Probabilistic statistical model for predicting the effectiveness of hydraulic fracturing

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Abstract. The article studies the effectiveness of single-stage and multi-stage hydraulic fracturing technologies using the mathematical statistics method. The studies are based on the geological and physical characteristics of the Shirotny Priob fields which makes it possible to substantiate the methods for choosing the hydraulic fracturing technology. Based on the probabilistic and statistical analysis of field efficiency data, quantitative criteria for the selection of fracture parameters by length, height and amount of injected propane have been established. They can be used to predict the use of multi-stage and single-stage hydraulic fracturing methods. The productive horizon AS12-3 has a complex geological and physical structure and low filtration and storage properties, which complicates its development and contributes to the active formation of hard-to-recover reserves. The one-stage hydraulic fracturing technology is efficient only for 3-4 years. The multistage hydraulic fracturing technology showed is more efficient in comparison with the single-stage one.

1. Introduction

Russian and foreign technologies used to increase production efficiency are based on hydraulic fracturing which increases oil flow. The technology is based on the mechanism of rock crack formation and propagation. In foreign and Russian works on hydraulic fracturing, the effectiveness of hydraulic fracturing is studied using the probabilistic-statistical approach. Few works determine the optimal number of hydraulic fracturing stages, with an estimate of distances between the fractures. Therefore, it is necessary to develop new criteria for multiple hydraulic fracturing in integrated reservoir stimulation using the probabilistic-statistical approach

2. Literature review

Many foreign and Russian scientists deal with the efficiency of hydraulic fracturing, especially in the conditions of hard-to-recover oil reserves. Many scientists [1–4] describe ways to improve the multistage hydraulic fracturing technology in anisotropic heterogeneous oil-saturated reservoirs.

[3–6] describe the possibility of assessing the productivity index of deposits based on indirect data when drawing up the first design documents and modeling oil recovery processes using the experience of developing fields that have been in operation for a long time.

The study described in [10] is based on the method of determining the amount of injected propane. It uses new equations that describe the fracture closure process. An analysis of the influence of fluid...
viscosity, its density, size and formation permeability was conducted. These studies will be useful when choosing a propane composition.

The experiment described in [10] is aimed at improving the efficiency of hydraulic fracturing using the pulse-technology of hydraulic fracturing of sand. The authors introduced the concept of discrete multi-layer grinding inside cracks. They proved that the use of pulse duration per formation can increase the productivity of wells, reduce the volume of hydraulic fracturing of the propane.

Despite some studies on reservoir productivity which can be improved using the single-stage and multi-stage hydraulic fracturing technologies, there are some unsolved issues. On the basis of publications and textbooks [14, 15], research using the apparatus of mathematical statistics, the authors determined the purpose and objectives of the study.

3. Research purpose and objectives

To achieve this purpose, the following tasks will be solved:

1) Statistical analysis of existing hydraulic fracturing technologies in Russia and abroad;
2) Theoretical studies of the effectiveness of the one-stage and multi-stage hydraulic fracturing technology;
3) Determination of effectiveness criteria for the hydraulic fracturing technology.

By processing statistical data of field efficiency, quantitative criteria for the selection of fracture parameters by length, height and amount of propane injected have been established. It was possible to improve the field efficiency of one-stage hydraulic fracturing and increase the annual cumulative production volume by at least 10-15%. However, 4 years after, the field efficiency of one-stage hydraulic fracturing began to decline, which required new ways to improve it based on the multi-stage modification. An analysis of the results of field testing made it possible to obtain quantitative criteria for the optimization of multistage hydraulic fracturing based on a reasonable choice of both the length and volume of fractures and their number, which made it possible to achieve the planned oil recovery factor during the development of the AS12-3 horizon within the terms established and agreed with the State Reserves Committee of the Russian Federation.

According to the geological and field studies, the oil-saturated thickness of the field has a stratal-garden character and is represented by the main productive horizon of the AS-12-3 formation of the Cherkashinskaya suite, whose thickness increases (up to 16-18 m) towards the top of the field and decreases (up to 4-5 m) in its wing area.

In accordance with the design task, the hydraulic fracturing mode was selected to obtain a single fracture in the productive strata with a height of up to 0.8–0.9 Npl, a length of 70–80 m and an opening (B) of up to 3–5 mm.

The field efficiency of hydraulic fracturing was about 50%. An analysis of the results of unsuccessful hydraulic fracturing showed that it is accompanied by low flow rates and an increase in the water cut compared to the initial one, although the selected wells were located in the zone of high residual reserves.

