RESULTS OF SCIENTIFIC AND TECHNICAL SUPERVISION OF HYDRAULIC FRACTURING OPERATIONS

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Abstract. The paper presents actual results of the research conducted as part of a field pilot project which consisted in interpretation of minifrac test data and evaluation of the efficiency of the scientific and technical supervision of fracking operations. The research program involved 11 wells targeting Devonian terrigenous reservoirs.

Minifrac tests in one perforation interval were performed only in seven wells, that is approximately in 64% of total well count. A reliable fracture closure estimate was obtained only in six wells (55%), beginning of pseudoradial flow was observed only in one well out of 11 wells (9%). Hence, conventional minifrac tests should be supplemented with other diagnostic injection tests.

Analysis of the performance of hydraulic fracturing operations conducted according to this pilot project plan indicates that fracture modelling, and scientific and technical supervision of fracking operations performed by Hydrofrac Research Laboratory of Institute TatNIPIneft Tatneft PJSC have yielded beneficial effects, namely 1.44 times increase in oil production rates.

Key words: hydraulic fracturing, scientific and technical supervision, minifrac test data interpretation, hydraulic fracturing performance

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In May-June 2015, Tatneft PJSC conducted pilot commercial development to assess the impact of multivariate modeling with implementing optimization calculations and scientific and technical support of works on the results of hydraulic fracturing. TatNIPIneft Institute of Tatneft PJSC was appointed as the executor of works.

The main tasks of pilot commercial development were:

- Analysis of hydraulic fracturing;
- Interpretation of the mini-fracturing data (mini-fracturing is test injection with operating flow before the hydraulic fracturing);
- Analysis of the reasons for getting STOPs. If the proppant prematurely forms a cork in the fracture during injection, this situation is known as "proppant blockage" or "STOP" – the working pressure will rise dramatically to the technical limit of the equipment (Economides Michael et al., 2002);
- carrying out optimization calculations;
- comparative assessment of the technological efficiency of hydraulic fracturing with modeling and scientific and methodological support by TatNIPIneft;
- issuing recommendations on improving the technology of hydraulic fracturing for the conditions of Tatarstan.

The article gives concrete results of this work concerning interpretation of the mini-fracturing and effectiveness of the scientific and technical support of hydraulic fracturing.

In the vast majority of cases, the mini-fracturing was not amenable to interpretation in accordance with the classical canons (Barree et al., 2007). The difficulties in interpreting the mini-fracturing were caused by the following factors.

1. The injection was performed simultaneously in several open intervals of perforation, or the formation was separated by very dense layers into several interlayers. In this case, it is difficult to recognize and divide the closing of the fracture in each individual formation.

2. Pseudo-radial flow regime is achieved only in rare cases, which does not allow correctly determining reservoir pressure and formation permeability. After the fracturing, there are alternating flow regimes: linear, bilinear and pseudo-radial (Cinco-Ley, Samaniego, 1981). Pseudo-radial flow is a steady flow to a well that has undergone a fracturing from the pseudo-radial drainage area of the formation.

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3. Premature termination of pressure drop recording.

4. Distortion of the pressure drop curve due to reduction of wellhead pressure to zero (well level is set), gas entering the well from the formation, presence of residual crosslinked gel in the borehole.

5. Lack of hydraulic communication with the formation (no hydraulic shock), STOP during the mini-fracturing. In this case, a qualitative interpretation of the pressure drop record is impossible.

6. Artifacts of the curves arising from the impact of the end effects – the resistance at the end of the crack. For example, the end of the derivative pressure line on the regression analysis graph goes down. But this is not a point reflecting the closing of the crack, but a decrease in resistance at the ends of the crack, since the position of this point varies with the change in the interval of the curve study.

7. Long period of closure and no closure of the fracture in shale deposits during the recording of the pressure drop. The pressure decreases slowly, for several hours.

There are also some features of computer simulators of hydraulic fracturing in terms of interpretation of mini-fracturing. For example, in the FracPRO program, the analysis of mini-fracturing is carried out always on bottomhole pressure, therefore, a preliminary simulation of the injection process is required. The MinFrac program analyzes both wellhead and bottomhole pressure. It is not necessary to simulate a mini-fracturing. The results of mini-fracturing and hydraulic fracturing analysis for 11 wells included in the program of pilot commercial development are summarized in Table 1.

Mini-fracturing in one interval of perforation was carried out only in seven wells. In one well (8677B of Oil and Gas Production Department (NGDU) "Aznakaevskneft" ("AzN")) STOP was obtained already with a mini-fracturing due to the lack of hydrodynamic connection with the formation. In 10 wells, there was connection with the formation, as evidenced by the appearance of hydraulic shocks when the injection was stopped. Nevertheless, in two wells out of 10, STOP was obtained during fracturing.

