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Elimination of uncertainties in solving the problems of ensuring the profitability of hydraulic fracturing using FiberFrac technology

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Abstract. The main type of geological and technical measures in the oil fields of Western Siberia today is hydraulic fracturing. The widespread use of this method of intensifying oil production is due to its undeniable advantages over other technologies. However, hydraulic fracturing is not without significant drawbacks - clogging of the bottomhole zone with proppant and products of chemical reactions, as well as premature watering of well products. All of the above is the reason for the relevance of improving this event. The FiberFrac technology is proposed, the essence of which is to add the chemical reagent of the same name to the process fluid with further formation of a reinforcing mesh in the last one. The purpose of the article is to study the features of the physico-chemical properties of the FiberFrac solution using the analysis of geological and field data, to evaluate the technical and economic efficiency of the application of this measure based on the correlation analysis of statistical data and the calculation of economic efficiency using the discount method, to substantiate the advantages of FiberFrac over the standard operation hydraulic fracturing.

1 Introduction

The technology of hydraulic fracturing (HF) consists in pumping a fracturing fluid under high pressure into the formation, as a result of which new fractures are created in the bottomhole zone of the well and the existing fractures expand.

In order to keep the fractures open after hydraulic fracturing, a sand carrier fluid is pumped into the formation together with a proppant. This part of the geological and technical intervention (GTM) is one of the most technically complex. To ensure full opening of the fracture, the proppant must be pushed into the fracture to the maximum distance, which requires it to be kept in suspension during the entire duration of the hydraulic fracturing [1]. In addition, premature settling of the proppant leads to clogging of the pore channels near the well, increasing the flow resistance and reducing the well productivity factor [2]. Due to these circumstances, high-viscosity solutions are used as a sand carrier fluid, the internal structure of which is able to prevent proppant settling [3].

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Another equally important problem is premature watering of wells as a result of hydraulic fracturing. The problem comes from the fact that a more fluid - water, ahead of oil, fills the most permeable channels. For this reason, hydraulic fracturing is unacceptable for use near bottom and contour waters, as well as in close proximity to flooded interlayers [4]. The solution to the existing problem is to limit their half-length and height, through the use of technological solutions with reduced viscosity [5].

It is from this moment that the main contradiction arises during hydraulic fracturing. Since the main condition for rupture of rocks is the excess of the process fluid injection rate over the rate of its absorption by the reservoir, the size of the created cracks directly depends on the viscosity of the injected fluid. The depletion of the main fund of Western Siberian fields and the high probability of premature watering of wells lead to a decrease in the size of hydraulic fractures and, consequently, to the use of a low viscosity fracturing fluid [6]. Due to the reduction of financial costs for well interventions, the same agent is used as a fracturing fluid and a sand carrier fluid, which, in turn, contradicts the requirement for the latter to have its proper sand-carrying capacity [7, 8].

Thus, hydraulic fracturing has a number of disadvantages and contradictions, which proves the relevance of improving this technology [9]. In 2021, for all fields in Western Siberia, the share of technologically inefficient measures was 18.5%.

One of the latest and most promising ways to improve hydraulic fracturing is the technology of fluid reinforcement with soluble FiberFrac fibers.

2 Methods

FiberFrac is a self-extinguishing fiber in dry or liquid form. When a reagent is added to the hydraulic fracturing fluid, a cross-linked gel which is a solution with a developed internal structure that prevents sedimentation of solid suspended particles inside it under the action of gravitational forces is created. This greatly improves the transport properties of the sand-carrying fluid, thereby ensuring the opening of the fracture for its entire half-length and preventing the proppant from blocking the pore channels located in close proximity to the bottom of the well.

The cross-linked gel solution is water-based. With constant stirring, gelling agent Gelling Agent, biocide BioClear 1000 (to suppress sulfate-reducing bacteria, the vital activity of which produces hydrogen sulfide - the main cause of corrosion of oil and gas equipment), clay and shale stabilizer NCL 100 (in order to prevent swelling of clay inclusions in the CCD and, as consequence, eliminating the likelihood of deterioration of its filtration and capacitance characteristics) and demulsifier NE 201 (due to undesirable foaming of the working fluid in the wellbore). At the end, FiberFrac fibers are added to the resulting solution, after which a cross-linked gel is formed within 1-2 minutes. Since FiberFrac fibers are crystallized acid in solid form, their dissolution in the fracturing fluid creates a slightly acidic environment (pH 6.4 units). The composition of the crosslinked gel is shown in Table 1.

