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Study of Horizontal Wells in Low-Permeable Reservoirs of the Bazhenov Formation: Comparison of Methods, Technologies and Approaches Efficiency

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Abstract

Expanding the share of unconventional oil and gas reserves involvement shifts the focus to analyzing well productivity increases. The cost of horizontal wells stimulation for increasing oil recovery rate carried out using multi-stage hydraulic fracturing is much higher. This requires the involvement of new technologies and services to facilitate optimal drilling, completion and stimulation returns. The use of developed technology to determine inflow profiles allows oil and gas producing companies to efficiently determine well productive intervals, thereby indicating high production rates and maintaining the profitability of facilities put into operation by eliminating non-productive intervals. These data allow planning field development with higher profitability due to increasing the oil recovery rate.

Introduction

The complexity of developing Bazhenov formation arises from the high risks associated with little reserves exploration – tight oil and gas reserves cannot be developed using conventional methods, and production is often characterized by a sharp decline in the well productivity. Because of this, the cost-effective development of Bazhenov formation requires introduction and application of new, innovative technologies.

Today, unconventional reserves involve deposits that differ from those that are traditionally developed. The complexity of Bazhenov formation development is primarily due to the characteristics of the formation itself; oil and gas in this case are also associated with the presence of kerogen, hydrocarbon compounds physically associated with kerogen and the matrix of formations, as well as free hydrocarbon compounds forming mobile oil accumulations in interconnected isolated pores. This category of reserves requires users to implement non-standard approaches to prospecting, exploration and production, and the introduction of new methods and technological solutions. The technology of drilling horizontal wells with multi-stage hydraulic fracturing is considered fundamental, however, the methods used in this case are also conventional: high injection rates, significant volumes of injected fluid, complex equipment. All of this distinguishes MFrac technologies for Bazhenov formations from those that have been successfully applied on conventional formations for a long time.

Beginning in 2016, for the first time in the Russian Federation, Gazpromneft implemented a full cycle of oil development technologies for developing unconventional reserves of the Bazhenov formation under conditions of technological restrictions imposed by sanctions. In addition to the cumulative assessment of the resource potential of unconventional reserves on current assets. One of the primary challenges facing the oil producing companies is the selection and testing of technologies for the development of unconventional reserves. The development and completion strategy is largely based on geological prerequisites, and involves the introduction of cost-effective production technologies and high-tech equipment (Heddleston, 2009).

Historically, the analysis of multi-stage hydraulic fracturing operations efficiency was based on geological and hydrodynamic modeling considering petro physical features, which include the analysis of reservoir characteristics such as porosity, permeability, mineralogy and total organic carbon.

However, the determination of flow profiles in production wells is the basis for making technical decisions aimed at increasing efficiency in field development, and optimizing well construction solutions or capital workover operations. In this regard, the interest of production companies to well production logging technologies is conditioned by the potential significant cost savings and increase in the quality of logging works.

Difficulties with conventional PLT

Production logging of oil, gas and water inflows is a key objective for creating an optimal strategy for production and development, as well as for the purpose of planning repair and water insulation works in a well. However, conventional PLT methods do not always produce satisfactory results due to the horizontal wells with MFrac flow characteristics, which are traditional for the Bazhenov formation development. Stratified fluid flow, the presence of gas bubbles, and possible recycling of the heavy phase and separation of the flow at different speeds all impose serious restrictions on the use of standard logging tools. The dynamic characteristics of multiphase flows determine its variability along the well. Therefore, the measurements made in the well lateral center do not provide adequate measurement accuracy as the sensors of conventional instruments are placed in the completion at a considerable distance from each other, which further complicates the analysis (Kolesnikova, Kremenetsky, Ipatov, 2016)

Today, several conventional production logging methods are used:

1. Field and geophysical research
2. Using ICD, ICV couplings in Smart well completions
3. Using fiber optic sensors and additional software
4. Tracer-based studies (marker technology)

Study Object

A complex evaluation of production logging technologies was conducted at one of the company sites, and several technological solutions were implemented at one of the fields in Russia. The study object is a production well in which a 7-stage hydraulic fracturing was carried out using the Slickwater frac technology. This well was commissioned in March 2018.

