Study of geological and technological factors on the efficiency of hydraulic fracturing

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Abstract. Using correlation analysis, the authors assess the impact of geological and physical, geological and technological properties on the technological effect in the development of fields using hydraulic fracturing. The dependence of technological effect of hydraulic fracturing from the quality of casing string annulus fixing is also considered. The analysis of technological efficiency of regular technology of hydraulic fracturing in conditions of JSC TATNEFT showed its insufficient level due to the lack of methods which take into account the impact of geological and physical, geological and technological factors. The study of correlation relationship between field results of hydraulic fracturing and reservoir properties established quantitative geological field criteria for its effective use, which allowed to make a more informed choice of objects of impact.

1. Introduction

Hydraulic fracturing technology (HF) is currently considered to be sufficiently developed in relation to various geological and physical, and geological and technical conditions [1, 5].

There are various types of fracturing techniques, the most common are the following:
- local, ensuring the opening of the productive reservoir by a crack at a small depth (some units of meters);
- massive, ensuring the opening of the productive reservoir with a crack at a medium (about 30-40 m) and large (up to 100 m and more) depth;
- selective, providing selective opening of the reservoir by a crack in any interval of the pre-selected depth of the reservoir.

2. Materials and methods

Correlation analysis of the mathematical statistics method was used to analyse the influence of geological and physical, and geological and technological properties on the technological effect in the development of fields using hydraulic fracturing.

3. Results and discussion

Analysis of the results of hydraulic fracturing at the Bavlinskoye field of the ‘Bavlyneft’ Oil and Gas Production Company, at Pavlovsk and East Leninogorsk areas of the Romashkino field of the ‘Aznakayevskneft’ Oil and Gas Production Company shows that the increase in additional oil production after the hydraulic fracturing is not observed at all sites, and the range of flowrates practically
does not change its values. It can be assumed that even if there is a well-developed technology of all the above-mentioned types of hydraulic fracturing, until recently an insufficient attention was paid to the study of a number of important factors that in the conditions of productive deposits of the same type can significantly affect its performance.

One of such important factors determining the effectiveness of hydraulic fracturing is fracturing fluid, or rather, its rheological properties, which have an impact not only on reducing its filterability into the pore space of the reservoir, contributing to clogging of the crack sides, but also prevents an inflow from the reservoir after fracturing.

At the same time, the mechanism of clogging can be caused not only by the penetration of fracturing fluid components into the reservoir, which have plugging (clogging) properties, but also by swelling of the clay material of different mineralogical composition (kaolinite or montmorillonite) contained in the rock skeleton caused by chemical incompatibility of fracturing fluid and bound water contained in the clay fraction of the reservoir.

Also, a significant disadvantage in the design and forecasting of hydraulic fracturing is an insufficient attention that is paid to the condition of insulation of the casing string annulus in certain geological and technological conditions [6 – 10].

In order to study in more detail, the factors affecting the mechanism of clogging of the pore space of productive reservoirs, as well as the condition of insulation of casing string annulus during hydraulic fracturing, the authors conducted relevant studies of this process on terrigenous reservoirs of Bobrikovian and Devonian horizons of the Bavlinskoye field and the Romashkino field [2].

In this paper, using correlation analysis, the authors assess the impact of geological and physical, geological and technological properties on the technological effect in the development of fields using hydraulic fracturing. The dependence of technological effect of hydraulic fracturing from the quality of casing string annulus fixing ($C_{qual}$) is also considered.

The technological effect for each fracture is estimated based on the dynamics of the current (monthly) flowrate of oil or water relative to the initial (baseline) level, which is used to calculate not only the value of accumulated oil or water production, but also its duration.

All the obtained data are used to study the presence of correlations between additional production in oil ($Q_{oil}$) and water ($Q_{water}$), their duration ($\Delta t_{oil}$, $\Delta t_{water}$) and reservoir porosity and permeability properties ($C_{oilsat}$, $C_{permeab}$, $C_{por}$, $C_{shale}$) of Bobrikovian and Devonian deposits.