Table 1. FiberFrac process fluid composition.

Reagent name	Purpose	Reagent concentration, l/m^3
Gelling agent	Gelling agent (gellant)	2.6-3.0
BioClear 1000	Biocide	0.02
NCL 100	Clay and Shale Stabilizer	2.0
NE 201	Demulsifier	2.0
FiberFrac	Fast stapler	1.25

The light white fibers formed as a result of a chemical reaction fix the proppant, preventing its premature settling (Figure 1). The slightly acidic environment of the working fluid after hydraulic fracturing destroys its polymer chains, facilitating its removal from the fracture fixed by the proppant. Characteristics of the main properties of FiberFrac fibers are presented in Table 2.

Table 2. Characterization of the main properties of FiberFrac fibers.

Parameter of FiberFrac fibers	Parameter value
density, kg/m^3	90-170
concentration of organochlorine compounds, l/m^3	-
fiber length, mm	3-24
fiber diameter, tex	0.12-0.19
minimum solubility in NaOH, unit fraction	0.9

At the same time, the viscosity of the working fluid corresponds to linear gels and is 150 mPa·s at a temperature of 75°C. Guar gels, in turn, have a viscosity of 200-400 mPa·s. This circumstance makes it possible to use the FiberFrac technology for the purpose of additional oil recovery in fields that are at the III and IV stages of development. The use of a low-viscosity agent as a fracturing fluid makes it possible to create small-sized fractures, avoiding their entry into water-saturated areas of the formation. At the same time, the same fluid can be successfully used as a sand-carrying fluid, thereby ensuring the profitability of this type of GTM.

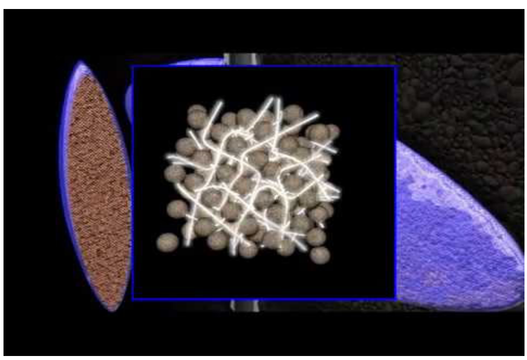

Fig. 1. Reinforcing mesh created in the working fluid using FiberFrac technology.

In addition studies of the FiberFrac process fluid revealed another, in essence, its main advantage over guar gels - the complete dissolution of fibers under the action of formation temperatures and the removal of the reagent from fixed fractures. As a result, after hydraulic fracturing, there are no plugged areas in the proppant pack, and its residual permeability increases significantly. Complete degradation of FiberFrac fibers, according to research, occurs at a temperature of 85°C. At reservoir temperatures below this value, this measure is not recommended.

Hydraulic fracturing using FiberFrac technology has been carried out on the territory of Western Siberian fields since 2011. In 2020 a total of 6 pilot operations were performed: 3 on the Achimov formations (Ach) of the Povkhovskoye field (wells No. 7514, No. 7534, No. 7105) and 3 - on formations YuV1 of the Vostochno-Pridorozhnoye field (wells No. 837, No. 767, No. 7161). The objects of these fields are composed of low-permeable rocks (Ah - 0.001 μm^2, SE1 - 0.014 μm^2), and the dynamics of selection from the initial recoverable reserves (NIR) for them is extremely slow. The most productive reservoir BV8, which accounted for 77% of the total production, was depleted by 77.7% (cumulative production - 194.3 million tons, NIH - 256.8 million tons).

The hydraulic fracturing parameters for all wells are similar: the proppant mass ForeProp 16/20 was 9.8-11.8 tons, the maximum concentration was 900-1000 kg/m^3, the fracturing fluid flow rate was 2.4-2.7 m^3/min, except for well No. 767, the flow rate at which was 3.2 m3/min. Gellant loading in all wells was 2.6 kg/m^3, except for No. 767 (3.0 kg/m^3).