Marked proppant was injected into the well during MFrac, allowing us to obtain valuable information on continuous well operation. Scheduled geophysical studies also allowed us to evaluate well operation, select the working intervals, and determine the composition and flow rate of the incoming fluid. When analyzing the information content of the studies described above, it should be considered that ambiguity risks related to interpretation exist in both cases, and each of the methods aids in providing a general understanding of the well operation parameters.

Marker Production Logging Technology

During the study, 44 formation fluid samples were tested. During the monitoring period of 6 months, 3 periods of tests were considered. Complex studies were carried out to isolate quantum marker-reporters separately from the oil and water phases in all formation fluid samples.

The production logging method is based on the injection of marker-reporters containing quantum dots in the proppant polymer coating. Quantum dots (several nanometers in size) are injected inside the insoluble microspheres (one micron in size), then placed in the proppant polymer coating. Fifteen tons of marked proppant are injected as normal proppant, with the last proppant pack used to ensure improved washability in the near-well zone (Ovchinnikov, 2019). Next, the markers are washed out of the coating and injected into the formation fluid; after this, samples are taken from the wellhead and tested in the laboratory.

The analytical method for determining marker-reporters is based on the instrumental method — flow cytofluorometry or simply cytometry (Ovchinnikov, Buzin, Saprykina, 2017). The principle of operation is as follows: inhomogeneities in the sample line up exactly one after another with the help of a crimping fluid and a finely tuned hydrodynamic system. Next, they are irradiated with several lasers. After irradiation, the signals are recorded by various detectors. For each point, 15 different parameters are fixed, the most informative of which are fluorescence channels in a different wavelength range. Marker-reporters are microspheres with quantum dots inside. These dots can fluoresce in different colors depending on the signature number or the marker code (Kawasaki, 2005) Marker production logging technology is presented on Figure 1.

