Investigation of fracture geometry

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Abstract. This article presents a study on hydraulic fracturing as one of the most effective methods of increasing the flow rate of wells, namely, the importance of evaluating the geometry of a hydraulic fracturing fracture when designing in difficult geological conditions is considered. The quality and success of the event depends on the correct assessment of the predicted crack geometry and the volume of the injected proppant. The fracture geometry is influenced by the mechanical properties of the rock, so, in the article, the results of a study of the mechanical properties of the core by dynamic and static methods are presented, and the main characteristics of the dependence are given. The results of modeling the fracture geometry of hydraulic fracturing at the stage of analysis of mini hydraulic fracturing are also presented. The findings indicate the need to use data on the mechanical properties of core samples with a high clay content to achieve more accurate predictions of the crack geometry. It is recommended to use a correlation model of the mechanical properties of rocks to account for various factors such as horizontal stress and poroelasticity coefficient. The development of new approaches to the analysis and modeling of these parameters will allow us to create more reliable tools for predicting the behavior of cracks in rocks and effectively managing the process of hydraulic fracturing.

1 Introduction

Hydraulic fracturing is one of the most effective means of increasing well flow rates, since it not only intensifies the production of reserves located in the well drainage zone, but also, under certain conditions, significantly expands this zone by attaching poorly drained areas and layers of the formation to the development, and, consequently, allows for higher final oil recovery.

When designing the design of hydraulic fracturing in difficult geological conditions, first of all it is necessary to evaluate the geometry of the fracturing fracture [1-2]. The predicted fracture geometry of the hydraulic fracturing is the main criterion for determining the amount of injected proppant and choosing the method of reservoir treatment. To assess the economic efficiency of hydraulic fracturing, the relevance of correctly calculating the achievable limits of the fracture geometry increases when:

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- Proximity of water-saturated zones (front of injected waters or oil-water contact).
- High fragmentation of the formation.
- The absence of pronounced clay bridges.

2 Methods and materials

At the depths of the field development facilities, the stresses do not exceed the elastic limit of most rocks. Therefore, the stress-strain state of rocks can be described within the framework of the theory of elasticity.

It is known from Hooke's law that the main mechanical properties of a rock that affect the geometry of a crack are the Young's modulus and the Poisson's ratio. It is assumed that the mechanical properties of rocks are isotropic in direction.

Conducting polarizing acoustic (AK) and density (GGCp) logging in the well also makes it possible to determine the dynamic mechanical properties of the rock. Due to the fact that the velocity of propagation of an elastic wave does not depend on its frequency, the mechanical properties of rocks calculated from logging and dynamic studies of core samples (under reservoir conditions) coincide.

The results of measurements of the mechanical characteristics of the rock depend on the measurement method, which is determined from the conditions of a specific task. Thus, static measurement methods are usually used to describe the elastic properties of rocks exposed to prolonged stress (untouched rocks in formation conditions), dynamic methods are used to describe instantaneous loads (perforation blasting, impact drilling, etc.).

When conducting hydraulic fracturing, it is necessary to know the mechanical properties of the rock determined by the static method. However, due to the small coverage of the development objects by studies of the mechanical properties of the core, it becomes fundamentally important to determine the method of converting the dynamic elastic properties of the rock into static ones. This method and type of dependence are influenced by the lithology and conditions of the rock occurrence [3, 4].

3 Results and Discussion

Young's modulus and Poisson's ratio can be measured by dynamic and static methods. Static core tests determine the elastic properties of samples during their deformation. The dynamic method is based on the excitation of sound and ultrasonic waves in a core sample with registration of the propagation velocity of longitudinal and transverse waves. Here and further, the indices D and S for mechanical properties mean, respectively, a dynamic and static research method:

$$E_D = p v_S^2 \frac{3v_p^2 - 4v_S^2}{v_p^2 - v_S^2} \tag{1}$$

$$v_D = \frac{v_p^2 - 2v_S^2}{2(v_p^2 - v_S^2)}, \tag{2}$$

$$G_D = p v_S^2, \tag{3}$$

$$K_D = \frac{p(3v_p^2 - 4v_S^2)}{3}, \tag{4}$$

Where ED – Young's module; r – density; vS, vP – the velocity of the transverse and longitudinal waves, respectively; nD – Poisson's ratio; GD – The shear modulus; KD – volumetric compression module.

Calculation of the mechanical characteristics of the rock according to the data of the standard complex of geophysical well surveys (GWS).