According to the results, after hydraulic fracturing using FiberFrac technology, a positive effect was achieved in 5 out of 6 cases, that is, the success of the event was 83%. At the same time, better performance is observed for all wells, in comparison with neighbouring wells treated with a standard hydraulic fracturing operation. The low effect of the FiberFrac technology was obtained only at well No. 767 and is associated with the incomplete use of all the possibilities of this activity.

To clarify the favourable geological and physical conditions for the most effective application of the treatment under consideration, studies are needed to clarify the scope of its application. The example of well No. 767 clearly showed this.

From the point of view of the financial component, fracturing using FiberFrac technology, like any other MIDN, is an investment project. Income from additionally produced oil does not always cover the capital costs of hydraulic fracturing [10]. Uncertainties associated with the selection of wells for cost-effective FiberFrac technology can be eliminated by applying the method of correlation analysis of statistical data.

As statistical data, the main geological and physical parameters of the formations penetrated by wells are taken, on which the development of a fracture during hydraulic fracturing depends. To determine them, we use the formula for the opening of a fracture near the well wall (1):

$$\omega_0 = \frac{4(1-2\nu)(1+\nu)(\Delta P_b - P_{hr})}{3E}\sqrt{\frac{VQ\mu}{2\pi^2 h^2 mkP_{hr}}} \quad (1)$$

where ω_0 – fracture opening near the borehole wall, m; ν – Poisson's ratio of a rock, depending on its mineralogical composition (mainly grit), unit fraction; ΔP_b – bottom hole pressure drop, Pa; P_{hr} – horizontal rock pressure, Pa; E – Young’s modulus, Pa; V – value of pumped liquid, m^3; Q – fluid flow, m^3/s; μ – viscosity of liquid, Pa·s; h – effective formation thickness, m; m – porosity, unit fraction; k – permeability, m^2.

Based on the parameters that determine the size of the fractures created during hydraulic fracturing, we will single out those that are determined by the geological and physical state of the near-wellbore zone. These are permeability (k), porosity (m), effective formation thickness (h) and net-to-gross ratio ($K_{n/g}$). Also, it is necessary to take into account the oil saturation of the formation (K_{os}), since the main task of FiberFrac is to limit the fracture in height and direct it precisely to the oil-bearing interlayers.

The essence of the method is to plot the technical and economic efficiency of GTM. To do this, the value of one of the geological and physical parameters is plotted on the abscissa axis, and the technological effect (Q) is plotted on the ordinate axis. Points corresponding to the given values for each well are put on the obtained coordinate plane. After that, a trend line is built for the obtained points. The line type is selected based on the maximum approximation of the approximation reliability value (R^2) to unity. The resulting dependence is adapted to the conditions of two fields in Western Siberia. Similarly, you can adapt the graph to any other field and get more correct results.

The analysis was carried out by the authors of the article for all 6 wells described above, where hydraulic fracturing using FiberFrac technology was used. The values of geological and physical parameters for each well, the values of their cumulative production for the reporting period, as well as the volumes of injected fluid are shown in Table 3.

Table 3. Parameters of wells treated with FiberFrac technology.

Well No.	7514	7534	7105	837	767	7161
k, $\cdot 10^{-3}$ μm^2	12.3	2.7	8.1	21.9	24.1	45.6
m, unit fraction	0.178	0.179	0.183	0.184	0.184	0.169
h, m	11.2	6.3	9.5	8.7	3.8	8.8
$K_{n/g}$, unit fraction	0.611	0.589	0.573	0.547	0.543	0.508
K_{os}, unit fraction	0.498	0.469	0.526	0.513	0.616	0.583
Q, t	5842	4107	991	4985	367	1654
Liquid volume, m^3	15.4	14.5	13.3	15.2	14.3	13.7

After the points corresponding to the parameters for each well have been plotted on the coordinate plane Qн-(k, m, h, $K_{n/g}$, K_{os}), a line of cost-effective cumulative production is constructed, showing such a volume of additionally produced oil, starting from which a positive the difference between financial inflows and outflows (profitability of an investment project) [11].

In order to assess the cost-effective level of additionally produced oil for each operation, it is necessary to evaluate their financial inflows and outflows [12]. Table 4 shows the cost of hydraulic fracturing using FiberFrac technology for each individual well, taking into account the cost of FiberFrac fluid, the cost of GFI and the operation itself.

Table 4. Cost of hydraulic fracturing using FiberFrac technology.

