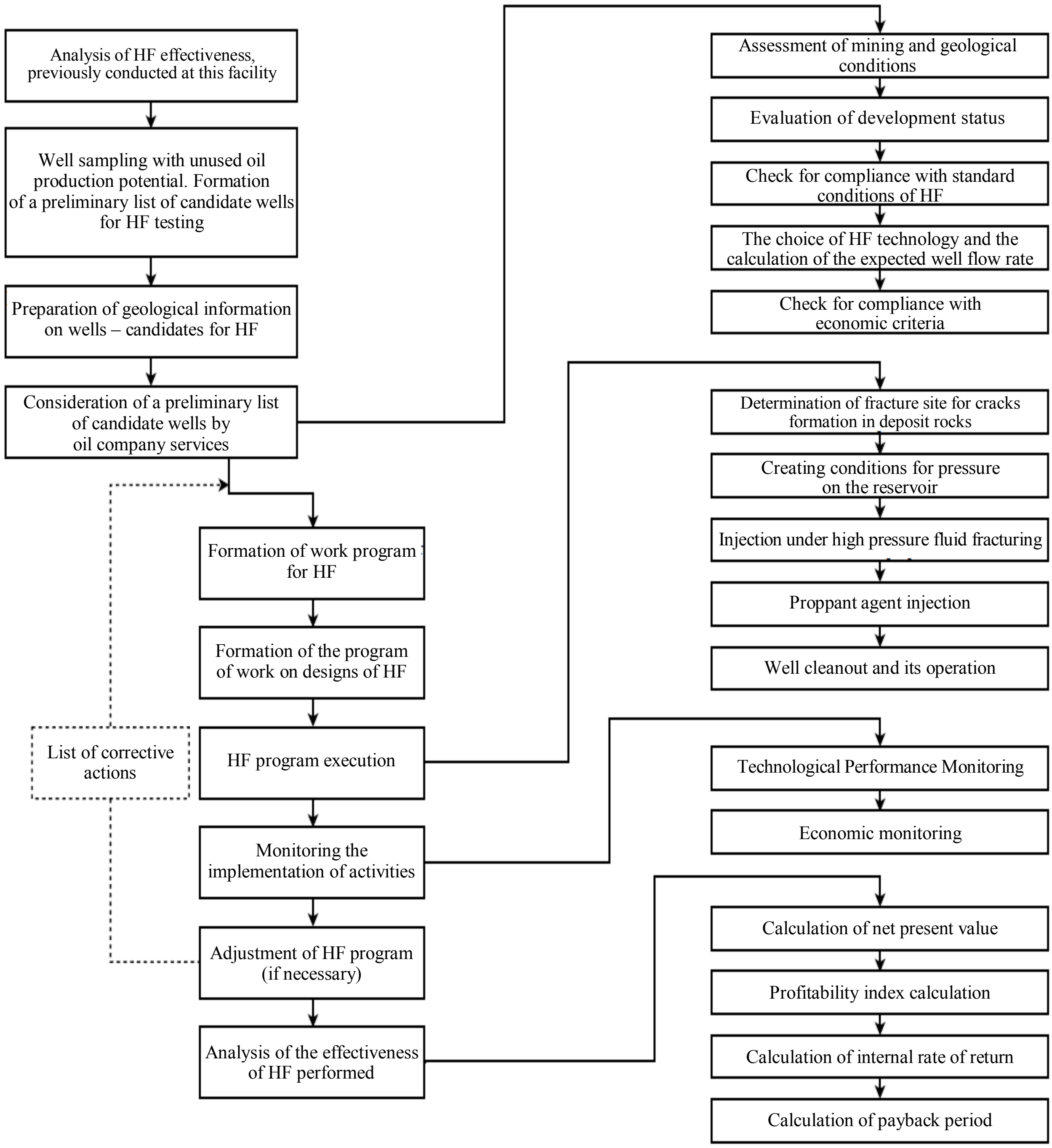

Fig.1. Algorithm of the process of HF planning and execution by an oil company

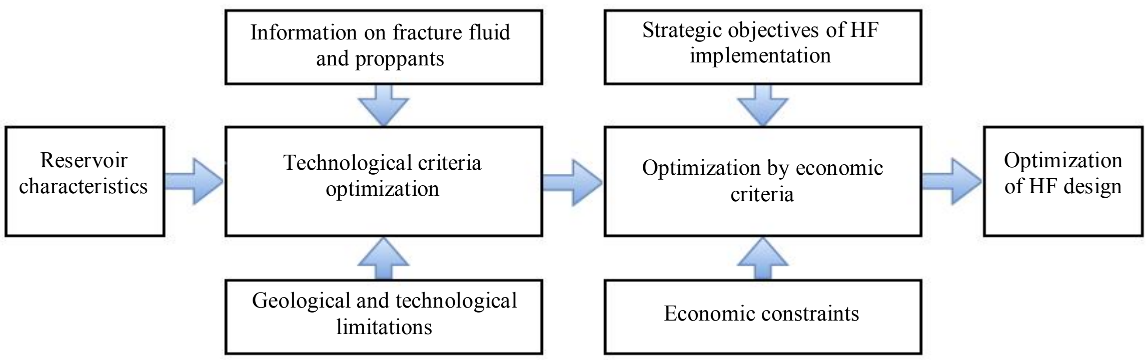

Fig.2. Schematic diagram of HF optimization

our opinion, the most adequate is criterion corresponding to the individual period of technological effect, and it is necessary to use its value when performing operational costs and indicators of HF effectiveness.

Approaches to the GTM planning used by oil companies are based on the need to link possibilities of calculating criterias of effectiveness of measures with existing accounting and reporting forms. Oil companies, wishing to simplify procedures for justifying HF effectiveness at the planning stage, proceed from the established average (for a group of wells, field, enterprise) the costs for HF, ignoring the fact that use of different technologies in different wells is characterized by individual cost indicators.

In this regard, for improving the quality of planning, it is obvious that it is necessary to calculate individual operating costs for wells included in the HF program, especially since modern computer technologies and information databases of oil companies allow such calculations to be made.

When HF planning, the most significant risks (technological and financial) are associated with determination of additional oil production for each well, the value of which determines both technological and economic effects of measures. The key role of additional oil production indicator in HF planning requires sound approaches to its calculation. In this regard, we consider the method used by oil companies to calculate this indicator.

In accordance with existing corporate methodologies for evaluating effectiveness of GTM, calculation of additional oil production at the planning stage of HF, as well as other GTM, is made on the basis of statistical or hydrodynamic models of well operation. In the absence of the necessary data, an approximate express method for calculating the technological effect of GTM, based on the use of various models for the formation of basic and forecast oil and liquid flow rates, is used to make calculations using the above models.

