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Practical Application of the Fluorescent Microspheres Method Technology in Horizontal Wells of the Upper Salym Oil Field: Efficiency of the Method, Technology and Approach

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Abstract

The development of hydraulic fracturing technology began with single operations and is currently the most effective tool for increasing the productivity of wells and managing field development. Without the application of the hydraulic fracturing method, many fields would not have been successfully put into operation. For example, in the USA, hydraulic fracturing technology is used almost everywhere, which enabled an increase in the share of recoverable reserves by 25-30%. The first hydraulic fracturing in our country was carried out in 1952. After this, the number of such works increased for several years, but then declined. This was due to the industrial development of large oil fields in Western Siberia. The application of hydraulic fracturing technology was resumed in the 1980s and has been growing steadily ever since (Usachev, 1986).

Horizontal drilling technologies are currently developing at a fairly rapid pace, which entails an increase in the accuracy of penetrating a given part of the formation. Multi-stage hydraulic fracturing is primarily used in the well to increase the flow rate. It is expected that in the perspective of 2019-2020, the share of horizontal drilling will reach 46-50%, which is due to plans for the intensive development of new fields in Eastern Siberia (Figure 1).

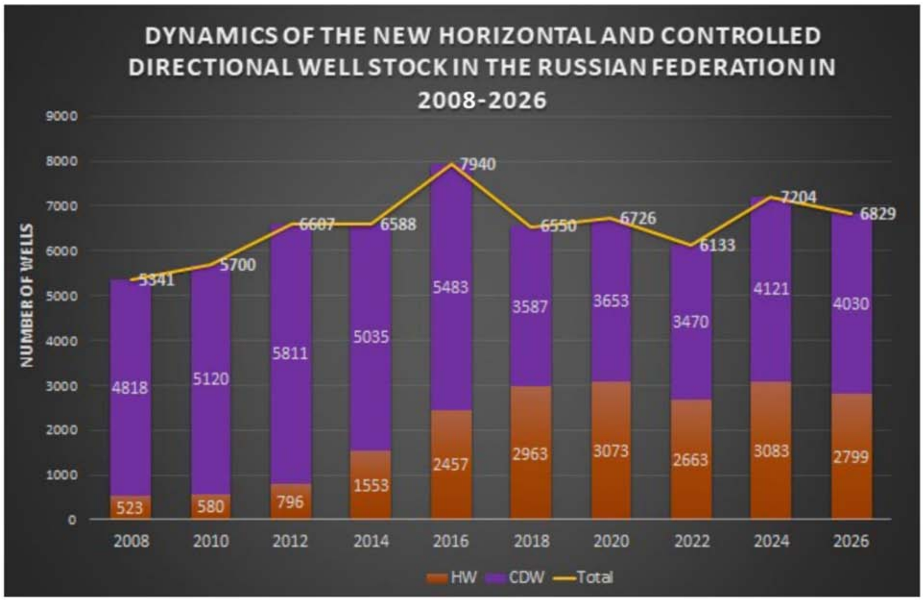


Figure 1—Dynamics of the number of wells completed using horizontal and controlled directional drilling in Russia in 2008–2026 (fact and forecast), units

There has been a steady increase in the share of horizontal drilling with the total volume of production in Russia since 2008 (Figure 2). This indicates qualitative changes in the technological approaches of today's production companies.

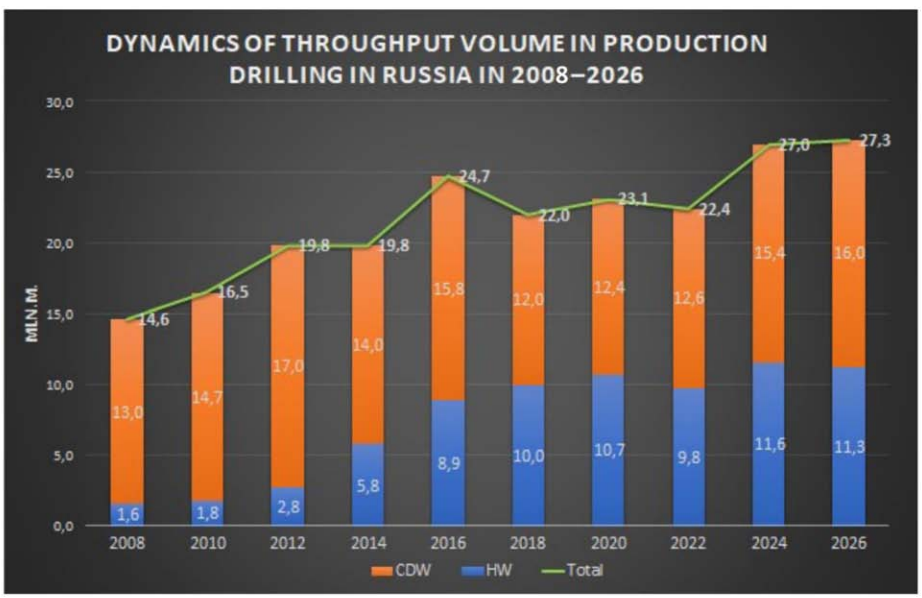


Figure 2—Dynamics of throughput volume in production drilling in Russia in 2008–2026 (fact and forecast), mln. m.