Well No.	7514	7534	7105	837	767	7161
Cost price of fracking, rubles	2465005	2471367	2408122	2459588	2442073	2448001

Using the data on the accumulated additional production for each well (Table 3), it is possible to calculate the increase in the event's profit (2):

$$P = Q \cdot (Pr - MET) - CP \tag{2}$$

where P – FiberFrac technology profit, rubles; Q – technological effect from implementation of FiberFrac technology, t; Pr – oil selling price on the market, rubles; MET – mineral extraction tax, rubles; CP – cost price of FiberFrac technology.

One of the most important parameters of the success of geological and technical measures is the profitability index (PI), equal to the ratio of profit to the cost price of fracking. If the PI value is greater than 1, the project can be considered successful. When PI is equal (or very close) to 1, hydraulic fracturing is considered to be unsuccessful. If PI is less than 1, the event is unprofitable [14].

After the indicators of all activities are found, it is necessary to determine the minimum cost-effective technological effect for each operation, that is, such a technological effect at which PI will be equal to 1 [15]. All obtained results are recorded in Table 5.

Table 5. The results of calculating the economic efficiency of all hydraulic fracturing operations using FiberFrac technology.

Well No	7514	7534	7105	837	767	7161
PI, units	1.36	1.35	1.24	1.36	1.05	1.30
Profitable production, t	307.1	308.3	301.0	307.3	304.1	305.7

The results of the table confirm that the FiberFrac technology was not successful only on well #767, since the total revenues exceeded the costs by only 5%. The average profitability indicator for all activities amounted to 305.58 tons. This straight line must be added to the above dependences Q-(k, m, h, $K_{n/g}$, K_{os}).

As is known, the main geological and physical parameter of the wellbore zone, taken into account during the operation of wells, is the permeability coefficient. Figure 2 shows how permeability affects the success of FiberFrac hydraulic fracturing.

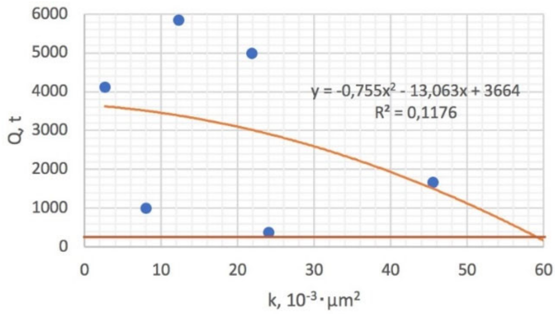

Fig. 2. Determination of reservoir permeability, which ensures the profitability of hydraulic fracturing using FiberFrac technology.

It can be seen from the graph that the trend line crosses the level of profitable production at a value of 0.0586 μm^2. This means that with higher CCD permeability, the FiberFrac technology will not be profitable. This fact is explained by the increased hydraulic connectivity of the formation sections, which significantly increases the rate of well watering after hydraulic fracturing. In addition, in highly permeable formations, a larger volume of working fluid must be pumped at a higher injection rate to fracture.

To analyze the remaining parameters, we will use the data obtained in Figure 3.

