

# THE CRITERIA FOR THE SELECTION OF WELLS FOR HYDRAULIC FRACTURING

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**Abstract.** Various methods of selection of wells for hydraulic fracturing are analyzed. It is established that all methods can be divided into three large groups: criteria in the table form of boundary values of parameters, statistical methods of pattern recognition, methods of engineering calculation.

The complication or use of additional parameters only leads to a reduction in the number of wells at which hydraulic fracturing is possible.

It is shown that the use of reservoir properties of rocks, which are already used by hydraulic fracturing simulators, is not practicable as selection criteria. It is required to include in the selection criteria only those additional factors on which the effectiveness of hydraulic fracturing depends directly.

**Key words:** well selection criteria, expert estimates, hydraulic fracturing

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Currently, the selection of wells for hydraulic fracturing (fracturing), as a rule, is carried out by expert assessments of specialists and based on the available field experience. This process is not strictly formalized, therefore different groups of specialists often come to different conclusions.

When selecting wells it is necessary to solve a number of issues:

1. Is it advisable to carry out hydraulic fracturing at a specific well?
2. What kind of hydraulic fracturing technology should be applied?
3. What treatment scale should we choose?
4. What increase in production rate can be obtained?
5. Will the cost of hydraulic fracturing pay off?

Items 4-5 require simulation in MProd, MNpv simulators or in hydrodynamic programs, and they are rarely performed.

Criteria for selecting wells for hydraulic fracturing are based on field experience and do not need any geological justification. Criteria are changed in connection with the improvement of hydraulic fracturing technology and access to new facilities. PJSC Tatneft processed many wells that did not meet the criteria, with positive results. On the other hand, often wells meeting all criteria without exception were not effective. That is, the criteria are the statistical rules for testing hypotheses, the adherence to which will ensure a fairly low percentage of errors of the first and second kind. Zero hypothesis –

the well, which will be selected for fracturing, will be effective. An error of the first kind – the well does not meet the criteria, but the hydraulic fracturing on it will be effective. An error of the second kind – the well meets the criteria, but the hydraulic fracturing on it will be ineffective. Criteria are developed on the basis of long field practices so as to minimize the sum of errors of the first and second kind.

Sometimes we can find statements that the criteria are bad, not geologically sound, and so on. What happens if we tighten the criteria? Then there will be a lot of wells left overboard, on which the hydraulic fracturing would be effective, but we rejected them. If we will soften the criteria, many inefficient wells will appear, which in their parameters meet the criteria. There are criteria that do not need any justification at all. For example, a well should be technically sound, and oil reserves are at the level of profitability. These are axioms.

Usually, the criteria for selecting wells are a table with a list of parameters and their boundary values. As the pilot works conducted, experimental processes and experience accumulated, the tables are gradually being improved.

The TatNIPIneft Institute created criteria for the selection of wells for the fracturing, considering the works of many specialists (R.G. Abdulmazitov, G.A. Orlov, R.T. Fazlyev, M.Kh. Musabirov and others), starting around 1997. There are several guideline documents on this issue, but in them all the parameters are mostly reproduced. The difference is only in numerical values for boundaries. Let's compare the selection criteria for 2015 and 2006. In the new criteria, the oil-saturated

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thickness of the reservoir decreased from 1.5 to 0.8 m; thickness of overlapping and underlying screens from 5 to 4 m. Now it is allowed to conduct simultaneous fracturing of two layers with a distance between them not exceeding 20 m; but it was no more than 3 m. The zenith angle of the well in the formation interval is no longer regulated. The additional requirements for producing wells decreased: the watercut of the production is not more than 90% (it was not more than 50%), the reservoir pressure is not less than 0.5 from the initial (was no less than 0.7 from the initial), the distance to the nearest injection well is not less than 200 m (it was not less than 300 m). The reduction in requirements is due to the fact that a large number of wells that do not meet the criteria are rejected in practice. If criteria are tightened or additional criteria are introduced, wells suitable for hydraulic fracturing can remain literally one.

A positive aspect is the additional requirements for acid fracturing, which was not in the previous version of the selection criteria. This is the solubility degree of rock in hydrochloric acid, the heterogeneity of the rock, Brinell hardness, the distance from the water-oil to the lower perforations. Criteria for the use of acid fracturing have also been developed by other authors (Zharlgapov, Nikulin, 2014).

