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ABSTRACT

This paper deals with the case of using the production surveillance inflow tracer-based method in one of multi-lateral wells located in West Siberia.

Tracer systems were placed in the well during the well construction by horizontal side tracking, and multi-stage hydraulic fracturing (MSHF) was performed, with the parent borehole remaining in operation. This technology allows developing the reservoir drainage area with a lateral hole and bringing the oil reserves remaining in the parent borehole into production, which results in an increased well productivity and improved oil recovery rate.

Tracer systems are placed into the parent borehole within a downhole sub installed into the well completion. Polymer-coated proppant pack was injected during multi-stage hydraulic fracturing to deliver the tracers to the side track lateral.

Dynamic production profiling was done to aid into more efficient development of complex and heterogeneous reservoirs and improve of the productive reservoir sweep ratio during the construction of multilateral wells, which enabled us to address several key problems:

1) Providing tools for waterflood diagnostics in multilateral wells and finding an easy water shut-off method for a certain interval
2) Assessing the efficiency of multi-stage hydraulic fracturing and elaborating the optimal treatment design
3) Selecting the optimal mode of the multilateral well operation to prevent premature flooding in one or more laterals
4) Evaluating whether well construction was performed efficiently, and a higher production was achieved by side tracking.

Currently, the proposed first-of-its-kind solution enables the operator to obtain a set of data that can help not only significantly improve the wells' productivity and increase the oil recovery rate, but also lead to a considerable economic savings in capital expenditure.

INTRODUCTION

It is common that conventional hydrocarbon reserves are rapidly depleting and in order to sustain the demands the industry pays more attention to unconventional, hard-to-recover oil and gas reserves. The drilling of horizontal multilateral wells used to increase oil recovery in such reserves especially when two or more productive zones exist in one well. Multi-lateral wells require more complex and more advanced technologies for optimal well construction, completion strategy and future interventions planning. The shift in focus is to have optimum reservoir surveillance in order to monitor and optimize well productivity.

Historically, the analysis of well production efficiency was based on geological and hydrodynamical modelling that considered petrophysical features, including porosity, permeability, mineralogy, and total organic carbon. However, the determination of flow profiles in production wells serves as the basis for making technical decisions that seek to increase efficiency in field development and optimize well construction solutions or workover operations.

For the last few years there is a significant trend worldwide of using various tracer-based surveillance methods to obtain data on the horizontal multilateral well's productivity. The main advantage of these technologies is the ability to obtain data over a long period of time with a significant decrease in the required resources, therefore providing new opportunities for horizontal and multilateral wells monitoring, reservoirs management and increasing the cumulative production.

Tracer-based production surveillance technologies involve the placement of tracers along the horizontal well or in each borehole of multilateral wells. When tracers contact target formation fluid (oil, water, gas), the fluid captures the tracer particles and move along with the flow. Fluid samples are taken from the wellhead and analysed to identify the number of tracers of each code in each type of fluid. Data on the oil, gas and water inflow distribution over each interval or borehole are interpreted based on the laboratory test results.

GEOLOGICAL SPECIFICITIES OF THE FIELD AND FEATURES OF TECHNOLOGY APPLICATION

The object of the paper is oil field situated near Khanty-Mansiysk city in West Siberia. In terms of the reserves quantity, it can be called a super giant oil field. The oil reserves in the field are mainly silt and sand deposits of the AS10, AS11, and AS12 horizons. The AS10 and AS12 horizons are identified as the main development targets within the field. The development of the field was considered uneconomic for a long time due to the extremely low permeability of the productive layers.

New technologies, in particular hydraulic fracturing and horizontal drilling opened up new opportunities for the oil production industry and made it possible not only to start the field development, but also to increase many-fold the production from 2.7 million tons of oil equivalent (o.e.) in 2005 to 12.5 million tons of o. e. in 2017. The initial recoverable reserves of the field in the ABC1+C2 category are about 469 million tons of oil. The initial oil in place exceeds 1,5 billion tons.

Table 1 shows the geological and engineering data on the target well of the field.

