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An Alternative Tool for Production Logging in Horizontal Wells

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Abstract

From year to year, well drilling is becoming more technologically advanced and more complex, therefore we observe the active development of drilling technologies, well completion and production intensification. It forms the trend towards the complex well geometry and growth of the length of horizontal sections and therefore an increase of the hydraulic fracturing stages at each well. It's obvious, that oil producing companies frequently don't have proved analytical data on the actual distribution of formation fluid in the inflow profiles for some reasons. Conventional logging methods in horizontal sections require coiled tubing (CT) or downhole tractors, and the well preparation such as drilling the ball seat causing technical difficulties, risks of downhole equipment getting lost or stuck in the well. Sometimes the length of horizontal sections is too long to use conventional logging methods due to their limitations.

In this regard, efficient solution of objectives related to the production and development of fields with horizontal wells is complicated due to the shortage of instruments allowing to justify the horizontal well optimal length and the number of MultiFrac stages, difficulties in evaluating the reservoir management system efficiency, etc.

A new method of tracer based production profiling technologies are increasingly applied in the global oil industry. This approach benefits through excluding well intervention operations for production logging, allows continuous production profiling operations without the necessity of well shut-in, and without involving additional equipment and personal to be located at wellsite.

INTRODUCTION

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A new method of tracer based production profiling technologies are increasingly applied in the global oil industry. This approach benefits through excluding well intervention operations for production logging, allows continuous production profiling operations without the necessity of well shut-in, and without involving additional equipment and personal to be located at wellsite.

Determining the flow profile of oil, gas and water is a key task for creating an optimal production and development strategy, as well as for planning maintenance and water isolation operations in the well.

The historical analysis of the effectiveness of multi-stage hydraulic fracturing operations was based on geological and hydrodynamic modeling, taking into account petrophysical features, which includes analysis of reservoir characteristics such as porosity, permeability, mineralogy, and organic carbon content (TOC).

However, determining the inflow profiles in production wells is the basis for making technical decisions to maximize field development and optimize well design. In this regard, the interest of oil and gas companies in inflow production profiling technologies drives operating cost efficiencies and more frequent and accurate data

PROPPANT MARKING TECHNOLOGY

The heart of the technology are the quantum dots – small semiconductor crystals 2-10 nanometers in size. High-quality quantum dots are well suited for optical encoding applications due to their durable structure, broad excitation profiles and narrow emission spectra. The use of quantum dots in GEOSPLIT® technology allows to achieve high accuracy and efficiency of diagnostics. Quantum dots are used as part of marker-reporters. Marker-reporters are polymeric spherical particles containing quantum dots (Figure 1). Various combinations of six types of quantum dots inside those spherical particles allows to create 63 unique combinations - codes (or signatures) of the markers.

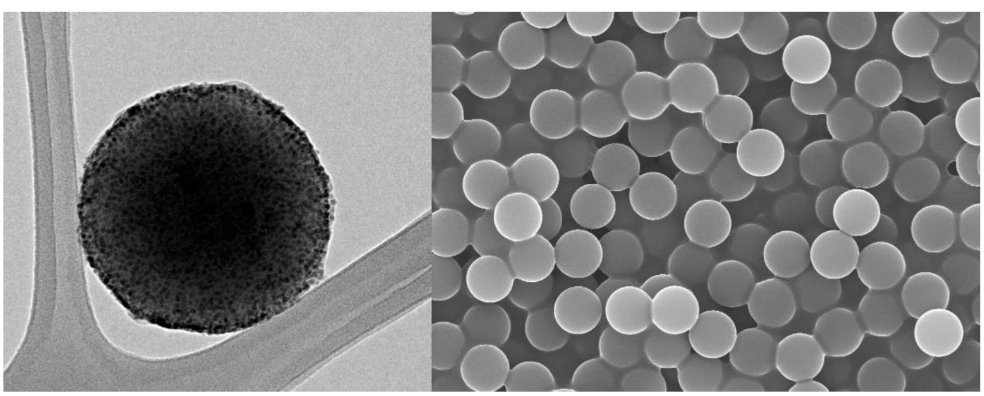

Figure 1—Microphotography of marker-reporters in transmission (left) and scanning (right) electron microscope.