Analysis of approaches to HF planning and evaluation of the effectiveness of its implementation shows that the choice of wells from the number of low-yield wells only on the basis of actual and predicted flow rates and geological parameters can not always ensure optimal decisions. In order to increase HF effectiveness, taking into account the non-triviality of its application for productive development of hard-to-recover oil reserves, a methodical approach to justifying the choice of wells – candidates for inclusion in the HF program should be comprehensive and at the same time object-oriented.

To ensure this approach, it is proposed to consider HF of each well as an independent investment project. This will make it possible to more reliably estimate the economic efficiency of the event, compare the results of HF with alternative options for enhanced oil recovery, choose the best option in each specific case and increase the level of responsibility of project participants for the success of its implementation.

When justifying effectiveness of the project for each well, it is recommended not to limit only the calculation of economic efficiency indicators (NPV, PI, IRR, payback period), and to supplement justification with calculations of these indicators, taking into account risks of the project, first of all, the risk of not confirming the actually confirmed volumes of oil production predictable. In this regard, in our opinion, it is advisable to consider an additional criterion for the selection of wells – applicants for inclusion in HF program – the marginal minimum profitable flow rate of the well and, based on its value, analyze the intervals of flow rates in which HF will be acceptable to the oil company. Using this criterion will allow to take into account not only technological limitations, but also the limits of economic feasibility of HF at each specific well.