Parameter	Value
Number of producing wells	1
Net pay, m	13
Reservoir pressure, atm	260
Reservoir temperature, ^oC	90
Number of hydraulic fracture zones, pcs	1 (out of 3)
Length of the horizontal lateral, m	361

Table 1. Geological and engineering data on the target well

A downhole tracer system sleeve containing tracer material was placed into the parent borehole. The tracer coated proppant was injected in one stage into the sidetrack during the hydraulic fracturing. **Fig. 1** shows the equipment placement diagram for the parent borehole and the sidetrack in the target well.

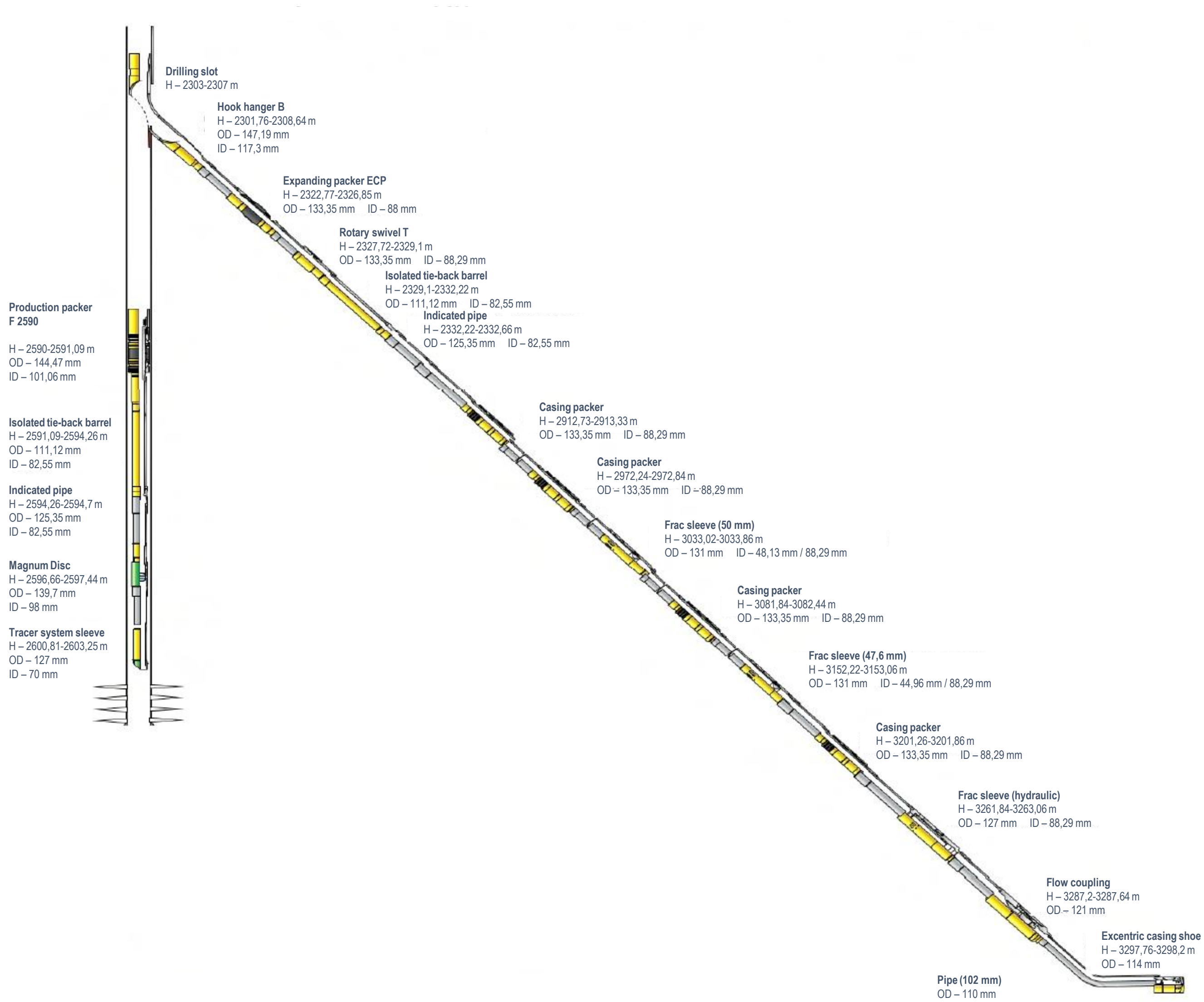


Figure 1— Equipment placement diagram for the parent borehole and the sidetrack

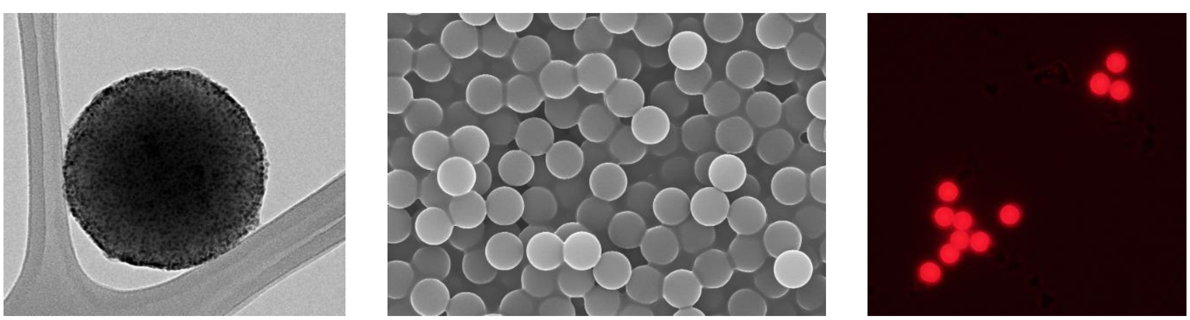
Fig. 2 shows the well sidetrack profile obtained through well logging during drilling, and the frac port layout.

Figure 2— Target well sidetrack profile