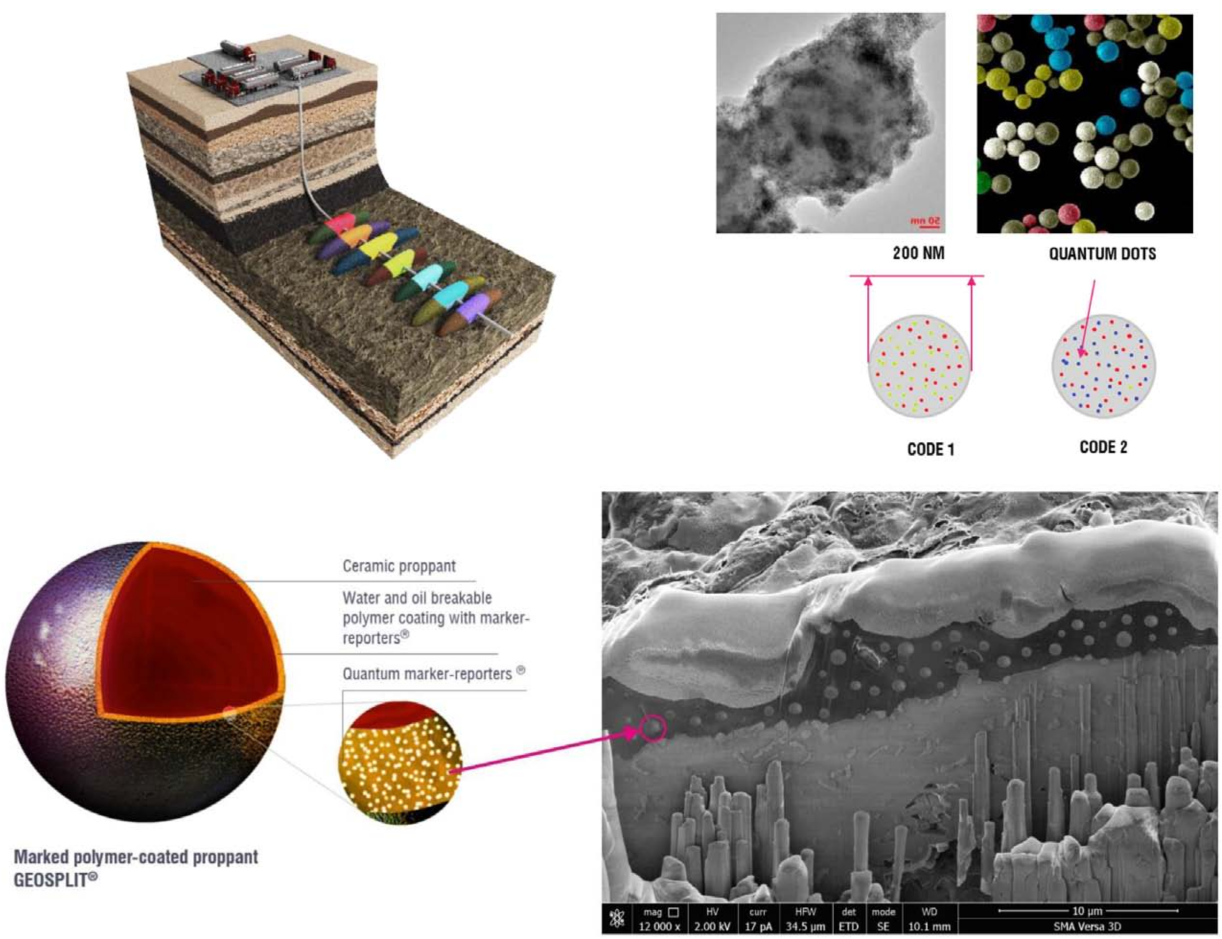

Figure 1—Marker Production Logging Technology

Each horizontal well productive interval is marked with a unique code, allowing users to evaluate the contribution of each interval to well operation. Each sample, divided into phases, is studied using the analytical hardware-software complex GEOSPLIT. Based on the results of the sample analysis and their interpretation, the relative content of marker-reporters of various signatures was determined, allowing for the determination of the percentage of inflows for each interval.

Based on the marker production logging results, the stages operation and the nature of the well intervals operation changed during the half year study (Figure 2). The fourth stage demonstrates the most positive dynamics of work change, where the oil inflow indicators increased to 41% by the third test period. Stage 2 indicates low oil and water inflow parameters, and the contribution to the total well rate slightly increases close to the final study period. During Stage 3, there was a decreasing trend in the performance indicators by the final period of the study, in which the oil inflow percentage decreased by 8% during the studied period. Stages 4 and 5 are marked as the most efficient, with maximum values of oil and water inflow. By the final sampling period, there was a significant drop in the performance indicators of Stage 7 – the percentage of oil flow decreased to 1%, making the smallest contribution to the total well flow rate.