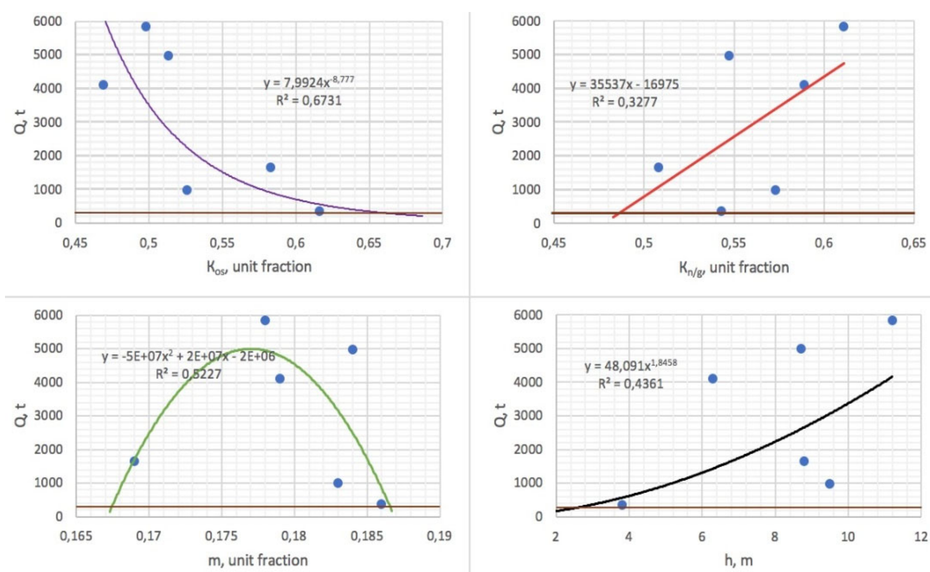

Fig. 3. Determination of the geological and physical parameters of the reservoirs that ensure the profitability of hydraulic fracturing using the FiberFrac technology.

3 Results

The graphs show the following conclusions about the value of reservoir parameters that ensure the economic feasibility of implementing the FiberFrac technology:

- oil saturation factor should not be more than 0.660. This circumstance is explained by the fact that with a higher oil saturation value, it does not make sense to use a more costly improved hydraulic fracturing technology;
- the net-to-gross ratio must not be less than 0.486. This is based on the fact that a lower content of sand and, as a result, a greater content of such plastic rocks as limestone and clay, prevents the creation of a crack of sufficient size and orientation;
- porosity should be in the range of 16.7% - 18.7%. With a lower value of porosity, the concentration of boundary-bound oil, oil in dead-end zones and oil in pores of such a small diameter increases that the pressure drop created in the near-wellbore zone is not able to overcome capillary forces without destroying the rocks of the bottomhole zone. Since porosity is petrophysically related to porosity, values greater than 18.7% lead to more intense outburst of bottom and marginal waters. This circumstance highlighted one of the disadvantages of using FiberFrac technology - a narrow range of application in relation to reservoir porosity. To eliminate this minus, it is necessary to re-run the analysis with a large sample value to correct and specify the results;
- the effective thickness of the formation should be at least 2.7 m. At a lower value, it is extremely difficult to direct the created fracture into the oil-saturated zone of the formation. To do this, it is necessary to improve the technology to limit the growth of a crack in height.

4 Conclusion

In the this work done the authors of the article described and analyzed the methodology for improving hydraulic fracturing using the FiberFrac technology, identified the main theoretical advantages over the standard hydraulic fracturing operation - separating the sand-carrying capacity of the process fluid from its viscosity, thereby allowing the use of the same composition at the stage of fracturing and consolidation, limiting the development of a fracture in height with a parallel improvement in the elaboration of its surface, complete decomposition under the action of reservoir pressure and temperature (preferably above 85°C) and, as a result, an increase in the permeability of the proppant pack.

On the basis of geological and field studies carried out on the territory of the Povkhovskoye and Vostochno-Pridorozhny fields of TPP Kogalymneftegaz, the advantages of FiberFrac technology over standard hydraulic fracturing were proven. The results based on 12 wells (6 - FiberFrac, 6 - standard hydraulic fracturing) showed that FiberFrac has a lower water cut, a lower well watering rate, a higher oil flow rate and a longer technological effect. All of the above indicates the reliability of the fracture limitation in height and its direction towards oil-saturated areas.

Since one out of 6 FiberFrac operations was unsuccessful (success - 83%), there are restrictions on the use of this technology. To eliminate these uncertainties, it was proposed to calculate the economic efficiency of the measures taken with the further construction of a correlation curve and a line of profitable production, depending on the main geological and physical parameters of the reservoirs, on which the creation of a fracture depends. The intersection points obtained indicate the boundary values, beyond which the risk of an unprofitable effect of hydraulic fracturing using FiberFrac technology is extremely high. Thus, it was determined that this operation is technologically and economically successful in reservoirs, with such geological and physical parameters as:

- permeability coefficient is no more than 0.0586 μm^2;
- porosity is16.7-18.7%;
- grit is not less than 0.486;

– oil saturation is no more than 0.660;
– effective oil-saturated thickness is not less than 2.7 m.

Thus, the authors of the article proposed a scheme that eliminates uncertainty during the FiberFrac operation, an improved technology for such a common type of geological and technical operations as hydraulic fracturing. In addition, it was found that this technology is most effective in medium and low permeability, sandy, highly porous reservoirs with high reservoir temperatures (more than 85°C), with oil saturation of no more than 66%.

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