During the hydraulic fracturing in the target well, 90 tons of proppant was injected, including 15 tons of tracer coated proppant. This quantity is required to ensure a sufficient tracer concentration in the fluid samples, to achieve a sufficient area covered by the tracer coated proppant released from the hydraulic fracture, and to ensure the required accuracy of the survey along with the surveillance duration.

TRACER-BASED WELL PRODUCTION PROFILING TECHNOLOGY

The core element of the technology described in this article are quantum dots that are fluorescent semiconductor nanocrystals [1, 6]. Quantum dots are perfectly suited for optical encoding due to their solid structure, broad absorption spectrum, and narrow emission spectrum. Due to high-quality quantum dots, the technology offers high accuracy and efficiency of survey. Quantum dots are not used separately, instead, they are encapsulated in the marker-reporters. Marker-reporters are polymer spherical particles containing various combinations of quantum dots (**Fig. 3**). Six types of quantum dots are used within a single polymer particle enabling creation of 63 unique signatures.



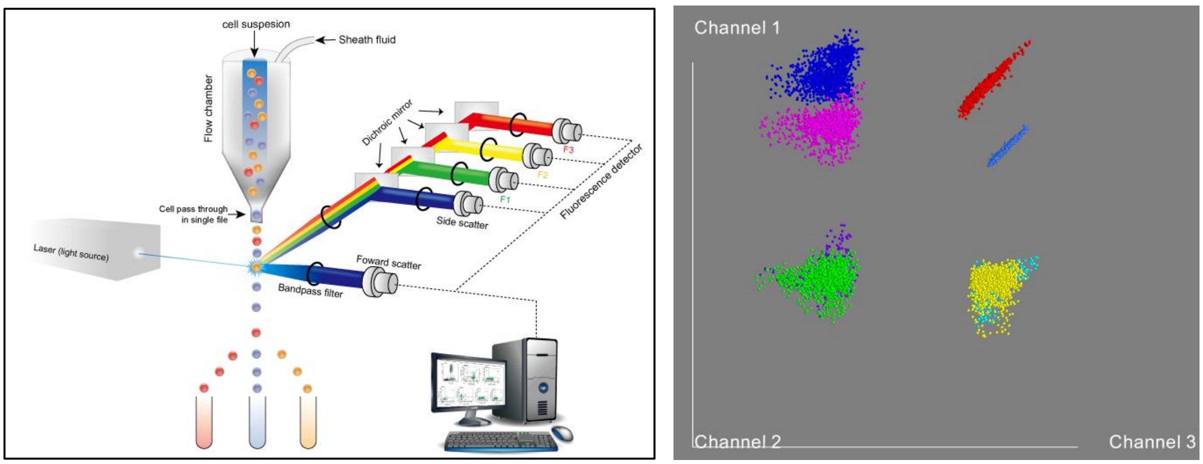
(a) (b) (c)