Similar tables of criteria are used in other oil-producing enterprises. For example, in (Al'mukhametova, Evdokimov, 2014), based on the analysis of the efficiency of hydraulic fracturing at the Priobsky field, it was established that the main criteria for the success of hydraulic fracturing operations are: oil saturated thickness – not less than 3 m; thickness of overlapping and underlying screens – not less than 3 m; the ratio of the current reservoir pressure to the initial pressure is not less than 0.9; watercut production – not more than 30%; the angle of the borehole deviation from the vertical in the interval of the formation is no more than 10°; depth of the well – no more than 3000 m.

Another method, actively recommended by some specialists, is the use of pattern recognition programs in various modifications.

For example, in work (Pichugin et al., 2007), an approach is proposed for predicting the efficiency of hydraulic fracturing on the basis of methods of neural network modeling, probability trees and support vector machines. The disadvantage is that the chosen methods, like any other statistical methods, do not allow achieving a high quality prediction without preliminary analysis of the results of hydraulic fracturing, careful preparation and formation of a database.

In work (Zalevskii et al., 2006), in order to determine the conditions for the most effective application of fracturing technology, calculations were performed using mathematical methods of statistical analysis, in particular, Mann-Whitney statistics and Wald's

sequential diagnostic analysis. Preliminary for all 684 fracturing operations conducted at fields of the Manufacturing Facility Uraineftegaz, a local database was developed that characterizes the geological conditions of the formations, the geological and physical conditions of their bottom-hole zones, the current values of the production indices at the time before, during and after the fracturing, and technological parameters of hydraulic fracturing.

Despite the novelty and sophistication of the mathematical methods involved, these approaches have not been widely distributed. The reason is that it is necessary to create and maintain extensive fracturing databases. As the authors of this approach write, the maximum efficiency from the use of an intelligent forecasting system can be obtained only if there is feedback, in the mode of continuous support of activities for the implementation of measures at wells (Pichugin et al., 2009).

Other approaches have been proposed, for example, using the mathematical apparatus of fuzzy logic (Galiullin et al., 2011; Perminov, Valeev, 2013). The authors of these papers recommend using a complex of two mathematical applications: cluster analysis and fuzzy logic. Cluster analysis allows automatically compiling a rating list of candidate wells and, on its basis, selecting wells that are prioritized for hydraulic fracturing. It is reported that the use of the fuzzy logic method makes the clustering algorithm more robust to errors and geological uncertainty of the main parameters.

There are other approaches to the problem of wells selection for hydraulic fracturing. For example, in (Serebrennikov et al., 2014), a generalized information is presented on the features of a complex approach to the validation of candidate wells for hydraulic fracturing, including: 1) the formation of pre-selection and the ranking of wells (sections of fields) by methods of Data mining; 2) expert evaluation of the criteria characterizing the wells and areas of the field for implementing the hydraulic fracturing. The main geological-technological and technical criteria revealed empirically, used in the analysis by Data mining methods, as well as factors whose formalization is a rather complex task are shown.

There are suggestions for using trees instead of decision tables. In work (Gaidamak, Pichugin, 2015) the possibility of application of the decision tree method for selection of candidate wells for fracturing is investigated. A method for identifying indicators that significantly affect the success of the hydraulic fracturing is described. The negative effect of increasing the spatial density of the fracturing performed on subsequent hydraulic fractures is established. A method is proposed for improving the quality of the forecast by varying the threshold value of success.

In work (Kulikov et al., 2016) principles of an express-method of wells selection for carrying out stimulation are presented. The method is based on the use of graphical correlation of the current flow rate values and the values of fluid potential index for the wells of a given deposit.

Engineering calculations and various proxy models for the selection of wells are used. A fundamentally new computerized technology was developed at the RITiMPS department of the TatNIPIneft Institute, based on an analysis of the state of impact elements. For the selection of wells-objects, geological conditions and technological indicators of the development efficiency, determined by the LAZURIT program, and the characteristics of the well itself, permitting fracturing, are used.

The program for selecting wells for the fracturing is based on criteria that have been repeatedly tested in Tatneft PJSC. The validity of the criteria is confirmed by the field practice, as evidenced by the achieved level of success (87%). The scientific basis of the method was developed jointly with the specialists of Tatneft PJSC (Sultanov et al., 2010).

The well selection methodology tested at a number of LUKOIL-Perm fields for intensifying oil extraction and increasing oil recovery is close to this approach, which includes the estimation of residual recoverable reserves in differentiated production wells; determination of the residual recoverable reserves production duration by wells; choice for the subsequent analysis of wells with high values of residual recoverable reserves and their production duration; assessment of the wellbore zone conditions; selection of technologies for conducting activities (Mordvinov et al., 2006).