Technical solutions are required for the delivery of geophysical equipment to the horizontal section of the well for horizontal wells production logging using an electric centrifugal pump (ESP). The existing Y-tool technology allows for lowering the geophysical equipment to the coiled tubing system, therefore bypassing the ESP system in close proximity to well operation mode, but this increases the well completion cost by 25%.

Along with the conventional methods of horizontal wells production logging such as PLT logging, oil producing companies are increasingly beginning to apply innovative methods based on marker technology.

This method applies the flow indicators that are able to trace the flow of each phase into the well separately and continuously for several years. The objective of this article is to describe the results of using the fluorescent microsphere method, taking into account their long-term use for estimating the inflow structure from each port of hydraulic fracturing in horizontal wells. This helps users to avoid risky and costly downhole operations at the pilot development stage.

Markers are monodisperse polymer spheres containing their unique code for each hydraulic fracturing stage. In the presence of a stream of water or oil over the surface of the proppant, only markers corresponding to their phase are released. Upon completion of all the works in the well, it is put in the planned mode of operation. After this, sampling of the formation fluid from the wellhead is performed. A specialized laboratory analyzes the samples to determine the concentration of markers for each code.

Production logging of the well with the application of marked proppant is carried out continuously for several years. The inflow profiles of the formation fluid along the horizontal well were designed on the basis of data obtained by analytical comparison. Long-term production logging will allow for a long-term analysis of the effectiveness of stimulation for each of the hydraulic fracturing stages and will aid in assessing the reservoir section's reserves.

One of the main advantages of this technology compared to traditional methods is the ability to obtain data on the intervals operation without requiring special means of instrument delivery. As a result, the technology minimizes the risk of downhole equipment getting stuck and is not subject to ambiguity in data interpretation. The technology of marker production logging has received confirmation throughout the market based on its performance. The placement of inflow indicators was carried out in the hydraulic fractures, thereby ensuring the long-term selective interaction of marker particles with the water and oil phases of the formation fluid. Information on the inflow profile obtained as a result of the analysis allows for planning effective geological and technical measures and leads to an increase in the hydrocarbon extraction coefficient.

Introduction

The Upper-Salym oil field is located in the Nefteyugansk district of Khanty-Mansi Autonomous Area of the Tyumen region. An insignificant south-western part is located in the Uvat district of the Tyumen region; this area is included in the Salym oil and gas region of the Middle Ob oil and gas region (Figure 3).

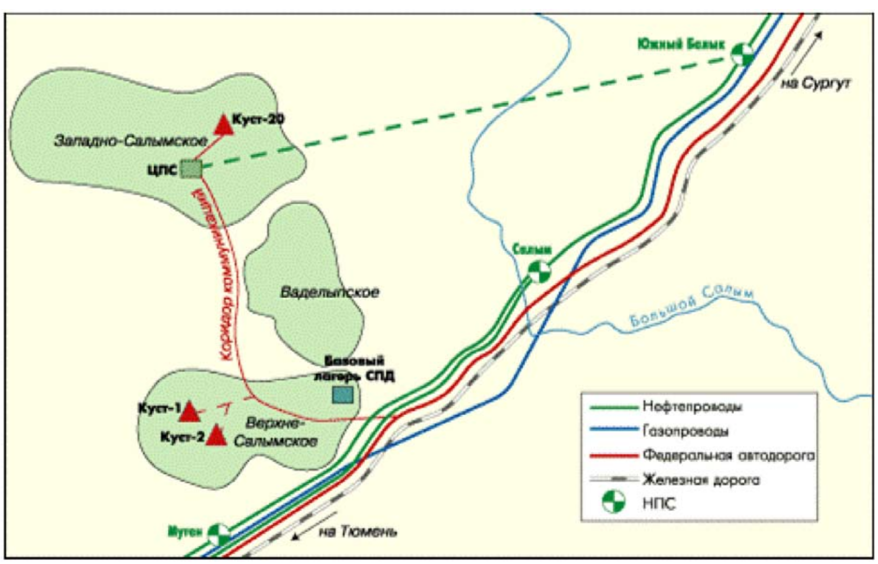


Figure 3—Location of the Verkhne-Salymskoye Oil Field

The field was first discovered in 1966, and the license area is 952.3 km2. Recoverable reserves of oil category C1 + C2 in the volume of 25 million tons were approved by the State Commission on Reserves of the Russian Federation. According to its structure, the field is very complex. Oil deposits are located in the Achskaya formation (Figure 3).