Figure 3—Microphotography of marker-reporters in transmission (a) and scanning (b) electron microscopes and microphotography in optical fluorescence microscopes (b)

A special polymer coating with quantum tracers can be applied to proppant or sand. Then, the tracer coated proppant is injected into the well in the course of multi-stage hydraulic fracturing, with a unique code placed in each stage. It is recommended to inject the tracer coated proppant as the last pack to enable maximum contact of the fluid with the marked polymer coating. During the subsequent long-term well operation, the markers are evenly released into the water or oil phases and arrive at the wellhead. After completing multi-stage hydraulic fracturing and injecting the tracer coated proppant, reservoir fluid samples are collected from time to time from the wellhead. These samples are then sent to the laboratory for further analysis.

A special sample preparation is required to identify the number of markers in the sample. It involves various physical and chemical methods and serves mainly for extracting the markers from the sample into deionised cleaned water. Both water and oil samples require preparation.

Flow cytofluorimetry is the main instrumental method for identifying and quantifying markers extracted from reservoir fluid samples. The basic principle of the cytofluorimeter operation can be briefly described as follows: due to the incompressible liquid, the marker dispersion flow is focused, then it enters the nozzle, where the markers line up strictly one after the other and are irradiated by lasers (**Fig. 4a**). The detectors placed opposite the lasers record the forward light scattering indicators, and the side detectors measure the intensity of the side light scattering and the intensity of the fluorescence, which is different for different marker-reporter codes.



(a) (b)

Figure 4 — Principles of flow cytofluorimetry operation (a) and a sample of data obtained as a result of cytometric analysis (b)

The analysis of samples from multi-stage fracturing wells yields a large amount of data. For example, the identification information for each marker-reporter is a point in a 25-dimensional space. Therefore, manual processing of the data would be very challenging. Machine learning and neural networks used to analyse cytometry data enable detailed analysis with high accuracy in a short time frame. In addition, the possibility of errors due to the human factor is zero at this stage of the work.

DEPLOYMENT OF A COMBINED PROPPANT-CASSETTE SOLUTION

The range of geological and engineering challenges that could be addressed by using tracer-based production profiling systems is wide, due to the availability of brand-new approaches to the placement of marker material downhole. The most suitable placement method is selected depending on the type of the work planned: drilling, stimulation or well workover. Based on this logic, there are three main approaches: tracer system integration in well completions, injection of tracer coated proppant during multi-stage hydraulic fracturing, as well as solid tracer injection into a liquid medium, for example, during selective acid stimulation (**Fig. 5**).