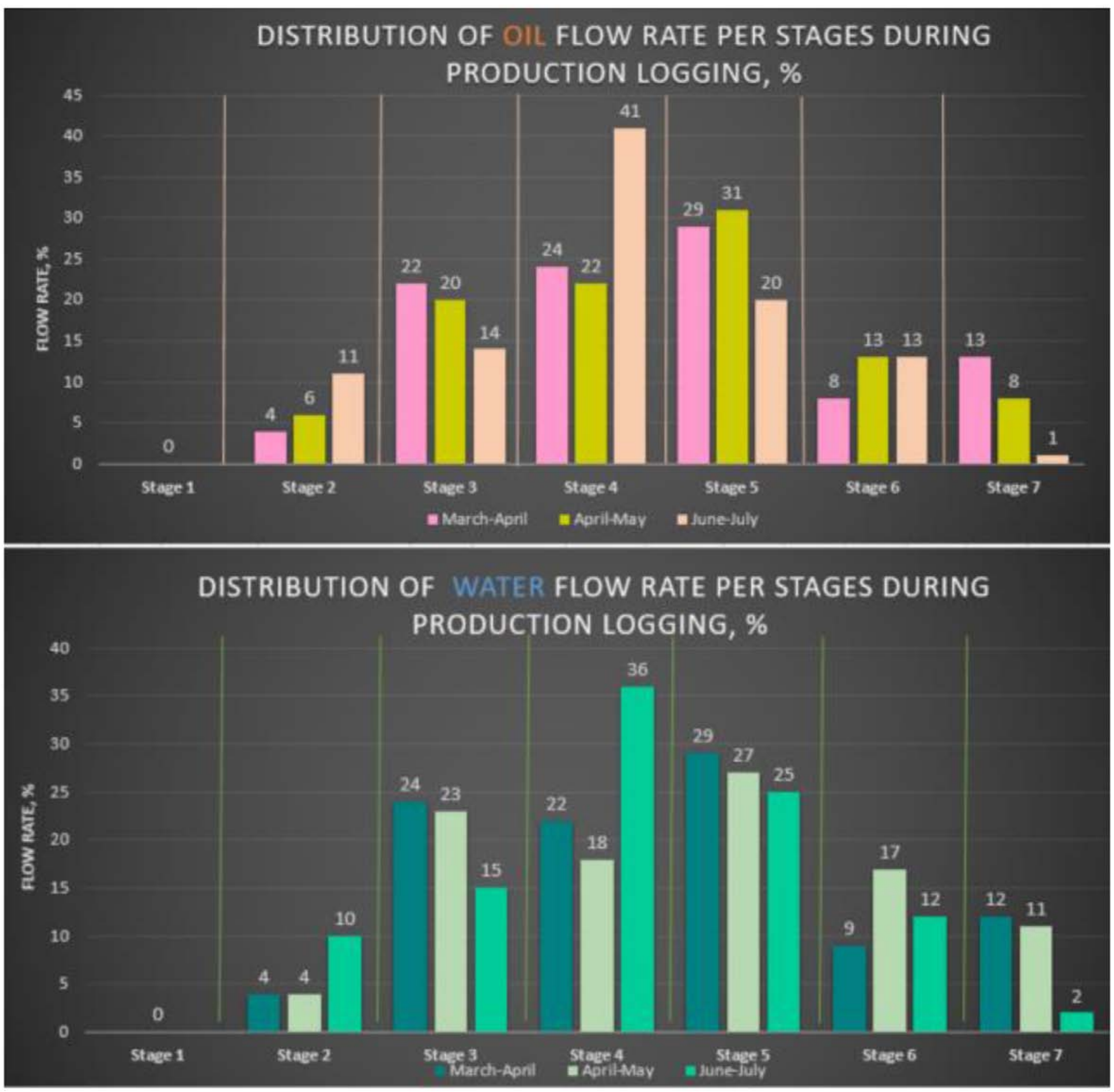

Figure 2—Distribution of oil and water flow rates by stages (data are rounded) in the period from 13.03.2018 until 26.07.2018

Production Logging Works

High-precision temperature and spectral noise logging (HPT-SNL) were performed from April 15 until April 20, 2018 in the idle well mode. The tools were lowered into the well using coiled-tubing services.

The following logging tools were applied:

1. Multi-sensor autonomous hardware complex GEO-2m6 (autonomous complex updated tool):
   - pressure
   - temperature
   - gamma logging
   - deep distance flow meter
   - moisture meter
   - collar locator
   - well thermo-conductive flowmeter
2. GEO-MST:
   - resistance meter
   - moisture meter
   - thermometer
3. GEO-MBA:
   - 6 distributed moisture meters
   - zenith angle sensor
   - device turning sensor
4. SNL:
   - spectral noise meter
5. INDIGO:
   - gamma logging
   - collar locator
6. DMPT:
   - temperature
   - pressure


0.96 m (SNL)
0.13 m (SNL)
0 m


INDIGO PT


DMPT 2

The studies were conducted on 3 flow modes (in the spouting mode using 6 mm, 5 mm and 7 mm choke) during a brief well shut-in:

- 15.04.2018 – The records of high-precision temperature and spectral noise logging was made in the well idle mode. The oil level in a stopped well is measured at the depth 1170 m, the level of the oil-water section – at a depth of 2695 m.
- 16-17.04.2018 - Measurements were taken in the inflow mode and during a brief well shut-in using a 6 mm choke.
- 17-18.04.2018 - Measurements were taken in the flow mode using a 5 mm choke.
- 18-20.04.2018 - Measurements were taken in the inflow mode and during a brief shut-in using a 7 mm choke.

The actual well operation parameters before production logging are indicated in the table below:

Q fluid, m3/day	Q oil, m3/day	Gf, m3/t	Pr, atm (20.03.2018)
52	24	274	243

Pressure curves were recorded during the tool lowering and descent in the interval of detailed studies for each mode, and demonstrated a discrepancy of more than 5%, which indicates the mode's instability.