The point of fracture closing is confidently found only in six wells. In five wells this could not be done, so the parameters for re-calculation of the fracturing design were not determined by the results of the process (redesign of the crack). The beginning of the pseudo-radial flow was noted only in one well of 11.

Let us consider some examples.

Mini-fracturing in well No. 24019 of Oil and Gas Production Department "Leninogorskneft" ("LN") was conducted through two intervals of perforation (Figures 1, 2).

The logarithmic derivative GdP / dG monotonically increases. GdP/dG is a special function called the G-time according to Nolti, which allows the pressure drop characteristic to be linearized and helps to identify the fracture closure (Economides Michael et al., 2002). Bending down at the very end of the record is an artifact. The closure point is set at this point conditionally.

Well No., Oil and Gas Prod. Dept.	Formation	Hydraulic connection, STOP	Number of perforation intervals	Presence of closure point	Determination of the origin of pseudo-radial flow
11304, «AN»	D0	Hydraulic shock	1	yes	yes
20154, «AN»	D1(a+b1+b3)	Hydraulic shock	3	yes	no
20191, «AN»	D1b3	Hydraulic shock	1	yes	no
20659, «AN»	D0+D1d	Hydraulic shock	2	yes	no
2133b, «AN»	D0	Hydraulic shock, STOP	1	no	no
8677B,«AzN»	D1a	STOP during mini-frac and hydraulic frac	1	no	no
2881bn, «AzN»	D1a	Hydraulic shock, STOP	1	yes	no
750, «AzN»	D1a	Hydraulic shock	1	questionable	no
39458, «LN»	D1(a+b2)	Hydraulic shock	2	questionable	no
24019, «LN»	D1(a+b2)	Hydraulic shock	2	no	no
22107, «JN»	D0	Hydraulic shock	1	yes	no

Table 1. Results of the mini-fracturing and hydraulic fracturing analysis

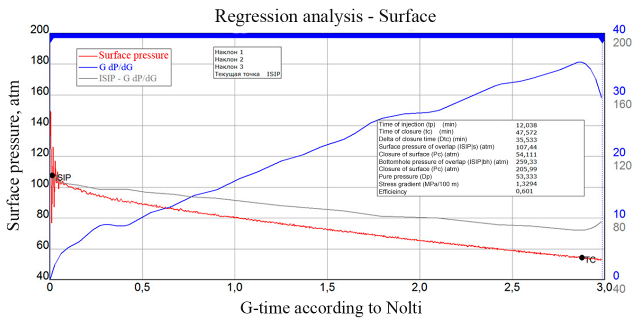

Figure 1. Well № 24019 of Oil and Gas Production Department "LN". Linear time analysis Nolti G

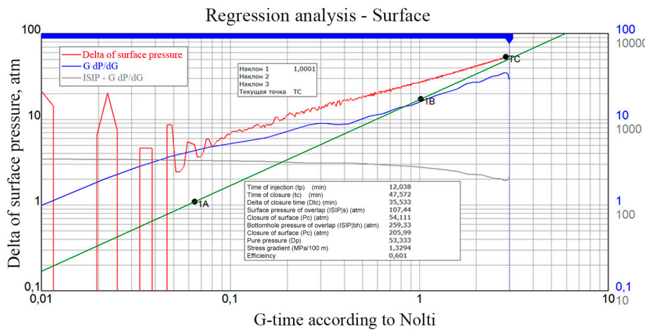

Figure 2. Diagnostic chart. Well No. 24019 of Oil and Gas Production Department "LN"

However, there is no closure of the crack. Moreover, the surface pressure curves and ISIP-GdP/dG monotonously diverge from the very beginning of the pressure drop (ISIP – instantaneous stopping pressure). The impression is as if there were no cracks. These curves should, according to theory, in the presence of a crack, go about the same way and disperse only after the point of closure.

On the diagnostic logarithmic graph (Figure 2), the slope of the pressure lines GdP/dG is about 0.5, which indicates that the crack, if it exists, is still open. There is no change in the sign of the derivative to minus or its stabilization. The tangent on this graph is drawn with an angular slope of 1, which corresponds to a linear flow from the crack to the formation. The actual slope of tangents to the curves is approximately 0.5, which corresponds to the bilinear flow (finite conductivity crack).