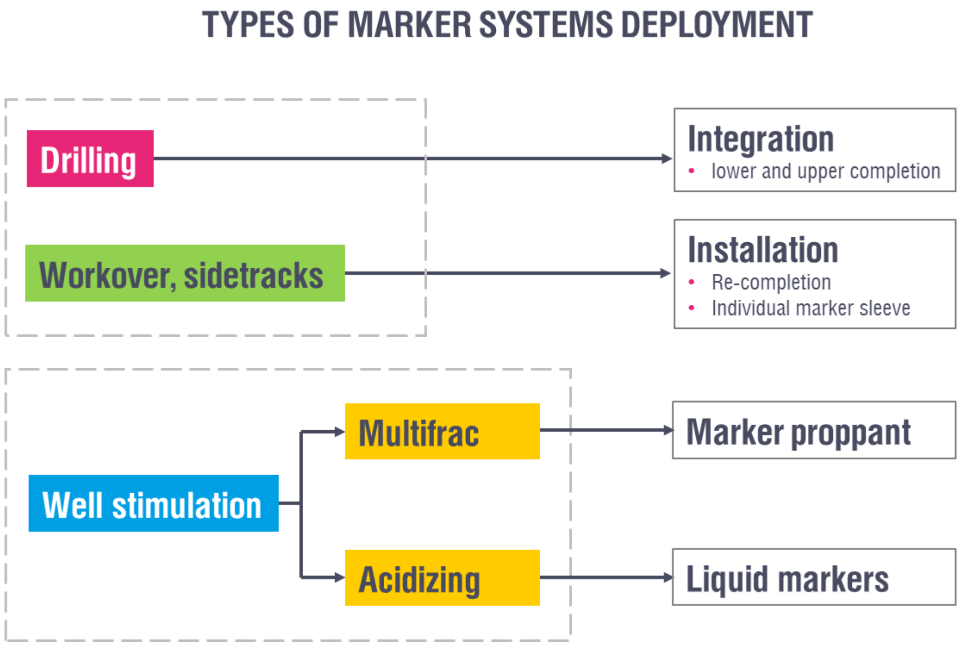


Figure 5 — Methods of marker placement in the well

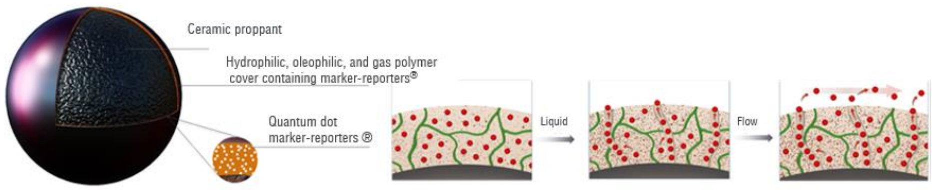
The placement of tracer systems in well completions is the most common application used both in drilling and for the existing well stock (**Fig. 6**). During drilling, depending on the completion design and type, the tracer material can be placed in the lower or upper completion by using slotted sleeves (**Fig. 7**), or by integrating the material into the completion equipment, such as flow control devices or well screens.

Figure 6 — Placement of marker systems in the lower completion (a) and recompletion (b)

Figure 7— Cross-section view of the tracer sleeves (a) and tracer inserts (b)

The tracer systems are used in the existing well stock most commonly in cases of high water cut, when it is necessary to identify its causes and sources. Tracer systems are run in the existing wellbore, either integrated into the re-completion, or by individual packer and anchor equipment. These works are usually performed simultaneously with well workover to avoid the need for additional involvement of the workover crew and minimise the loss of well products recovery.

When planning various kinds of well stimulation operations, tracer-based production profiling systems can be placed by either using marked proppant during hydraulic fracturing operations or by injecting solid tracers in a liquid fluid systems (acid or fracturing fluid). The use of marked proppant is the most common solution since it enables long-term dynamic monitoring, reaching three years or more. The method consists in injecting the marked proppant having a unique code in the last pack into each of the frac stages to quantify the profile and composition of the flow. A distinctive feature of the marked proppant from the standard one is the presence of a surface polymer cover constituting a matrix incorporating quantum inflow tracers (**Fig. 8a**). In the process of operation, as the composite material swells in contact with the target reservoir fluid, diffusion channels are formed in the polymer layer, enabling the release of markers (**Fig. 8b**).



(a) (b)

Figure 8 — The structure of the marked proppant (a) and the marker release process (b)

Completions of wells in which multi-stage hydraulic fracturing was performed can be equipped with marker sleeves, among other things. In this regard, there is a problem of choosing the most rational method for placing marker systems, which requires identifying the most reliable and economical way. The use of marked proppant does not require any changes in the completion design, while an additional cost advantage is achieved by using the marked proppant for injection instead of the standard ceramic one. If economically feasible, different placement methods can be combined, in the attempt to cross-reference the results and have independent self-validation methodology (**Fig. 9**).

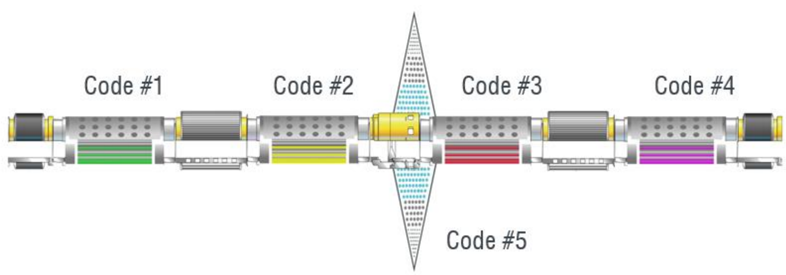


Figure 9 — Combined solution for placing marker systems

The availability of various approaches to the placement of marker systems in wells described in this section opened up the possibilities to effectively address the problems of reservoir surveillance in the drainage area penetrated by the sidetrack and evaluating the remaining reserves recovery in the parent borehole in the drainage area.