Grains of marked polymer coated proppant consists with quantum marker-reporters are used to place material into the well. When conducting multi-stage hydraulic fracturing, proppant is pumped into each stage, marked with a specific code, the last proppant pack to ensure maximum contact when washing the formation fluid coming from the formation into the well. During the subsequent long period of the well performance, the marker-reporters are gradually washed out, in controlled manner, with water or oil and transported by the reservoir fluid flow to the well-head. Marker-reporters are released both in the hydrocarbon and aqueous phases of the formation fluid. After the completion of the multi stage hydraulic fracturing field operation and putting the well on production, periodic sampling of the formation fluid from the wellhead was carried out, after which the samples were transported to the laboratory for analysis

To estimate number of markers in the sample, specific sample preparation is used. This sample preparation involves different physical and chemical processes. It proceeds individual for oil and water phases. The main purpose of those treatments to collect markers from sample to deionized water without contaminations.

The main analytical tool for measuring and quantifying markers extracted from the samples – is flow cytofluorometric method. During flow cytometry, a sheath fluid hydrodynamically focusses the markerreporters suspension through a small nozzle such that only one particle passes the laser light at a time (Figure 2, left). A detector is placed in front of the laser beam such that it can capture the forward scattered light from the cells, while several detectors are also placed to the sides to measure the amount and intensity of fluorescent light that is different for each code.

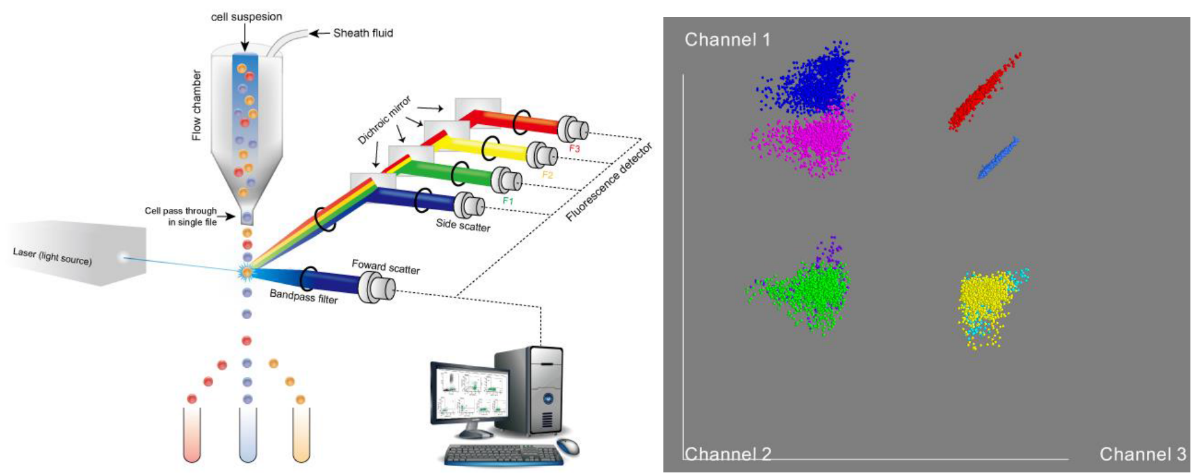

Figure 2—Principles of flow cytometry (left) and examples of data obtained from it (right).

The studies of multistage wells involve working with large amounts of data. For example, information on the identification of each marker-reporter is a point in a 25-dimensional coordinate space, so the manual calculation method will be very labour intensive. One of the key elements of the technology is using machine learning and neural networks methods to qualify and quantify data from flow cytometry. Consequently, the technology of marker diagnostics uses specialized intelligent software. It allows to provide comprehensive analysis and obtain high accuracy data in short period of time.

GEOLOGICAL FEATURES OF THE OILFIELD

The subject of research in this paper is the Jurassic sediments within the study oilfield recognized as one of the largest by the volume of recoverable oil reserves. Due to the river conditions of sedimentation and presumably meandering (wandering) channels, this oilfield is characterized by a lateral inconsistency in the thickness of reservoirs and shallowed intervals and the presence of compacted layers and coals that are extremely hard to incorporate into the wells planning.

The following properties define the target reservoir: porosity – 14.6%, average permeability from 3.8 to 6.4 mD. Reservoir pressure – 262 atm., saturation pressure – 80 atm., Reservoir temperature 80°C. Besides, the drilling practice and geological and physical information obtained from various studies showed the significant replacements of permeable rocks with tight rocks in the target reservoir.