Temperature Modeling

Temperature modeling was carried out while considering temperature perturbations (cooling anomalies) associated with previously injected fluid during hydraulic fracturing. According to the temperature modeling results, the total gas flow rate was 18 m3 / day, oil – 13 m3 / day, water – 9 m3/day for reservoir conditions. Fluid phase separation (hydrocarbons + water) is approximate, taking into account wellhead measurements from the beginning of operation and during the studies.

The main fluid inflow falls on hydraulic fracturing Stage 4 (27% of the total volume), hydraulic fracturing Stage 7 (25% of the total volume) and hydraulic fracturing Stage 3 (22% of the total volume). In these intervals, activity is indicated according to spectral noise measurement data, and changes in the temperature gradient are recorded in the inflow mode (Figure 3).

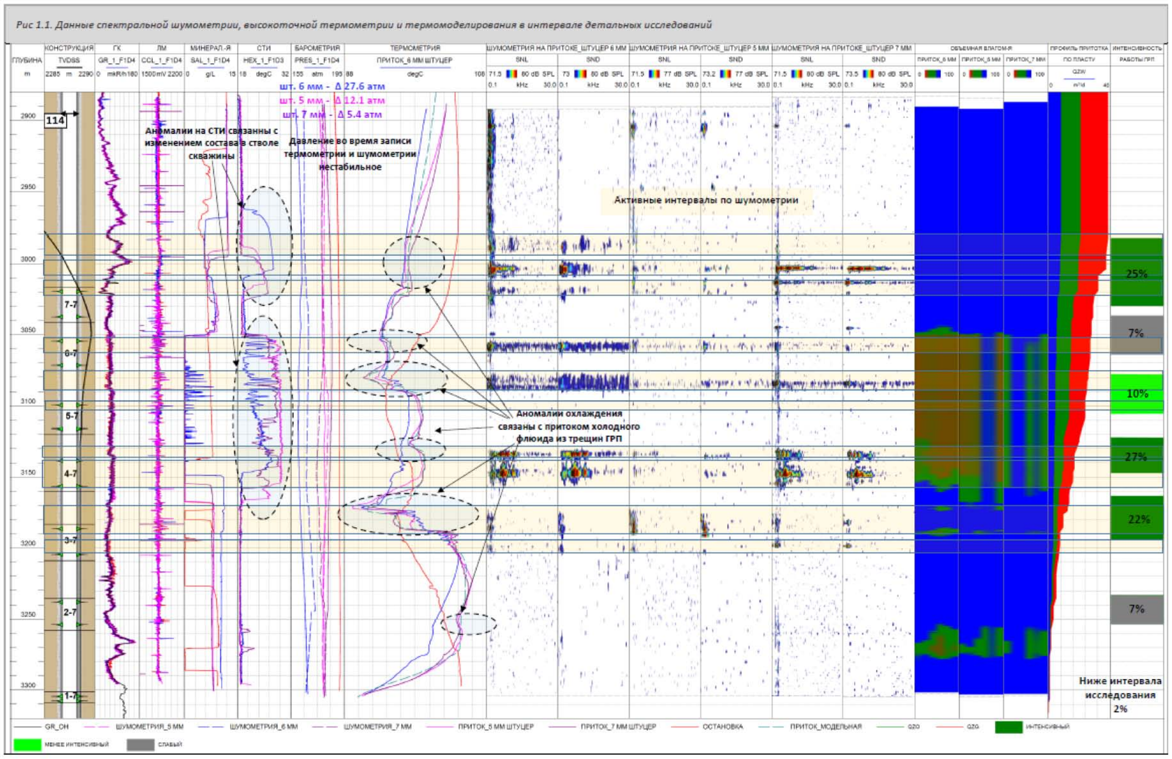

Figure 3—Geophysical logging results

The gas inflow falls during the following stages: hydraulic fracturing Stage 3 (28% of the total gas volume), hydraulic fracturing Stage 7 (27% of the total gas volume) and hydraulic fracturing Stage 4 (20% of the total gas volume). Water inflow is recorded from all of the hydraulic fracturing working stages. With a relatively low liquid flow rate (20 m3 / day), determining the intervals' most intensive water inflow is impossible.