For effective control over the processes of production and injection of the fluid into the reservoir, the company implements a project to manage wells and reservoirs that are aimed at developing systemic approaches and ensuring the sustainability of field development. As part of this project, for the first time in Russia, the oil producing company has introduced an innovative “Smart Fields” technology, which allows for remote monitoring of the entire well stock of the Salym oilfield.

Currently, there is a steady growth trend in the share of horizontal drilling in the oil and gas industry, with an increase in both the total number of horizontal well drilling and the average length of the horizontal well with the number of associated hydraulic fracturing stages (Rudnitsky, Ananenko, Kravets, 2017). In most cases, oil and gas companies do not have reliable information on the operation of various sections of the horizontal wells in terms of their phase contribution to the total flow rate.

Horizontal wells production logging involves two basic methods for delivering downhole equipment, which involve flexible tubing systems and downhole tractors. Delivery of downhole instruments and the recording of production logging complex often requires extensive preliminary preparation of the well. This includes drilling out the saddles of the multiple hydraulic fracturing tool, gauging, among others with the subsequent fishing works. Accident response measures lead to additional costs associated with well shut-in and require additional resources to eliminate them. Therefore, there is currently a shortage of tools that serve to calculate the optimal length of horizontal wells and the number of fracturing stages. There are also difficulties associated with assessing the well management system efficiency, etc. which complicate the implementation of effective solutions for production and development of fields using horizontal drilling.

Alternative methods have been steadily growing in popularity, such as the technology of well production logging using markers (tracers) in the global oil industry. Significant advantages of these methods include the absence of the need to perform downhole operations during production logging, the ability to obtain data on the selective inflow of water and liquid hydrocarbons for each interval in the monitoring mode over a long period of time, and no need of well shut-in that involves expensive equipment and numerous personnel.

Well Production Logging Technology with the Use of Marker-Reporters Based on Quantum Dots

The technology of well production logging using markers is based on the application of quantum marker-reporters, which are highly accurate indicators of the formation fluid inflow. Marker-reporters are polymer microspheres (Figure 4) doped with quantum dots. Figure 4 displays the basic set of quantum dot light spectrum. Combinations of quantum dots form the code (signature) of the marker.

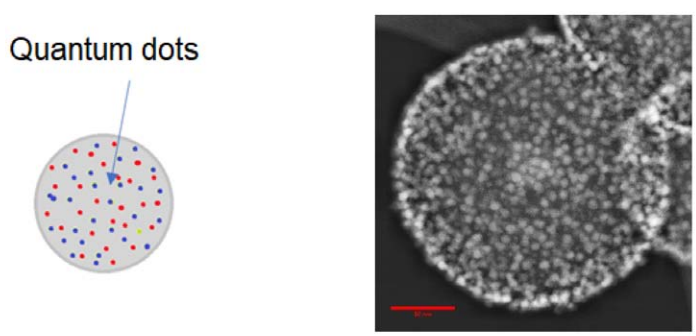


Figure 4—Marker (polymer microsphere doped with various combinations of quantum dots). Left – a visual demonstration of the composition. Right – a photograph in the electronic microscope.

Figure 5 displays the fluorescence of dispersions containing quantum dots of different marker codes (signatures).

Figure 5—Fluorescence of Dispersions Containing Quantum Dots of Different Codes

Marker-reporters are synthesized in the required amount for injection into the proppant polymer coating. Figure 6 shows a photograph of marker-reporters in a scanning electronic microscope.