DETERMINING THE IMPACT OF INJECTION WELLS ON HYDROCARBON PRODUCTION

Tracer diagnostics includes a comprehensive analysis of the obtained inflow profiles, geological features of the oilfield, information on drilling, hydraulic fracturing, production performance of the well in study, and the immediate environment.

During the multi-stage hydraulic fracturing, the marked proppant of various codes was injected at every stage of hydraulic fracturing performed in horizontal wells No. 1 and 2 (Figure 3) within the considered oilfield. Marker-reporters are controllably released from the marked proppant's polymer shell, when contacted with the target formation fluid during the well's operation and transferred to the surface with the fluid flow. The formation fluid was sampled in the wellhead during the operation of the wells in study and further analyzed. The inflow composition distribution profile for the water and hydrocarbon phases was constructed based on the data obtained.

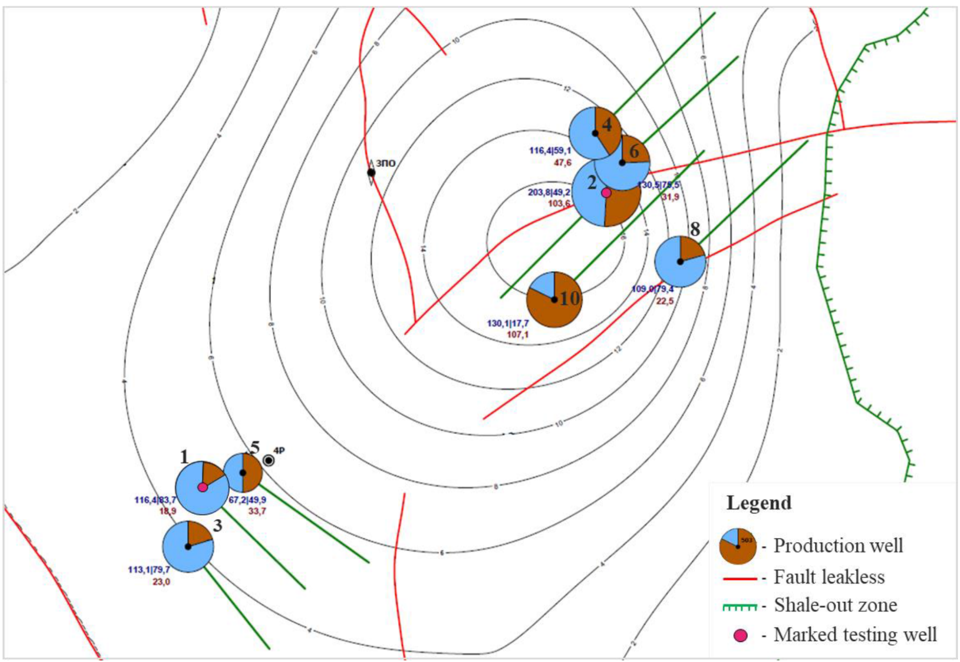

Figure 3—Bubble map of the current fluid sampling at the tested reservoir

Based on the analysis of the current sampling map, it should be noted that only production wells have been drilled in this area, and there is no reservoir pressure support system. Besides, the map shows the shale-out zone (replacement), and the geological boundaries are represented by impermeable faults. These features affect the oilfield development parameters and the formation of a reserves' drainage area.

Since the change in the well's performance affects the formation of the inflow profile, the information on the changes in the well's performance or significant changes in the phase composition of the produced product is considered when preparing the contribution to the intervals' operation. In this regard, the information on the wells' production history was analyzed.

After analyzing the historical data of well No. 1 (Figure 4) it was noted that the bottom-hole pressure dropped from 256 to 138 atm from the start-up, and pressure build-up cycle was observed to 228 atm. Then the well was started up 14.04.2020 and the pressure was dropped to 100 atm by 04.05.2020. Then it was a long pressure build-up period from 15.05.2020 to 13.07.2020. Following development showed a gradual drop in bottom-hole pressure to 20 atm with steady filtration conditions (by 27.08.2020).