The study of structural features of the field and their comparison with the direction of the underlying basement faults showed that in the wing zones of the sedimentary strata, there are areas of the stressed state of the rock accompanied by the natural fracturing, which has a predominantly axial (along the swell-like structure of the field) direction.

The comparison of the unsuccessful hydraulic fracturing in the zones of residual reserves concentration and the natural fracturing direction showed that it was caused by penetration of the second fracture wing into the zone of depleted reserves with a high level of water cut [2].

At the stage of pilot testing of the single-stage hydraulic fracturing technology, the wells were selected by the following criteria [7]:
- oil-saturated reservoir thickness is not less than 3 m;
- potential production rate is not less than 10 tons / day;
- initial oil saturation $Kn > 0.4 + 0.15 \cdot \left(1 - \sqrt{\alpha_{rc}}\right)$;
- the thickness of the overlapping and underlying screens is at least 3 m.
- the ratio of the current reservoir pressure to the initial one is not less than 0.9.
- the condition of the cement stone in the perforation interval ± 20 m is good;
- the well should not have behind-the-casing flows;
- water cut of products is no more than 50%;
- the angle of deviation of the wellbore from the vertical in the reservoir interval is not more than 10°;
- water cut of surrounding producing wells is not more than 70%.

In order to study the dependence of the technological efficiency of hydraulic fracturing on the implementation technology, the following fracture parameters were studied: length, height, width, amount of propane.

It was found that with an increase in the fracture length, the initial oil production rate increased and the water cut decreased (Figures 1, 2).

At the same time, it was found that with an increase in the fracture height relative to the effective reservoir thickness, the oil production rate decreases, and the water cut increases (Figure 3). This behavior is due to a decrease in the effective oil-saturated reservoir thickness.

It was found that with an increase in the mass of injected propane, the oil production rate also increases (Fig. 4). The dependencies made it possible to correct the one-stage hydraulic fracturing technology by increasing its technological and economic efficiency.

Using the criteria for choosing the optimal parameters of the single-stage hydraulic fracturing technology, it was possible to increase the accumulated current production volume during the operation of the BV8-1 formation.

Figure 1. Dependence of the well production rate after single-interval hydraulic fracturing on the fracture length.
Figure 2. Dependence of the water cut of the well after one-interval (one-stage) hydraulic fracturing on the fracture length

Figure 3. Dependence of the oil production rate after one-stage hydraulic fracturing on the ratio of the effective reservoir thickness to the fracture height
Figure 4. Dependence of the water cut after one-stage hydraulic fracturing on the ratio of the effective reservoir thickness to the fracture height

4. Results
As an alternative to the single-stage hydraulic fracturing technology, the multistage hydraulic fracturing technology has been developed. A horizontal wellbore is drilled in the formation and several fractures located at a certain distance from each other are created [7, 14].

Figure 5 shows the ranges of flow rates: the initial (stop) flow rates before the hydraulic fracturing, the calculated (predicted) and real flow rates, flow rates three and six months after the hydraulic fracturing.

The above dependencies show that the range of calculated and starting flow rates coincides, which indicates a rather perfect method for predicting the field effect from the multistage hydraulic fracturing [7]. However, 3 and 6 months after, the real production rates differ significantly from the calculated data. They can either decrease or increase in comparison with the calculated data. This behavior is due to the systemic water cut calculation error.

We used the statistical data for 2015 and determined the deviations of real flow rates from the predicted ones.

Since when stimulating production using the multistage hydraulic fracturing technology, a gradual decrease in the current flow rate is inevitable due to the depletion of oil reserves, we studied the dependence of differences between the actual decline in the oil production rates and the water cut.

As a result of an analysis of the relationship between the probability of a positive forecast for an increase in oil production and a decrease in its water cut, additional quantitative criteria that determine the optimal properties of the fractures were obtained. They ensure the required technological efficiency of the EOR method.
Figure 5. Graphs of well flow rate distribution after multistage hydraulic fracturing of AS12-3 formation

5. Conclusion
1. The BV8 1 horizon development intensification technology based on one-stage hydraulic fracturing is efficient within 3-4 years;
2. The multistage hydraulic fracturing technology applied on the AS12-3 horizon is more efficient. However, the positive predictive indicators did not exceed 50%;
3. An analysis of the statistical indicators for the multistage hydraulic fracturing showed that the geological and physical properties of the AS12-3 horizon were not taken into account;
4. The results of an analysis of statistical indicators of the field results of application of the multistage hydraulic fracturing technology on the AS12-3 horizon made it possible to specify the ranges of the main parameters of hydraulic fractures (length, volume, number of fractures and propane weight).

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