In well No. 39458 of Oil and Gas Production Department "LN" mini-fracturing is conducted also through two intervals of perforation. The resulting record is difficult to interpret, since three extrema are clearly distinguished on the logarithmic derivative (Figure 3). The ISIP-GdP / dG curve diverges from the pressure drop curve at the beginning of recording, the point of divergence approximately corresponding to the position of the first extremum. The tangent to the first extremum gives the values of the gradient of the fracturing pressure of 1.56 MPa / 100 m and the liquid efficiency is 0.353. However, the tangent to the second extremum also gives adequate values of the parameters: 1.28 MPa/100 m and 0.541.

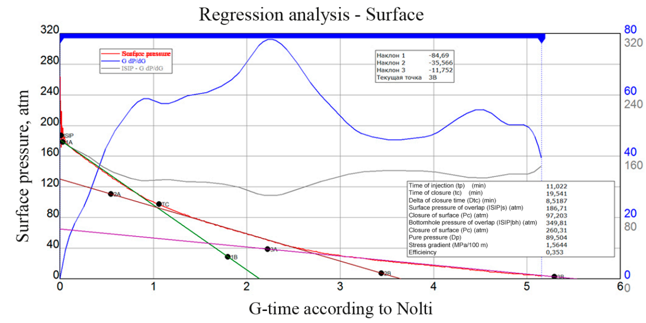

Figure 3. Well No. 39458 of Oil and Gas Production Department "LN". Linear time analysis Nolti G

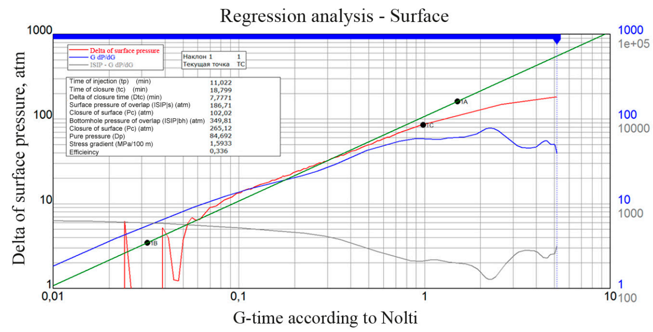

Figure 4. Diagnostic chart. Well No.39458 NGDU "LN"

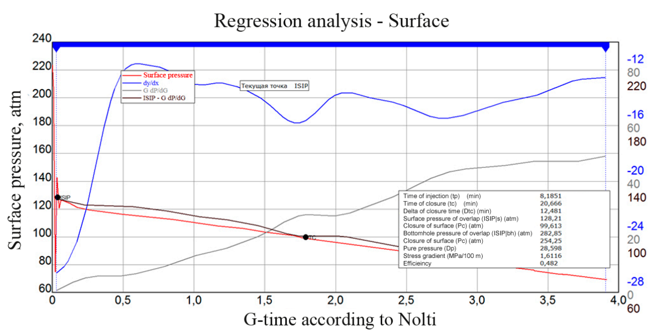

Figure 5. Well № 21336 NGDU "AN". Linear time analysis of Nolti G

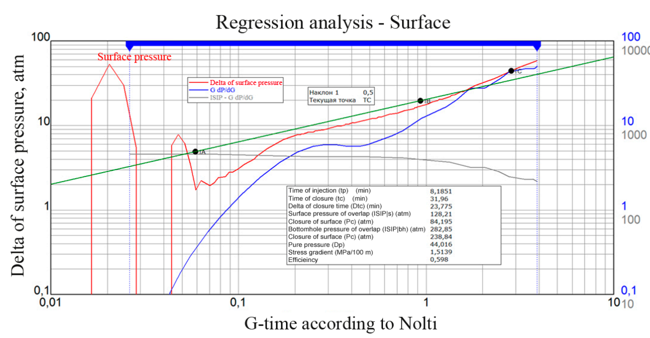

Figure 6. Diagnostic chart. Well № 21336 of Oil and Gas Production Department "AN"

However, the data from diagnostic graph allow us to conclude that the position of closure point is more correct at the time Nolti G, equal to 1 (Figure 4).

Figures 5 and 6 show graphs of the pressure drop analysis in the well 21336 of Oil and Gas Production Department Almetyevneft (*"AN"*). The surface pressure drop curves and ISIP-Gdp/dG go together without disintegrating throughout the entire recording. The curve

Well No., Oil and Gas Prod. Dept.	Oil production rate before hydraulic fracturing, t/day	Oil production rate after hydraulic fracturing, t/day	Oil production rate on 01.01.2016, t/day	Increase in oil production rate on report date, t/day
11304, «AN»	4,1	4,29	8,73	4,63
20154, «AN»	4,38	7,76	7,94	3,56
20191, «AN»	9,29	14,73	12,33	3,04
20659, «AN»	5,57	5,57	2,5	0
21336, «AN»	5,98	6,64	27,16	21,18
8677Б, «AzN»	0	1,43	0,94	0,94
28816н, «AzN»	0	6,4	6,4	6,4
750, «AzN»	0,04	0,71	2,05	2,01
39458, «LN»	2,57	8,88	11,65	9,08
24019, «LN»	2,75	5,96	4,41	1,66
22107, «JN»	1,65	10,38	13,06	11,41

Table 2. Data on the efficiency of hydraulic fracturing

Gdp/dG increases monotonically and does not show a tendency to deviate downward.