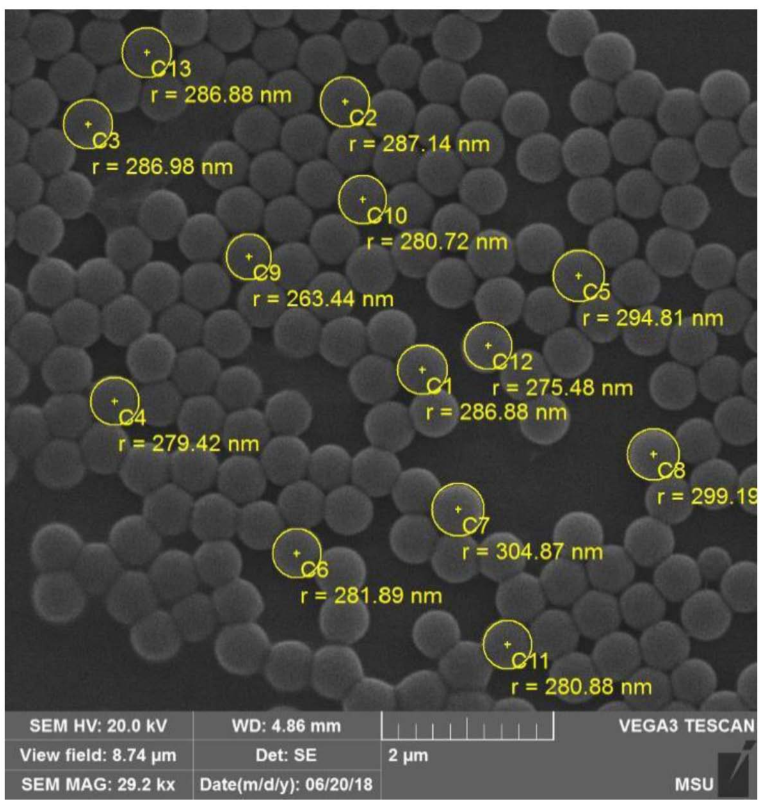


Figure 6—Image of Marker-Reporters in a Scanning Electronic Microscope

This technology involves the injection of markers in the formation with the application of marked polymer-coated proppant that is injected during the multi-stage hydraulic fracturing (Gurianov, Katashov, Ovchinnikov, 2017). Figure 7 displays the grain of the marked proppant; markers are injected into its polymer coating.

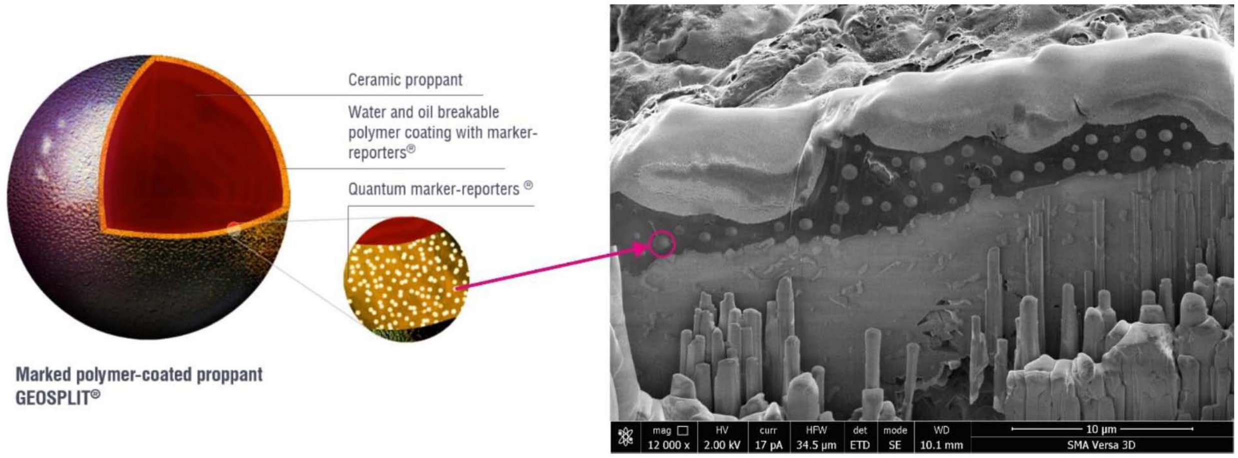


Figure 7—Grain of the marked polymer-coated proppant with quantum marker-reporters

The thickness of the polymer coating is several tens of microns, meaning the fractional composition of the proppant is not disturbed. Upon contact with the target formation fluid (water or liquid hydrocarbon), marker-reporters are separated from the polymer shell of the proppant and transported to the wellhead with the formation fluid. The markers, being captured by water or oil, cannot overcome the phase boundary and remain in each of them forever due to their small size and physicochemical inertness.

During the multi-stage hydraulic fracturing, marked proppant of a specific code is injected into each stage, with the last proppant pack (near-well zone) used to ensure maximum coverage of the formation fluid flowing from the formation into the well (Figure 8).