In the sidetrack, in order to identify the flow rate and fluid composition and evaluate the effectiveness of sidetracking oparation, it was decided to use a marked during hydraulic fracturing. The monitoring of the remaining reserves in the parent borehole was enabled due to the quantum marker insert mounted on the packer (**Fig. 10**).

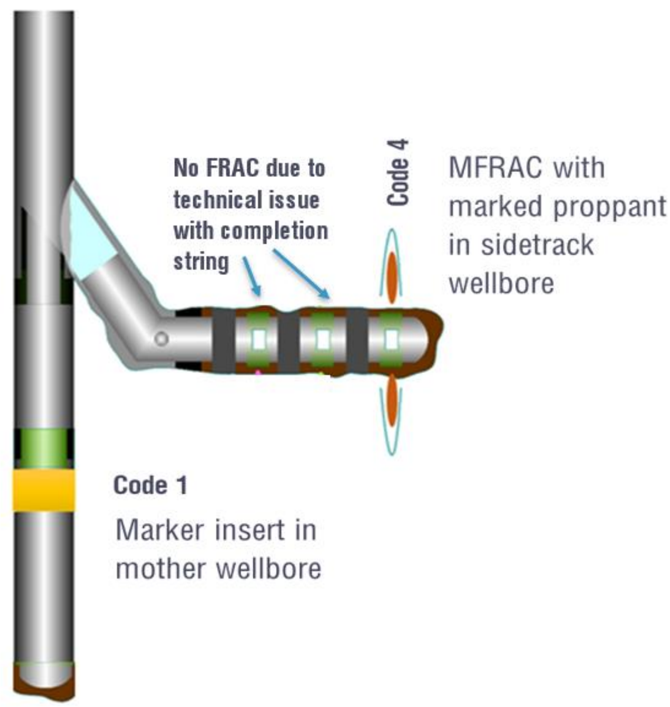


Figure 10 — A combined solution at the well

PRODUCTION PROFILING TEST WITH COMBINED MARKER SOLUTION

To assess the current state and perform long-term production profiling surveillance at the well, reservoir fluid samples were taken from the wellhead. Sampling was performed in several steps: first, immediately after commissioning in April 2020, then after a month of operation, and eventually six months later (March 2021), when the well came into the steady-state operation mode.

The analysis took into account historical data of the entire well production dynamics, (flow rate of total fluid, oil rate, water cut, bottom-hole pressure) over time. This kind of information helps track the production history and downhole pressure dynamics at the well and compare them with the shaped flow profile at a particular time, as well as take into account various well interventions or even analyze the interference with the neighbouring producing and injection wells [2, 4].

First, looking at the **Fig. 11** which shows production history as well as the time points of sampling, it is noted that the water cut on average below 10%. The bottom-hole pressure, however, is very unstable, it ranges from 217 to 267 atm, and in January 2021, the pressure drops to 52 atm. The fluid flow rate before the well shutdown (August 2020) has a specific pattern, showing a decrease from 69 to 25 m^3/day from the commissioning. After a short-term well shutdown, the starting fluid flow rate gradually decreases and comes to stay at 22 m^3/day approximately in a month.