Spectral Noise Logging

Spectral noise logging (SNL) is used to determine formation fluid flow intervals. The noise spectrum is displayed on the color bar, and the noise amplitude is displayed in different colors: red - high-amplitude noise; yellow, green, blue represent low-amplitude noises (arranged in descending order); and white displays noise with an amplitude below the tool sensitivity threshold. The noise frequency diagram determines the flow components, such as the in-column flow, movement along the cement stone, the flow associated with the well structure integrity, and distinguishing the inflows along the fracture.

Despite the unsteady production mode (according to wellhead measurements) and unstable well operation, the repeatability of noise measurement data is observed in all 3 modes of operation of the well (choke 6 mm, 5 mm and 7 mm). All chokes indicate the operation of hydraulic during fracturing Stages 3, 4, 5, 6 and 7. No additional fracturing intervals were observed on any choke, which is possibly related to a minor and unstable depression during spectral noise logging.

Analysis of Production Logging Results

According to the complex of aggregate data and temperature logging results, the main fluid flow is associated with hydraulic fracturing Stages 4 (27% of the total volume), 7 (25% of the total volume) and 3 (22% of the total volume). These intervals show activity subject to spectral noise logging as well as changes in the temperature gradient recorded in the inflow mode:

- The most stable well operation for production logging was carried out with a 6mm choke.
- The presence of low-frequency noise is presumably associated with the movement of fluid along the broken cement.

Telemetry data indicate a potentially inaccurate interpretation:

- Data from Stage 7 indicates the maximum fluid heating, which cannot indicate the maximum fluid flow;
- Data from Stage 5 indicates the maximum fluid cooling, which cannot indicate the minimum fluid flow.

The results of the comparative evaluation of marker production logging and PLT logging are shown in Figure 4:

- 4 out of 6 studied well intervals indicate a high convergence of the results obtained by GEOSPLIT marker production logging and PLT logging.
- A discrepancy is observed during the assessment of the contribution of Stages 5 and 7.