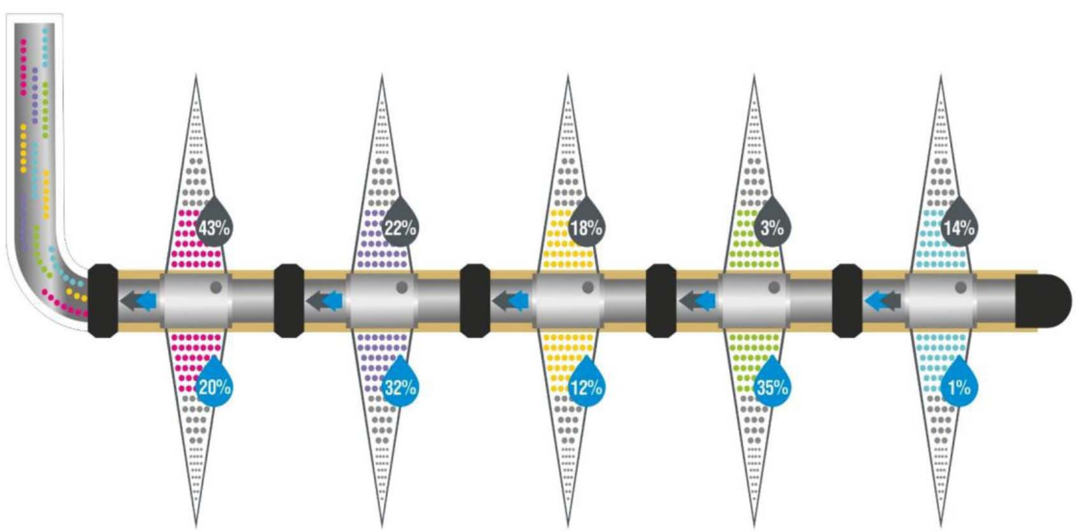


Figure 8—Scheme of multi-stage hydraulic fracturing with injection of the marked proppant with the last proppant pack at each stage.

Marked proppant has two types of polymer coating, oleophilic and hydrophilic. Oleophilic coating focuses on interaction with liquid hydrocarbons, while hydrophilic coating focuses on interaction with water. Figure 9 demonstrates that oleophilic proppant is not wetted with water, unlike the hydrophilic proppant. The use of various coatings allows the oleophilic proppant to allocate markers only in liquid hydrocarbons, and hydrophilic only in water.

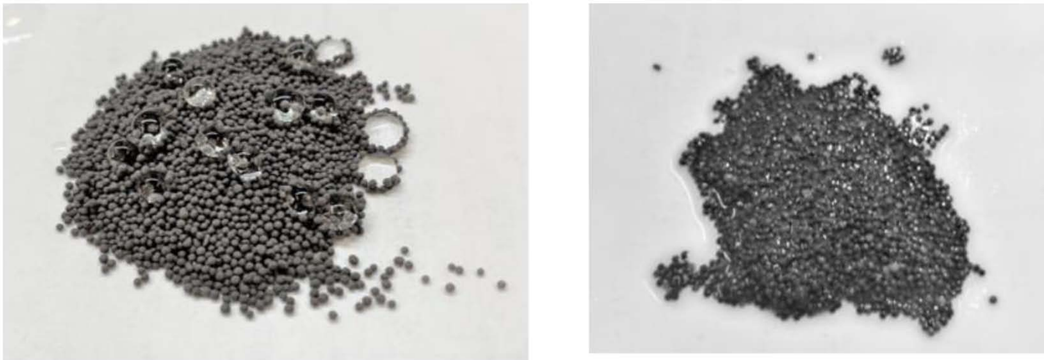


Figure 9—Reaction to oleophilic water (left) and hydrophilic (right) coating of the marked proppant.

The technology involves the injection of 15 tons of marked proppant at each stage of hydraulic fracturing. This pack contains proppant in the ratio 50% hydrophilic and 50% oleophilic. Unlike solutions based on the use of natural fluorophores, this technology involves the synthesis of an unlimited number of codes. At the moment, the oilfield services company has synthesized 63 marker codes. Each marker code can be both oleophilic and hydrophilic. Thus, it is possible to mark more than 60 analyzed intervals in the well. At the same time, an unlimited number of production logging operations can be conducted.

After the completion of the hydraulic fracturing, the well is put into operation. Formation fluid samples are then taken from the wellhead, after which a laboratory analysis is performed. When identifying markers in samples, the hydrocarbon and aqueous phases are separated and, after sample preparation, are analyzed using the analytical hardware-software complex (Figure 10). In this complex, a stream of small-diameter liquid is formed. Markers line up in a row and the flowing fluid with the markers is irradiated with a laser and a light-scattering signal, both direct and lateral, individually identifies the marker of each code. Therefore, the analysis of the total volume of samples allow the user to identify the quantitative ratio of the phases (water and liquid hydrocarbon) in the total flow rate.