Figure 1 shows an example of correlation dependence of the value of technological effect during hydraulic fracturing on coefficient of shaliness of Bobrikovian and Devonian deposits of the Bavlinskoye field. To establish optimal criteria for the selection of wells for hydraulic fracturing, the graphs include a line of minimum economic profitability, which was assumed to be equal to 2000 tons of accumulated oil per year.

The development and analysis of correlations between the dependence of technological effect on geological and physical, geological and technological properties of the reservoir, as well as on the insulation quality of casing string annulus, allowed to obtain a summary table of diagnostic criteria for the conditions of Bobrikovian and Devonian deposits of the Bavlinskoye field (see Table 1), from which we conclude that they differ significantly for each of these deposits [3].
Figure 1. Correlation dependence of technological effect during HF on coefficient of shaliness: a) – of Bobrikovian deposits; b) – of Devonian deposits of the Bavlinskoye field; – – – – level of profitability.

Table 1. Criteria for selecting wells for the conditions of the Bavlinskoye field.

| Type of deposit | Geological and physical properties | Geological and technological properties | Geological and technical properties |
|-----------------|------------------------------------|----------------------------------------|-----------------------------------|
|                 | $C_{\text{por}}$, % | $C_{\text{permeab}}$, % | $C_{\text{shale}}$, % | $K_{\text{oilsat}}$, % | $V_{\text{liq}}/V_{\text{pa}}$ | $C_{\text{qual}}$ (+ 20 m) | $C_{\text{qual}}$ (~ 20 m) |
| Devonian        | 13–16                | 0–80                   | 0–2                   | 45–75                | $\geq 14$               | 0.50                  | 0.30                  |
| Bobrikovian     | 14–19                | 0–250                  | 0–6                   | 50–80                | $\geq 12$               | 0.40                  | 0.30                  |
The obtained results of processing and analysis of correlation and statistical relationship of Bobrikovian and Devonian deposits of the Bavlinskoye field allow the authors to draw the following conclusions:

1. The reservoir permeability has a significant impact on the technological efficiency of hydraulic fracturing; with an increase in permeability we observe a decrease in the amount of additional oil production, which is associated with the filtration of fracturing fluid into the pore space of the reservoir.

2. The effect of shaliness in the reservoir is reduced to a decrease in its permeability as the content of clay material in the rock skeleton increases and, accordingly, to reduce the possibility of filtering the fracturing fluid into the pore space of the reservoir.

3. It is obvious that the problem of increasing the effectiveness of hydraulic fracturing in high-permeable reservoirs of Bobrikovian horizon can be solved by changing rheological properties of the fracturing fluid by reducing its ability to filter into the pore space of the reservoir.

4. Devonian deposits reservoirs have better reservoir properties compared to Bobrikovian deposits, for this reason the fracturing fluid is actively filtered into their pore space, creating near the crack wall an extensive clogging zone which becomes deeper as the porosity (permeability) of the reservoir increases.

Using a similar technique for the Devonian deposits of Pavlovsk area and East Leninogorsk area of the Romashkino field, the authors consider the influence of reservoir properties over the entire capacity of the productive reservoirs for each of the wells where hydraulic fracturing was carried out. The value of accumulated oil and water production in these areas, as well as the total duration of the effect, are estimated.

Comparing the obtained data on technological efficiency of hydraulic fracturing in these two areas, the authors come to the conclusion that it has a significant difference in them, despite the fact that the type of deposits and hydraulic fracturing technology in both cases were similar, especially since the same contractor performed the work: Leninogorsk Board for Enhanced Oil Recovery and Well Workover of JSC Tatneft.

The authors built and studied correlation and statistical relationship between technological indicators of hydraulic fracturing and geological and technical, reservoir, porosity and permeability properties of reservoirs. Figure 2 presents an example of the dependence of accumulated oil production on shaliness in Pavlovsk area and in East Leninogorsk area of the Romashkino field. To establish the optimal criteria for the selection of wells for hydraulic fracturing, as in the previous example, the graphs include a line of minimum economic profitability, which was assumed to be equal to 2000 tons of accumulated oil per year.