The clamping point on the chart is set arbitrarily, probably, the crack did not close or formed. However, on the diagnostic chart, the slope of the lines is close to 0.5, which speaks for the bilinear flow and the presence of a crack.

The closure pressure can be conditionally predicted at the very end of the curve. However, the derivatives themselves continue to grow monotonically.

The examples given show how carefully we should approach the analysis of the mini-fracturing. In many cases, the mini-fracturing in its standard version does not give practically meaningful information.

Mini-fracturing through several intervals of perforation deserves particular attention. The theory for such a case is absent. In a rare case, all cracks are joined simultaneously. But they can close together and successively one after another, distorting the pressure drop curve. Therefore, it is recommended to perform a mini-fracturing separately for each interval of perforation, isolating them with double packers.

Virtually all the fracturing processes, like mini-fracturing, were a joint fracturing of the formations. Despite the fact that low-permeability reservoirs were subjected to processing (up to 10 mD), the hydraulic fracturing technology remained the same, traditional, based on the use of cross-linked gel. Technologists of LLC Leninogorsk-RemServis with some modifications applied the proppant supply with stops. In addition, a stepwise increase in the concentration of proppant was used.

In conclusion, the effectiveness of the fracturing operations carried out in accordance with the pilot commercial development plan with the participation of TatNIPIneft was evaluated during May-June 2015. For comparison, the efficiency of fracturing operations was taken as an average for each oil and gas production department for 2015. The analysis was based on official data from corporate information systems "Tatneft-Neftedobycha" and ARMITS, verified by independent sources (databases). The results are summarized in Table 2.

The average increase in oil production rate in the Oil and Gas Production Department "AN" after conducting hydraulic fracturing in 2015 is 3.53 tons per day. The average increase in oil production through five wells of pilot commercial development – 6.48 tons per day.

The average increase in oil production in the Oil and Gas Production Department "AzN" after conducting hydraulic fracturing in 2015 is 4.58 tons per day. The average increase in oil production rate for three wells of pilot commercial development – 3.12 tons/day (Well 8677B is a lateral shaft, well 28816 is injection, and in its area there are six reactive production wells (Nos. 10993, 19528, 4990A, 768, 8257, 8258)). The increase in oil production from the site is 6.4 tons per day.

The average increase in oil production rate in Oil and Gas Production Department "LN" after conducting hydraulic fracturing in 2015 is 3.89 t /day. The average increase in oil production through two wells of pilot commercial development – 5.37 tons/day.

The average increase in oil production rate in Oil and Gas Production Department Jalilneft ("JN") after conducting hydraulic fracturing in 2015 is 5.36 tons/day. The average increase in oil production rate for one well of pilot commercial development is 11.41 tons per day.

Thus, averaging the figures for all 11 wells, we obtain an average increase in production rate for wells of pilot commercial development 5.81 tons/day.

Averaging the figures for all Oil and Gas Production Departments, we obtain an average increase in oil production after fracturing 4.03 t/day.

The average increase in oil production rate for wells on which the simulation and scientific and technical support of the TatNIPIneft fracturing processes was carried out, is by 1.78 tons/day more than for wells without scientific and technical support. The multiplicity of the increase in production rate is 5.81/4.03 = 1.44 times.

Conclusions

1. Long periods of the fracture closure are noted, despite the high enough permeability of the formations.

2. No pseudo-radial flow is achieved in any of the analyzed wells.

3. The classical mini-fracturing has a number of disadvantages associated mainly with an ambiguous interpretation of the pressure drop curve in order to determine the change in the slope angle.

4. When several layers are opened with one filter (joint hydraulic fracturing) or with the development of multiple cracks, between which there is an additional interaction, the determination of closure pressure becomes ambiguous due to the multiple closures arising from the difference in stresses in the formations. The pressure drop curves can be difficult to interpret, so in such cases a combination of a step test and injection/outpour test is recommended.

5. For shale deposits water fracturing, linear gel technology, and hybrid technologies (water and linear gel) should be used.

6. Modeling and scientific and technical support of the fracturing processes by the TatNIPIneft Institute gave a positive result (the multiplicity of the increase in the production rate was 1.44 times) in comparison with the results of the hydraulic fracturing performed unaccompanied.

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