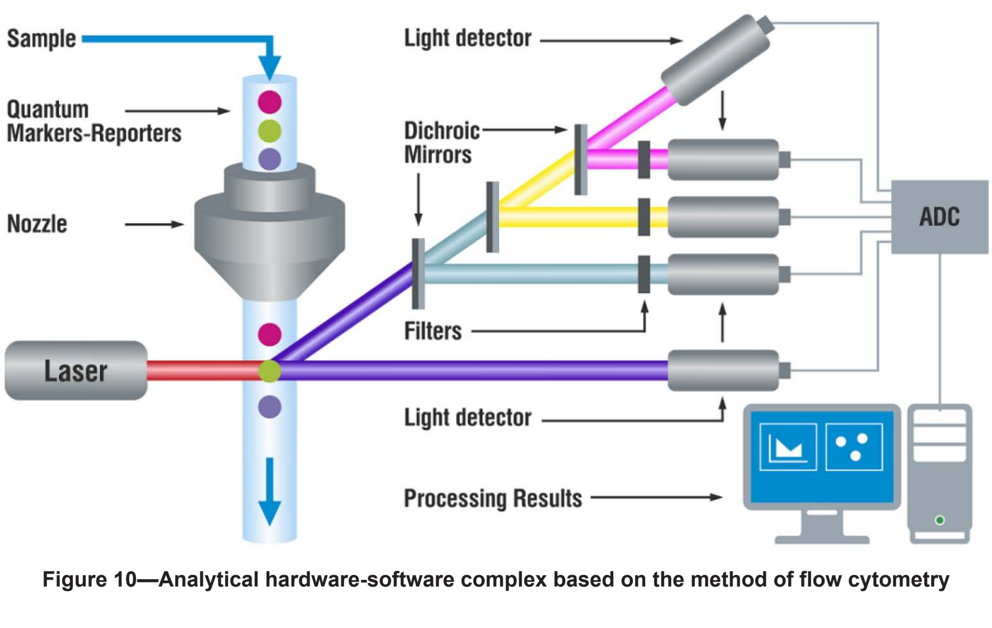


Figure 10—Analytical hardware-software complex based on the method of flow cytometry

One of the key elements of this technology is the use of artificial intelligence and machine-learning; their characteristic feature is not a direct solution to the problem, but involves learning in the process of applying solutions to many similar tasks. Horizontal well production logging involves working with large amounts of data. The information on the identification of each marker-reporter represents a point in the 15-dimensional space of coordinates (15 detection channels), so any manual calculations will be extremely laborious. To address this, special intelligent software that utilizes machine-learning with the “Random Forest” algorithm is applied.

In simple terms, this process can be described as follows: initially the neural network is trained on “referee” samples of marker-reporters. From this, a “decision tree” is built, where parameters are sorted at each depth step (for example, whether the particle is green or not). The depth of the tree can vary. These trees, differing in structure, are created in a large variety. As a result, when passing through a given tree, the marker of the desired code falls into a strictly defined “basket.” After learning from the “referee” data, the algorithms understand which basket each particular code should fall into. Then a mixture of a large number of markers is examined on the created tree and sorted, i.e. the algorithm counts the number of markers and their type in the mixture. Each tree makes its decision or, relatively speaking, “votes” on the composition of the mixture (Figure 11).

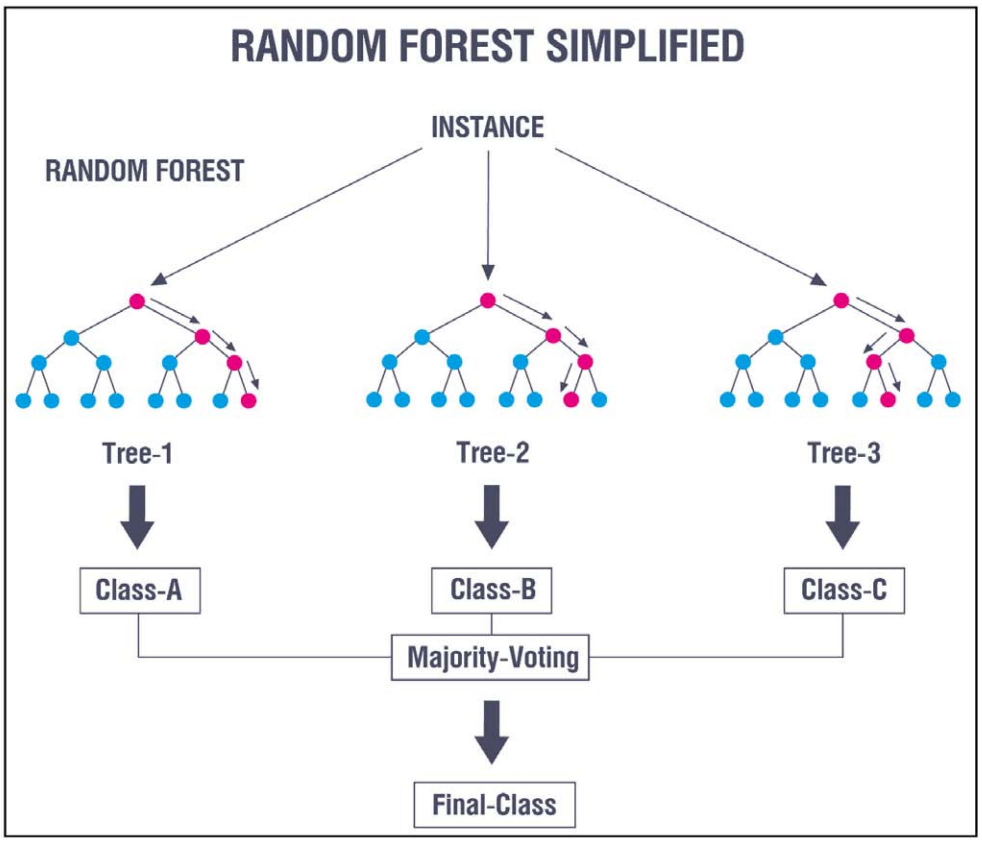


Figure 11—Machine-Learning Algorithm and Building a Decision Tree

Analytical hardware-software complex provides high accuracy in data interpretation. In general, machine-learning algorithms allow users to process a large array of data with high accuracy in a short time frame, while eliminating errors related to the “human factor.”