According to conducted studies, it can be concluded that shaliness of the rock skeleton is the main determining factor that has a predominant effect on the permeability of the rock and accordingly on the filterability of the fracturing fluid into it. At the same time, the higher shaliness of the reservoir is, then the filterability of fracturing fluid into the reservoir is lower and the efficiency of hydraulic fracturing is higher.

The development and analysis of correlations between the dependence of technological effect on geological and physical, geological and technological properties of the reservoir, as well as on the insulation quality of casing string annulus, allowed to obtain a summary table 2 of diagnostic criteria for the conditions of Devonian deposits of Pavlovsk and East Leninogorsk areas, from which we conclude that they differ significantly from each other, namely, East Leninogorsk area has two subranges of criteria.
Figure 2. Dependence of accumulated oil production on shaliness: a) – in Pavlovsk area; b) – in East Leninogorsk area; ——— level of profitability.

Table 2. Criteria for the selection of wells for the conditions of Pavlovsk and East Leninogorsk areas of the Romashkino field

| Area        | Type of deposit | Geological and physical properties | Geological and technological properties | Geological and technical properties |
|-------------|----------------|------------------------------------|----------------------------------------|-----------------------------------|
|             |                | $C_{\text{por}}$, % | $C_{\text{permeab}}$, mf | $C_{\text{shale}}$, % | $V_{\text{liq}}/V_{\text{pa}}$ | $C_{\text{qual}}$ (+ 20 m) | $C_{\text{qual}}$ (– 20 m) |
| Pavlovsk    | Devonian       | 13–17 | 0–250 | 0–4 | 75–85 | $\geq 5.5$ | 0.70 | 0.50 |
| East Leninogorsk | Devonian | 13–15 | 0–100 | 0–2 | 58–78 | 6.0–11.5 | 0.30 | 0.15 |
The results of studying the influence of reservoir, porosity and permeability properties on technological efficiency of hydraulic fracturing performed on the Pashian horizon, allow the authors to draw the following conclusions:

1. The effectiveness of hydraulic fracturing in the specified areas decreases with increasing permeability, which is due to the advanced filtration of fracturing fluid into the pore space of the reservoir.

2. An increase in shaliness of the rock skeleton contributes to an increase in the efficiency of hydraulic fracturing by reducing the permeability of the pore space of the reservoir and, accordingly, reducing filtration of the fracturing fluid into it [4].

The authors also study the influence of geological and technological factors on the efficiency of hydraulic fracturing. Figure 3 presents an example of the dependence of accumulated oil production after hydraulic fracturing of Bobrikovian and Devonian reservoirs of the Bavlinskoje field on the ratio of the volume fracturing liquid and proppant agent \((V_{\text{liq}}/V_{\text{pa}})\). In this case, optimal criteria for the ratio \(V_{\text{liq}}/V_{\text{pa}}\) were also chosen based on the level of profitability equal to 2000 tons/year.

![Figure 3. Dependence of accumulated oil production after hydraulic fracturing of Bobrikovian and Devonian reservoirs of the Bavlinskoje field with a change in the relative value of fracturing liquid volume.](image)

4. **Findings**

The performed analysis of technological efficiency of regular technology of hydraulic fracturing showed its insufficient level due to the lack of methods which take into account the impact of geological and physical, geological and technological factors. The study of correlation relationship between field results of hydraulic fracturing and reservoir properties established quantitative geological field criteria for its effective use, which allowed to make a more informed choice of objects of influence.

5. **Conclusion**

1. The study of correlation relationship between field results of hydraulic fracturing and reservoir properties established quantitative geological field criteria for its effective use, which allowed to make a more informed choice of objects of influence.

2. The study of correlation relationship between field results of hydraulic fracturing and quality of casing string annulus insulation above and below the exposure interval within ±20 m established quantitative values of insulation quality factors for different types of deposits, and the requirements for the quality of insulation from the underlying aquifers were 1.5-2 times higher than for the above-lying ones.
3. The studies performed by the authors of the degree of influence of geological and physical, geological and technological properties on the efficiency of regular hydraulic fracturing, as well as the quality of insulation of productive deposits of various types, showed that it is distinguished by a considerable variety and is largely determined by these properties, i.e. it has an adequate character of high level.

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