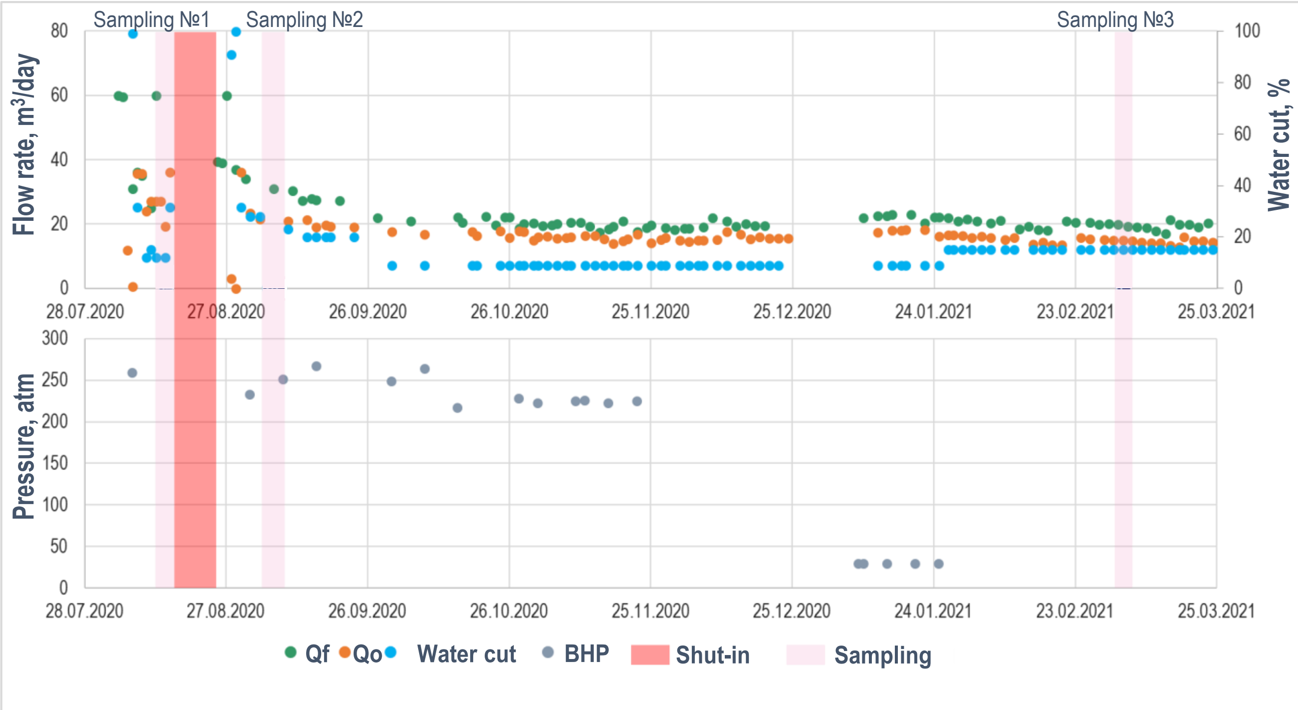


Figure 11— Production history of tested well

As noted earlier, fluid samples were taken three times: at the initial flowback period, which is characterised by transient flows, in September 2020 (the well operated a transition mode), and in March 2021 when the steady-state production mode was reached. In this regard, production profiling revealed that the initial recovery rate remained at the same level from the beginning of the well commissioning (**Fig. 12**). With the new level of zonal production surveillance, the end user can evaluate the decision made to drill and frac the lateral. A consistently high flow rate has been observed for a long time from the sidetrack lateral. This was determined by the fact that the hydraulic fracturing lead into expansion of the drainage area outbound the directional borehole, while the parent vertical hole was not subjected to any reservoir stimulation measures. After 6 months of well operation, the contribution of the sidetrack lateral shows gradual decrease from 81 to 66 %. This decline in production can be explained by several factors: first, the production is affected by the specifics of the target reservoir since the AC10.1-3 formation does not have high porosity and permeability (the average permeability is 1 mD) and, in addition, the deposit is highly heterogeneous. Secondly, the target formation area is closely drilled, which leaves the possibility of strong interference between the neighbouring producing wells open. In addition, the reservoir pressure maintenance system in the drainage area of the well does not balance a decreasing reservoir pressure, which also affects the dynamics of production. Such insights allow the end user to evaluate the economics of drilling the lateral for the future wells and get quick insights on any production interference from surrounding wells.

Thus, the results of production surveillance helped evaluate the multi – lateral completion strategy in the context of its contribution to the well performance; detect gradual depletion during long-term production profiling surveillance; and also make assumptions concerning the reasons for the gradual decline in the oil production.