Often, independent studies of the fracture geometry of hydraulic fracturing show a discrepancy between the achieved and predicted fracture geometry, which is primarily due to incorrect values of the mechanical parameters underlying the design of hydraulic fracturing. The average values cannot characterize a wide range of mechanical properties of rocks with sufficient accuracy. (Figure 1) shows the distribution of mechanical properties used by hydraulic fracturing contractors in the design of hydraulic fracturing and the results of core studies of this formation [5-6].

It shows that each service company providing hydraulic fracturing services uses its own mechanical properties of the rock, which are not consistent with each other or with the results of core studies.

To replicate the results of measurements of the static mechanical properties of the core, the authors considered two only possible approaches to calculating the properties of the rock according to the data of the standard GWS complex.

1. Based on studies of the mechanical properties of the core and data from polarization acoustic and density logging (GIW ↔ dynamic mechanical properties according to AK and GGKp = dynamic properties of the core ↔ static mechanical properties of the core).

2. Based on studies of the mechanical properties of the core and porosity data (GIW ↔ porosity ↔ static mechanical properties of the core).

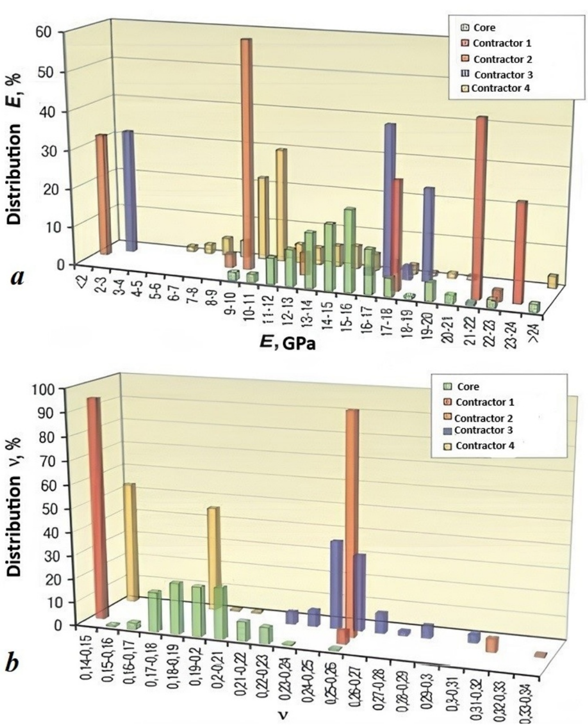

Fig. 1. Distribution of values of Young's modulus E (a) and coefficient Poisson's law V (b) in the design of hydraulic fracturing.

The preparatory stage. To restore dependencies, 10 wells of the field were considered. One of the wells was a test one. The porosity values of j are determined from nuclear magnetic logging data. The dynamic characteristics of the rocks were calculated from the data of density and polarization acoustic logging in accordance with expressions 1-4. Without going into detail into statistical methods, we note that the GIS data were filtered from outliers of values and noise. The functional dependence of the rock properties on the data of the standard GIS complex is defined as [7-11]:

$$Y = A + \sum_{i=1}^{\xi} B_i X_i + \sum_{i=1}^{\xi} C_i \log X_i, \quad (5)$$

Where Y – the property of the breed; A, B_i, C_i – the required dependence coefficients; X_i, log X_i – accordingly, the value and logarithm of the GIW value (PS, GC, NC, BC, IC), which are explanatory variables.

Table 1 shows the characteristics of the dependency. Note that the most significant GIW methods are NC, PS and GC.

Table 1. The main characteristics of addiction.

Y	Correlation coefficient		Relative error, %		Sensitivity to logging, %			
	Regression	Test	Regression	Test	GK	PS	NK	IK
E_D	0.83	0.85	6.68	6.52	20	4.2	75.3	0.5
V_D	0.73	0.76	3.33	3.32	17.3	29.8	52.2	0.7
φ	0.74	0.76	12.22	12.14	6.6	62.7	30.6	0.3
V_p	0.83	0.86	2.45	2.24	21.9	1	76.7	0.4
V_s	0.82	0.84	3.63	3.58	20.8	8.2	70.9	0.1
ρ	0.72	0.73	1.18	0.63	14.2	75	8.8	2
G_D	0.83	0.85	7.13	7.09	20.8	1.7	77.1	0.4
K_D	0.7	0.72	5.11	3.27	13.7	23.9	61.5	0.9

Figure 2 shows the results of modeling the fracture geometry at the stage of mini-fracture analysis (redesign design) and studying the fracture height. It can be seen from Figure 3 that the use of special GIS data and studies of the geomechanical properties of the core provides more reliable modeling of hydraulic fracturing processes and, as a result, makes it possible to optimize fracturing [12-17].