Since no matrix of solutions can provide a 100% guarantee of the success of hydraulic fracturing, many researchers offer additional criteria. For example, in work (Solov'eva et al., 2009), the necessity of using an additional criterion for the selection of an object for fracturing is justified. Its essence consists in revealing the vertical conductivity of non-reservoirs separating oil-saturated strata from aquifers, through the actual pattern of watering the reservoir and the location of the candidate well for the fracturing.

Methods for selecting wells for specific geological conditions are known, for example, analysis of the fracturing operation results performed on wells with low reservoir pressure of RN-Purneftegaz LLC has formed the basis for the development of wells selection with low reservoir pressures for fracturing operations (Borkhovich et al., 2012).

Often statements are made that in the selection criteria of wells for fracturing it is necessary to include reservoir (filter-capacitive) rock properties. We will show the fallacy of this situation on the example of the results of pilot industrial works for fracturing into

Mendymyskian, Domanic and Sargaevskian deposits of the Republic of Tatarstan.

Using the apparatus of mathematical statistics, according to the actual values of porosity and clay content of the Domanic deposits, the curves of their theoretical distributions were reconstructed (Figures 1, 2). For this purpose, the mean values and root-mean-square deviations of each of the parameters were calculated. Then, using the function EXCEL NORM.DIST, the distribution curves of each parameter were restored. On the basis of the results of numerous studies, it was assumed that these distributions obey the normal law.

The root-mean-square deviation for small samples ( $n < 10$ ) was estimated by the sample size. It is known that with a normal distribution, as an estimate of the scattering characteristic, we can use the sampling range

$$R = x_{max} - x_{min}, \quad (1)$$

where  $x_{max}$  and  $x_{min}$  – the maximum and minimum values in the sampling, respectively.

It is shown, that

$$MR = \alpha_n \sigma, \quad (2)$$

where  $M$  – the symbol of mathematical expectation;  $\alpha_n$  – a function of the sample size, the values of which are given in the tables;  $\sigma$  – root-mean-square deviation.

Thus,

$$M\left(\frac{R}{\alpha_n}\right) = \sigma. \quad (3)$$

At small  $n$  ( $n < 10$ ), this estimate of the parameter  $\sigma$  has a rather significant efficiency, but at large  $n$  it is ineffective in comparison with  $s$ . For the sample size  $n = 6$ , the parameter  $\alpha_n = 2.534$  (Smirnov, Dunin-Barkovskii, 1969).

It can be seen from the figures that the distributions of the studied properties of the formations have a significant overlap that does not allow their effective differentiation with respect to the properties studied. If we use the property values as a boundary criterion at the points where the curves intersect, then this will lead to large errors of the first and second kind.

For example, let the porosity value be 6%. Then the probability that the treatment of this formation will be successful, according to Figure 1, will be approximately 13%. The probability that the treatment of this formation will be unsuccessful, will be approximately 17%. Then, according to the formulas of probability theory, if this formation is chosen for processing, the probability of success will be  $13/(17+13) \times 100 = 43\%$ , which is approximately half of all wells. If the porosity value is 10%, then the probability of successful treatment is about 10%, and the unsuccessful about 4%. Probability of treatment success is  $10/(10+4) \times 100 = 70\%$ . Conclusion with a probability of at least 95% can be given only in situations where we are far from the center of the

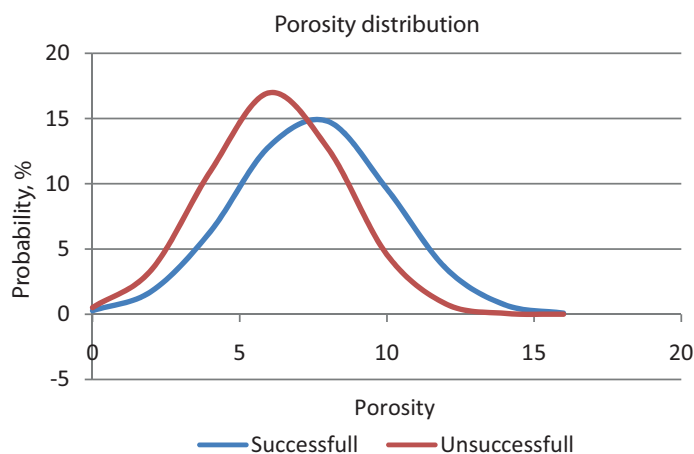


Figure 1. Theoretical distribution of porosity for successful and unsuccessful fracturing processes