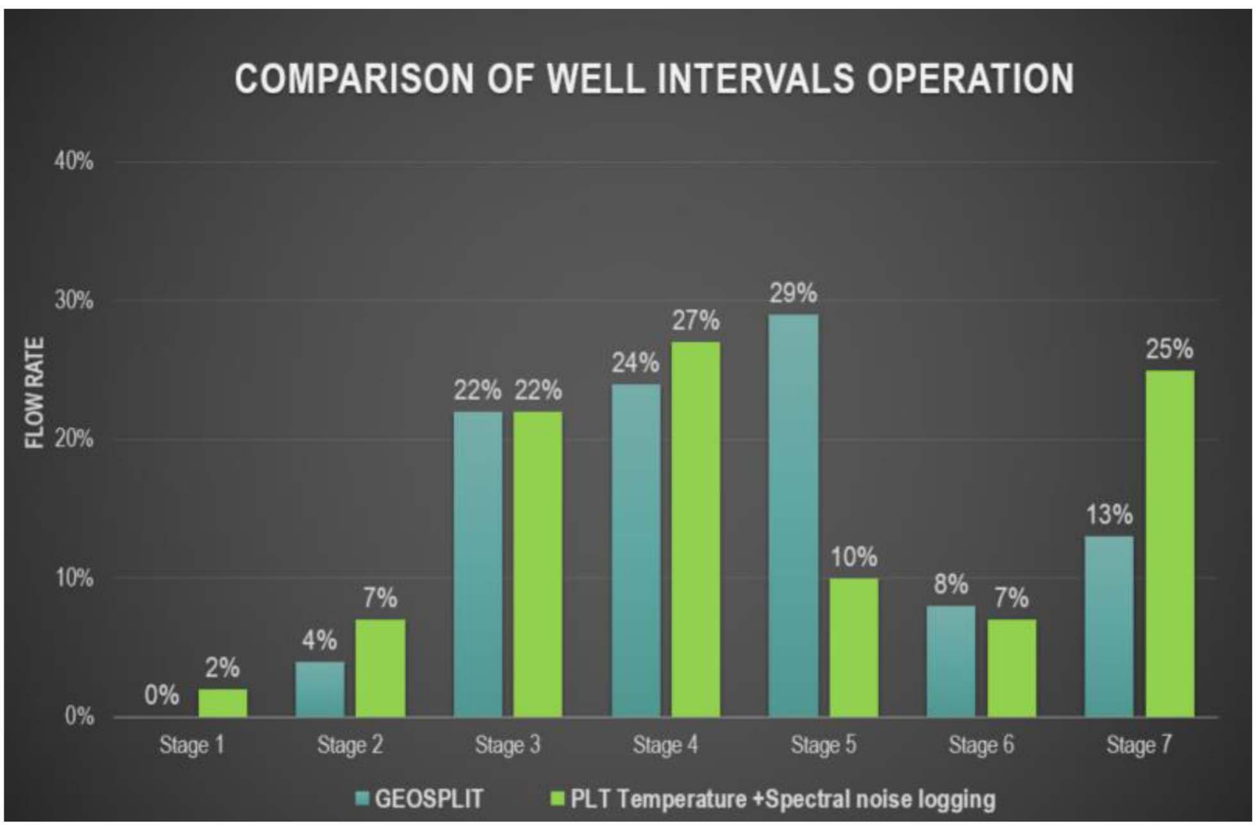

Figure 4—Results of the comparative evaluation of marker production logging GEOSPLIT with conventional PLT logging.

The discrepancy in the results could have been caused by, for example, the fact that PLT and marker production logging data may characterize different periods of well operation, as the tests are not carried out simultaneously. It is also necessary to note the difficulties associated with conventional PLT logging under conditions of multi-phase fluid inflow. The most mobile light phase moves along the upper part of the horizontal well section, and the heavy phase located below, as a rule, moves at a significantly lower speed. It can, occasionally, be filtered into the zone located on the lower absolute elevations; this complicates the interpretation of the flow distribution along the well. Another potential cause for the discrepancy in the assessment of the contribution of Stages 5 and 7 is the gas zone. As the spectral noise logging records a significant influx, the temperature logging results indicate a moderate influx.

Conclusion

Conventional PLT logging methods, though well-proven in vertical wells, require expensive technical solutions, including CT, specialized delivery tools for geophysical instruments (downhole tractors) and Y-tool bypass systems in horizontal wells. The accuracy of horizontal well logging data interpretation wells can be diminished due to multiphase flow and changes in fluid flow velocity, and the CT effect on the pressure measurement accuracy and the flow rates.

The obtained production logging and marker diagnostics results serve as important information related to the in-depth analysis of the data on the deposits in the working area and enabled the evaluation of well operation. Obviously, contemporary PLT logging complexes and methods for delivering downhole equipment to the bottomhole are capable of providing informative data on the horizontal well operation. However, analysis of gas and water breakthroughs will require non-stationary measurement techniques with periodic, multi-temporal measurements to determine the fluid composition in the well due to the inflows immediately after putting the well into operation.

Temperature logging requires the presence of contrasting temperature anomalies, but their absence in the well is rarely observed (for example, the temperature of the formation is often equal to the temperature of the formation fluid). For the Bazhenov formation, which is generally characterized by a relatively stable gas factor, contrasting anomalies in all ports allow for a reliable estimation of the inflows at all stages. Spectral noise logging helps to confirm the presence of flow stages and, in combination with temperature logging, provide a complete picture of well productive intervals operation. The disadvantage of this solution is that currently a reliable quantitative interpretation of the incoming fluid is complicated.

Standard existing software products assume a uniform distribution of proppant, but do not consider, for example, the vector of linear velocities and mechanisms of proppant movement. This means that marker production logging and its practical application at this stage are not supported by modeling the proppant injection area, which complicates the approach to the technology evaluation. Also, in view of the uncertainties described above, not all proppant injected into the well may operate properly, and partial fractures or complete closures may occur.

Today, we cannot claim that marker diagnostics can replace conventional PLT logging complexes because the fluid flow processes along the fracture have not yet been analyzed with a sufficient degree of certainty. However, the results of marker diagnostics can significantly improve the final interpretation results as they allow users to obtain and monitor dynamic information on the well productive intervals operation over a long period of time without well shut-in. The authors of this article believe that at this stage of the complex technology's application, the comparison between these methods is inappropriate. In this case, different technologies can complement each other and ensure the best quality of the information received, because the interpretation of the marker diagnostics results and micro-seismic well monitoring data (MSM) will also be required to provide a correct and effective interpretation to the oil producing company. These results are required for the estimation of the fixed part of the fracture as compared to the induced.

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