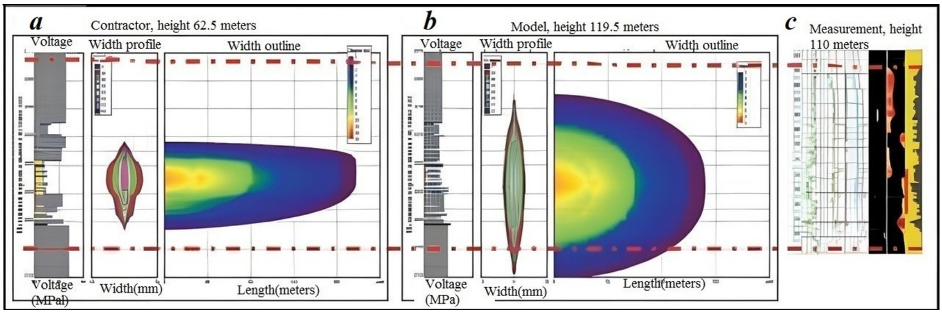

Fig. 2. The geometry of the crack predicted by the contractor (a), according to the model (b) at the stage of analysis of mini-fracturing, the actual measurement (c): a, b – the height of the crack is 62.5 and 119.5 m, respectively.

According to the results of studies of the mechanical properties of the core, the correlation dependence is determined by dynamic and static methods. In our case, it has the following form:

$$E_S = 0.014{E_D}^2 - 0.41E_D + 17.4; R = 0.8 \quad (6)$$

$$v_S = 0.15v_D + 0.18; R = 0.77 \quad (7)$$

$$K_S = 0.018{K_D}^2 - 0.42K_D + 10.3; R = 0.76 \quad (8)$$

$$G_S = 0.035G_D^2 - 0.39G_D + 7.1; R = 0.8 \quad (9)$$

Similarly, based on the results of core studies, we obtain the dependence of Young's modulus on porosity according to the formula:

$$E_S = 1179.5\varphi^2 - 340.7\varphi + 37.9; R = 0.7 \quad (10)$$

4 Conclusion

The use of special methods for measuring the height of cracks and injection pressures of hydraulic fracturing allows us to successfully solve the problem of restoring the real geometry of a fracturing fracture after a well operation.

The difficulty of predicting the actual fracture geometry (a direct task) compared to the previous task is that neither the injection pressure nor the measured fracture height are known. When developing a hydraulic fracturing design, the only thing that can lead to a successful forecast is an adequate model of mechanical and filtration properties, as well as a correct stress calculation. When planning hydraulic fracturing in the well of the field, studies of the fracture height and density logging were included in the work schedule. This made it possible to consider this well as a candidate for testing the methodology for predicting fracture geometry.

The Young's modulus and Poisson's ratio were restored and the horizontal stress profile along the entire section of the well was calculated. The hydraulic fracturing design was designed in parallel with the hydraulic fracturing contractor. Only the Young's modulus, Poisson's ratio and horizontal stress were changed in the contractor's design. The height predicted by the contractor was 62 m, according to the model – 120.5 m. Based on the results of the mini-fracturing, the efficiency of the liquid was calculated (68%), the closing pressure (40.8 MPa) and the formation pressure according to Horner (30 MPa) were determined. Horizontal stresses were recalculated in the model and the leakage coefficient profile was adjusted. The Poisson's ratio and Young's modulus did not change. Together with the specialists of the contractor, it was decided to reduce the volume of hydraulic fracturing fluid at the stage of the "cushion" of the mini-hydraulic fracturing from 200 to 175 m^3 and reduce the injection rate from 4.2 to 4 m^3/min.

Since only data on the mechanical properties of sandstones were used in the design of hydraulic fracturing in this well, it is possible to increase the accuracy of calculations of the fracture geometry using data on the mechanical properties of core samples with a high clay content. The correlation model of the mechanical properties of rocks and the implemented calculation of horizontal stress – tectonic and lithostatic, as well as the coefficient of poroelasticity allowed to increase the accuracy of the fracture geometry prediction.

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