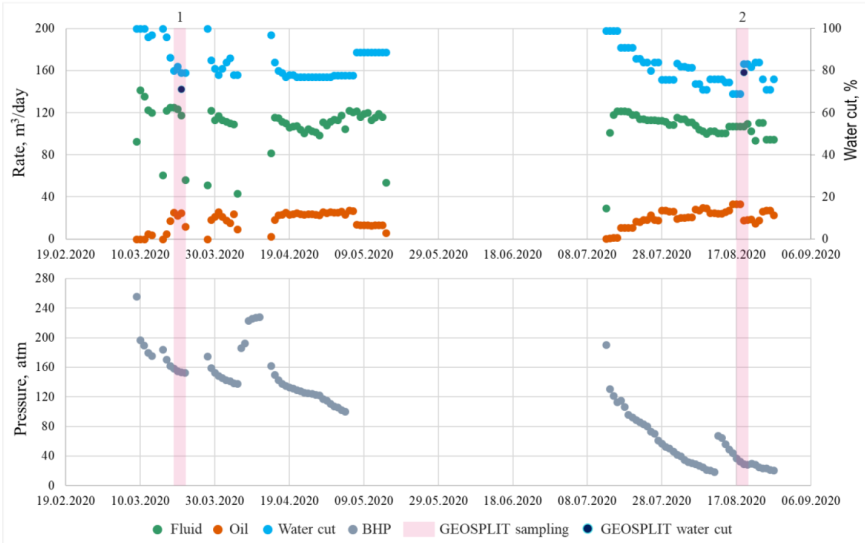

Figure 4—Production history of well No.1

The water cut has decreased from 100% to 77%, but then increased to 89% following the start-up after a short shutdown (05.05.2020). The gradual change from 100% to 69% in the water table in the extracted product's composition was observed when the well was launched on July 13, 2020.

The liquid flow rate drops from 142 to 109 m³/day. A decrease from 115 to 98 m³/day is observed upon restart after a short shutdown to get the PBU curve. From 29.04.2020, the liquid flow rate increased due to a change in the pump operating mode. The production level was 121 m³/day and slightly decreased as production progressed after a prolonged shutdown followed by the start-up.

According to the production history of well No. 2 (Figure 5), a pressure decreased from 191 to 57 atm since the start-up. The well was operated accompanied by a gradual increase in the pump frequency, while the production parameters were stable: the liquid flow rate is on average 213 m³/day, with a low percentage of water cut (13%).

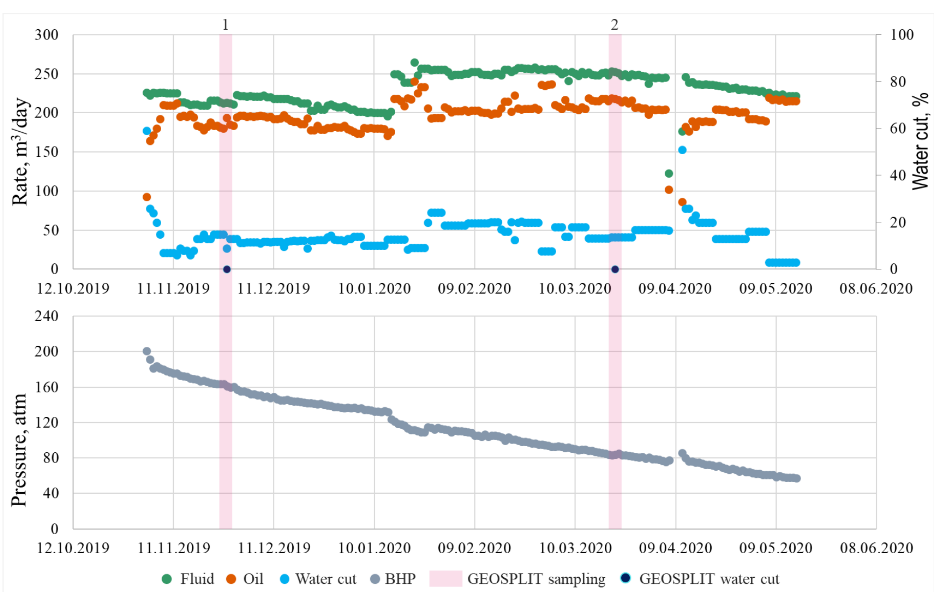

Figure 5—Production history of well No.2

Since January 15, 2020, the pump frequency has been increased from 42 to 51.5 Hz resulting in an increased flow rate, a slight "drop" of pressure, and increased water cut to 24%. The pump frequency was increased to 54 Hz at the end of February, while the liquid flow rate decreased by 10 m^3/day compared to the previous operating mode. A decline in production was observed following the well's planned shutdown in April. The gas-oil ratio from 27.1 to 32.1 m^3/t has slightly increased since the start-up. A consistent decline in production was observed after the second sampling.