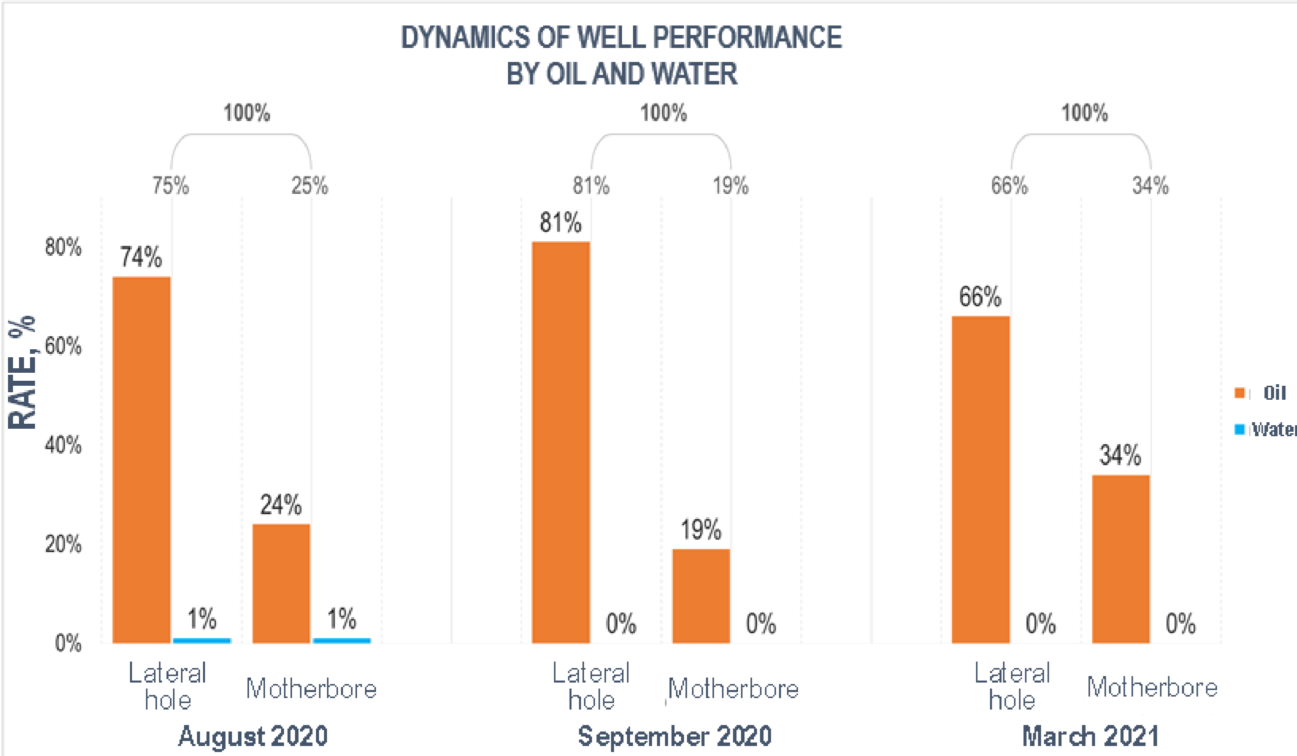


Figure 12— Tracer-based production logging

RESULTS AND CONCLUSION

The tracer-based systems for production profiling surveillance are an effective alternative to the traditional logging methods. Unlike traditional methods of logging in horizontal wells, this technology involving the use of marked proppant and downhole marker sleeves is intervention less, substantially reducing HSE and operational risks and substantially reducing the cost. It also reduces uncertainty of the results interpretation obtained in the case of a complex fluid flow pattern and low flow rates.

The production profiling operations performed in the multilateral well of the tested field yielded data on the operation of each of the laterals over time. The use of dynamic fluid production profiling surveillance methods enabled us to solve several key problems:

1) Offering the tools provide production surveillance in multilateral wells without deploying asset-heavy logging tools associated with significant operational risks and the possibility of obtaining ambiguous data.
2) Evaluating the operation effectiveness based on the flow intensification in the sidetrack.
3) Evaluating whether well reconstruction was performed efficiently, and a higher production was achieved by sidetracking, the basic production rate remaining unchanged

The implementation of the combined tracer coated proppant and tracer-based sleeve solution enabled quantification of the multilateral well performance, as well as the involvement of the remaining oil reserves of the parent borehole into production.

Based on the results of the works performed at the first multilateral well, it was decided to evaluate potential implementation of the same methodology in the future wells. In this regard, a promising application for the results of this work may be an assessment of the reserves recovery at the reservoir area, based on the accumulated average daily production for each lateral.

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