Example of Production Logging in the Well with 8 Fracturing Stages

In well No. 8105, pad 82 of the Verkhne-Salymskoye field, 8 hydraulic fracturing stages were planned. But, according to the results of the mini-hydraulic fracturing from the 1st stage, it turned out that the formation does not accept liquid. Therefore, the injection of proppant at this stage was canceled. The remaining stages were carried out in the normal mode and, after the completion of work of 7 hydraulic fracturing stages and putting the well into operation, samples were taken and analyzed. Based on this analysis, the inflow profile was constructed. BS-8 reservoirs belong to the Achskaya Formation with a reservoir pressure of 215 atm and a temperature 110 C. Besides the oil, the formation is saturated with water. There was a risk of water breakthrough at this interval during hydraulic fracturing, which may lead to a significant decrease in oil production after hydraulic fracturing.

The volume of proppant injected at each stage was 20 tons, including a 15-ton marked proppant with its own unique code for each stage. The calculated fracture conductivity profile is shown in Figure 12.

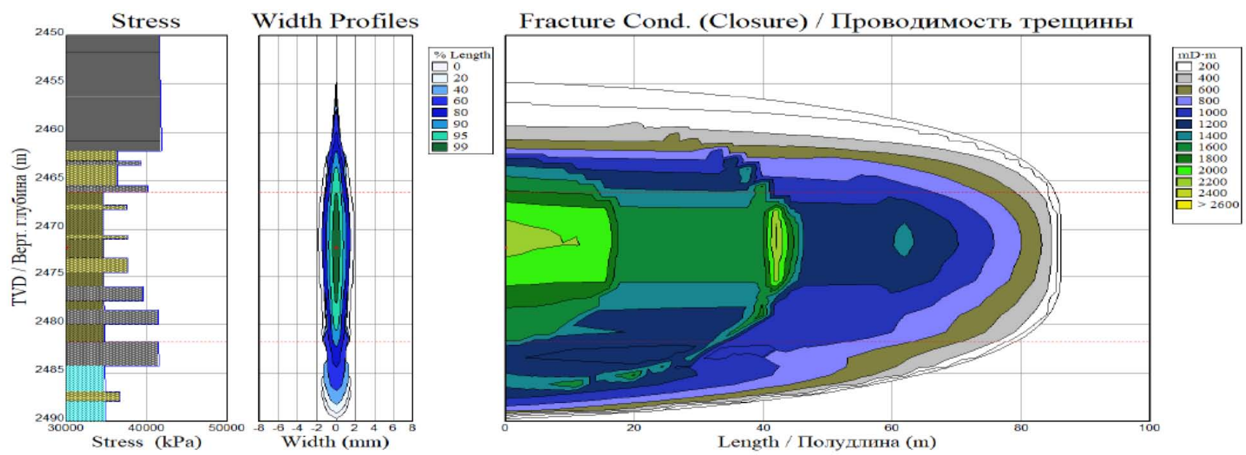
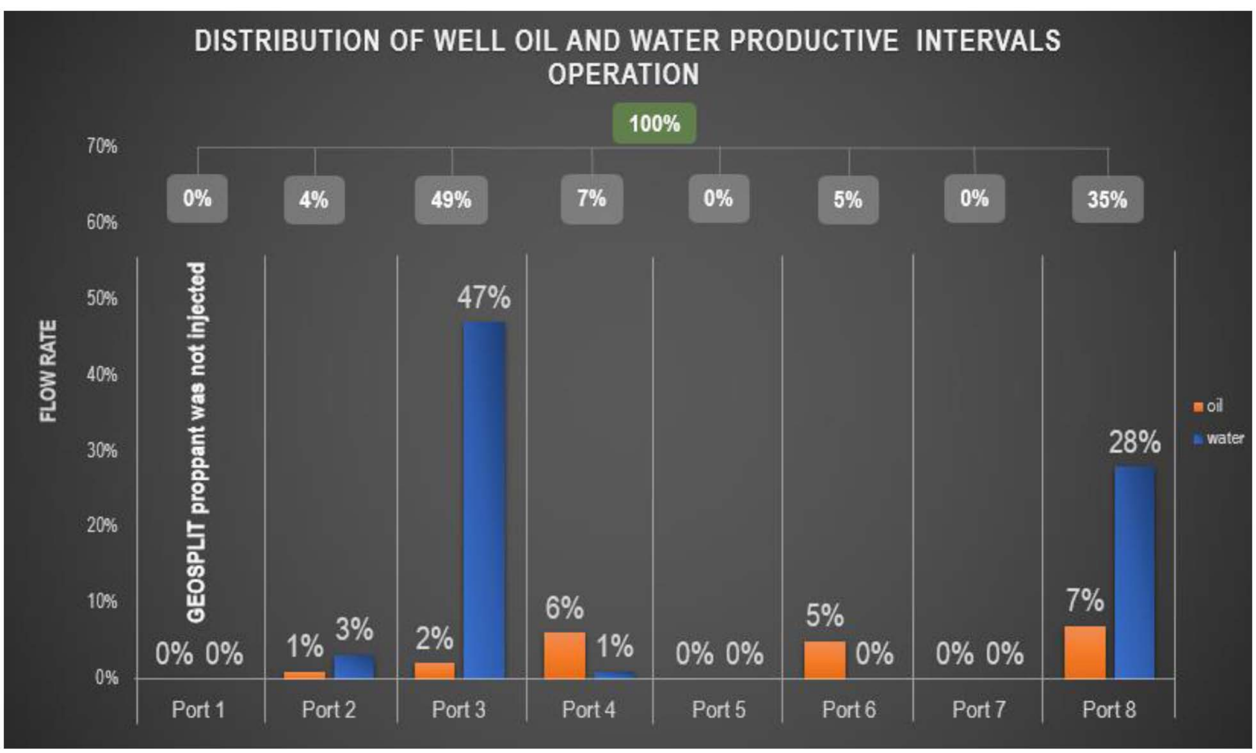