Methodology for calculating the break-even point can be applied to calculate the minimum profitable well flow rate. The break-even point shows the critical volume of production and sales of products, excess of which provides the company with a profit. When volume of production and sales of products is below the break-even point, activity of the enterprise is associated with losses. This indicator is an important indicator of optimal technical, economic and managerial decisions.

The minimum profitable well flow rate can be calculated by the formula

$$\mathrm{MPFR} = \frac{C_{fix}}{\mathrm{T}(P - C_{\mathrm{var}})30.4R_{\mathrm{u}}}$$

where MPFR – the minimum profitable flow rate; C_{fix} – annual semi-fixed costs; T – settlement period, taken equal to 12 months; P – the price of oil; C_{var} – annual semi-variable costs; 30.4 – the average number of days in a month; R_{u} is well utilization rate.

The proposed criterion – the minimum profitable flow rate of a well allows linking costs with indicators of technological efficiency and substantiate the limits of economic expediency of using this method. If the planned flow rate is greater than or equal to the calculated formula, well can be included in the program of hydraulic fracturing. Otherwise, one should either improve technological solutions for HF or consider using other geological and technical measures.

In contrast to the methods of HF planning used by oil companies, which are based on generalized indicators and aggregated calculations, the proposed approach is based on taking into account the individual costs of wells, which increases the accuracy of the calculations. In addition, an important distinction and at the same time the advantage of the proposed approach over the methods of decision-making on conducting HF common in world and domestic practice, by reference to standard performance indicators of investment projects, based on NPV, PI, IRR criteria and payback period, is to increase the reasonableness and efficiency of investment decisions at the initial stages of program formation, since the proposed additional criterion allows already at the preliminary screening stage important candidates exclude a priori unprofitable events.

Comparison of the results of HF planning and implementation on the current and proposed approaches, using the example of Lukoil-West Siberia LLC data for 2017, confirms that the proposed approach reduces the likelihood of unprofitable measures being included in the HF program. Calculations using the recommended approach to HF planning at wells showed that out of 111 hydraulic fractures performed in 2017, the costs of which did not pay off during the estimated technological effect period, 20 measures (or 18.9 %) were a priori non-payable. In this case, the total loss from these 20 obviously economically ineffective HF is about 118 million rubles.

Conclusion. Due to peculiarities at the current stage of oil industry development in Russia, characterized by the entry of most high-yield fields into the late development stage, accompanied by a decrease in oil production, an increase in well water-cut, an increase in the share of hard-to-recover reserves, an increase in the number of small unprofitable fields, the optimal solution to the problem increases increase the degree of extraction of oil from the subsoil, the rational use of existing oil companies Nij wells. Slowing down the rate of decline in oil production and their stabilization, extending the life of marginal wells and ultimately improving the efficiency of using reserves are achieved through the use of various types of geological and technical measures, coupled with significant costs for their implementation and significant geological and financial risks.

Selection of wells – candidates for inclusion in the HF program without sufficient economic justification or incorrect implementation, consisting in the application of aggregated calculations for the entire block of hydraulic fracturing, the company's average cost of implementing this type of geological and engineering measures, the absence of economic calculations for each individual well, leads to the inclusion in programs of a significant number (according to the results of the analysis carried out in this work – 18 %) a priori unprofitable measures, a significant decrease in the effective cost of funds and the failure to implement plans for oil production.

Taking into account the proposed directions for improving methodological approach to HF planning in corporate regulations will allow oil companies to formulate HF programs based on strategic priorities, more rationally spend funds on GTM, increase their performance, reduce the level of investment geological and financial risks and ultimately account improve performance.

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