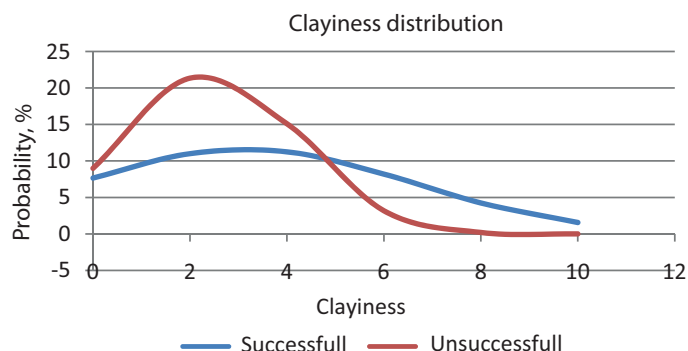


Figure 2. Theoretical distribution of clay content for successful and unsuccessful fracturing processes

parameter distribution. For example, with a porosity of 14%, the probability of success is approximately 0.7, and the failure rate is 0.07. Then the reliability of the conclusion on the success will be  $0.7/(0.7 + 0.07) = 0.91$ . Despite the extreme situation, we do not reach the required level. There is nothing we could do, nature works by its own laws.

In this example, we tried to show that the “scientific justification” and the introduction of some new criteria for selecting wells for hydraulic fracturing (especially associated with the reservoir properties) is a dead-end path.

Hydraulic fracturing is carried out in reservoirs with any reservoir properties. For example, the permeability can be from units of nanodarsi (in shales) to hundreds of millidarsi (in sandy rocks). And everywhere hydraulic fracturing is carried out, changing only the technology used. But permeability is a reservoir property of the rock. The same applies to porosity and clay content – these are also reservoir properties. The hydraulic fracturing simulators take into account the reservoir properties and the values of the process fluid leaks, therefore, in the selection criteria for wells, there is no need for limitations on the reservoir properties of rocks.

There are situations in which the attraction of additional selection criteria is simply necessary, for example, when designing acid fracturing in carbonate sediments. The work of the TatNIPIneft Institute showed that the rock hardness by the Brinell is the necessary

criterion in this case (Ibatullin et al., 2011). Although the simulator takes into account the hardness of the rock, however, starting from some minimum hardness value, the conductivity of the fracture becomes zero. Therefore, it makes sense to screen out such losing options in advance. Hardness does not play a significant role during proppant fracturing.

The second situation is the choice of intervals for fracturing in thick shale strata. The purpose of the hydraulic fracturing is to obtain a branched grid of fractures, covering as much as possible the largest volume of the formation. The difference of technology lies in the use of low-viscosity fracturing fluids. Brittleness and rock toughness begins to play a major role in these conditions. Since no single indicator allows predicting the creation of the best grid of fractures, a complex indicator is used that includes both indicators, which is called fracability (Jin et al., 2014).

The mathematical model of the fracability index in terms of brittleness and rock toughness is defined as follows

$$FI = \frac{B_n + K_{IC-n}}{2}, \quad (4)$$

where  $B_n$  – normalized brittleness;  $K_{IC-n}$  – normalized rock toughness.

$$B_n = \frac{B - B_{\min}}{B_{\max} - B_{\min}}, \quad (5)$$

where  $B_{min}$  and  $B_{max}$  – minimum and maximum brittleness of the investigated formation, respectively.

$$K_{IC\_n} = \frac{K_{IC\_max} - K_{IC}}{K_{IC\_max} - K_{IC\_min}}, \quad (6)$$

where  $K_{IC\_max}$  and  $K_{IC\_min}$  – minimum and maximum rock toughness of the investigated formation, respectively.

The  $FI$  index is in the range from 0 to 1. The interval with  $FI = 1$  is considered as the best candidate for fracturing, and the interval with  $FI = 0$  is the worst.

The main goal of hydraulic fracturing design in shale sediments is to increase hydrocarbon production by selecting candidates with the highest fracability index. It is reported that this index has been successfully used to optimize hydraulic fracturing and to drill horizontal wells in the Barnett shale play.

## Conclusions

1. Criteria for selecting wells for hydraulic fracturing depend on the area of works and vary with time. The main form of the criteria is to represent them in the form of a table of parameter boundary values.

2. Distributions of reservoir properties for a set of successful and unsuccessful fracturing processes largely overlap, not allowing to effectively recognize them.

3. Reservoir properties (porosity, permeability, clay content) do not reflect the efficiency of fracturing processes. Moreover, they cannot act as criteria for selection of candidate wells.

4. If the factors on which the hydraulic fracturing efficiency depends are determined, it is possible to include them in the selection criteria for the wells. However, the parameters that the fracturing simulator takes into account (such as porosity, permeability, etc.) cannot act as well selection criteria for fracturing.

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