Figure 12—Estimated Profile of Fracture Conductivity

Based on processing the results of the wellhead sample pack, taken 5 weeks after the multi-stage hydraulic fracturing, a working schedule of each stage was constructed. This characterizes the well operation during the production logging period (Schedule 1). This data presentation allows for well production logging and performing a step-by-step analysis of the formation fluid flow dynamics, the water content and other important indicators.



Schedule 1—Distribution of Well Intervals Operation

The results of MFrac ports operation efficiency indicate the following:

1. High water content of reservoir products – 79%.
2. Port 3 displayed the highest general fluid inflow – 49%: oil – 2%, water – 47%.
3. The operation of port 4 is characterized by a high contribution to the total oil production rate compared to other stages and the total oil content (21%) – 6%, 1% – water.
4. Port 6 contributes 5% to the well operation for oil and 0% for water.
5. Port 8 contributes 7% to the well operation for oil, 28% for water, or a total of 35% of the total well flow rate.
6. Ports 2, 5 and 7 are characterized by the minimum percentage values in the contribution to the well operation and are within the statistical error.

According to the results of the production logging using markers, it can be concluded that the largest contribution to the well operation is made by port 3 and port 8, providing a total of 84%.

Conclusion

Multi-stage hydraulic fracturing at the Upper-Salym field was conducted with a small amount of proppant due to the risk of a fracture breaking into the water interval during hydraulic fracturing. This may entail a significant decrease in oil production after hydraulic fracturing. The total volume of proppant, including marked proppant, for each stage of hydraulic fracturing was 20 tons.

The formation properties during horizontal drilling were heterogeneous due to the geological structure, which affects the filtration of multiphase flow and ultimately leads to changes in phase permeabilities. This greatly complicates the prediction of the oil deposits efficiency. Based on the lack of the formation reaction during mini hydraulic fracturing, the first stage of the proppant injection was completely eliminated. When conducting mini hydraulic fracturing during the first stage, low values of formation filtration properties were revealed. Based on this, the decision was made to exclude this stage from hydraulic fracturing. The remaining stages were carried out in the normal mode.

The applied method of production logging using markers allows for assessing the degree and source of watering, fluid flowing into the well and, in the long term, excluding the areas with the largest amounts of water breakthrough. The resulting inflow profile of well 8105 is the basis for selective insulation works. Unlike conventional methods of horizontal wells drilling, the production logging technology using markers did not require specialized delivery tools and minimized the risk of downhole tools getting stuck in the well.

Based on the results of the conducted work, the contribution of each of the 7 hydraulic fracturing zones was estimated. The gathered information on the inflows will be the basis for further planning of effective geological and technical measures and increasing the oil recovery factor. The list of such events can include:

– improving the efficiency of well operations by reducing the water content and leveling the flow profile;
– increasing the oil recovery rate due to localization and development of residual recoverable reserves;
– construction of fractures/intervals dynamic characteristics;
– adjustment of the model for compaction of the well grid, etc.

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