In terms of production performance, there is a sharp decrease in bottom-hole pressure and fluid flow rate due to the lack of a reservoir pressure maintenance system in the study area. Besides, production is carried out with a pressure below the bubble point pressure, affecting the efficiency of development in the oilfield area in study.

PRODUCTION OF THE FORMATION DRAINAGE AREA BASED ON MARKER RESEARCH

In addition to analyzing the production history of every well under consideration, it is also necessary to incorporate the field studies results that display the fluid inflow intensity to represent the characteristics of the reservoir development using not just a single measurement but long-term monitoring. This approach was carried out by diagnosing the productive intervals' operation (fracture propagation areas) through marker monitoring of the inflow profile for a prolonged time.

Results of the multi-stage hydraulic fracturing efficiency study for oil and water performed in the well No. 1 (Figure 6) on 21.03.2020 shows that the most considerable contribution to the well's production is made by Port 1 (29%). The percentage of the Port 6 contribution to the well's production equals to 16%; Port 7 contributes to the well's production is at 15% from the total flow rate (8% of oil, 7% of water). Ports 2, 3, and 9 operate relatively equally.

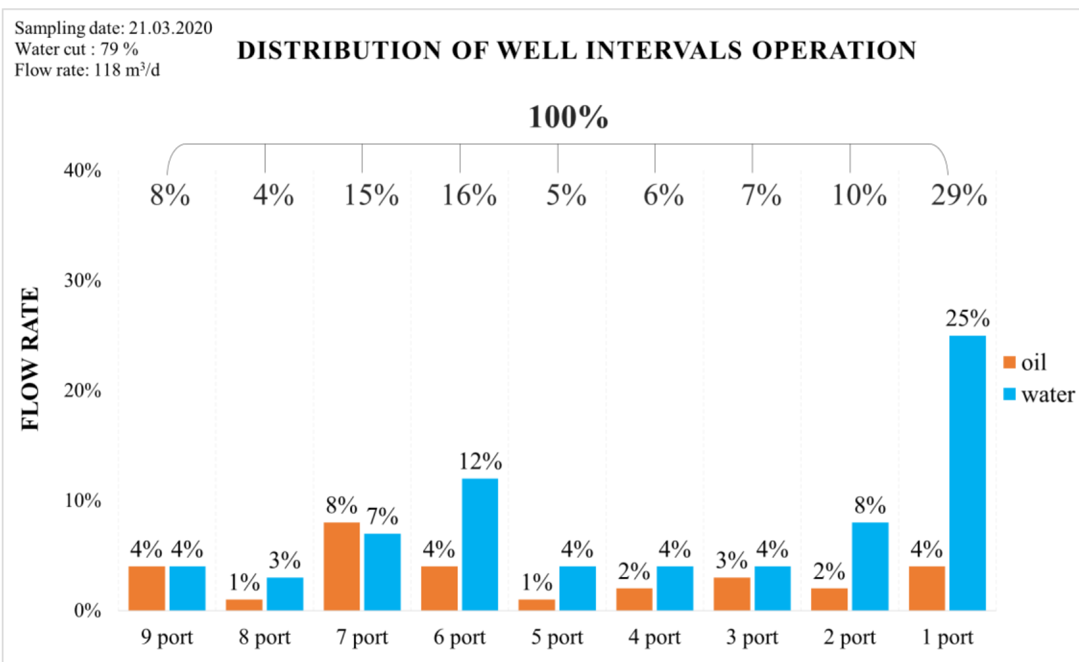

Figure 6—Flow rate distribution for oil and water according to the well No.1 ports, as of 21.03.2020

According to the results of marker diagnostics performed in the well No. 1, it is noted that almost the entire profile is slightly watered, and the water comes mainly from Port 1. Considering the direction of the well's horizontal section, it was believed that the fracture in Interval 1 could pass towards the overlying water-saturated interbeds.

The following conclusions can be made on the efficiency of the multi-stage fracturing ports of well No. 1 (Figure 7), based on the results of marker studies for 19.08.2020. Port 6 makes the most considerable contribution to the well's production - 29% (3% of oil, 26% of water). Port 1's contribution percentage reaches 22%; Port 4 contributes 19% to the total well production rate; and Ports 2, 3, 8, and 9 run at low rates.

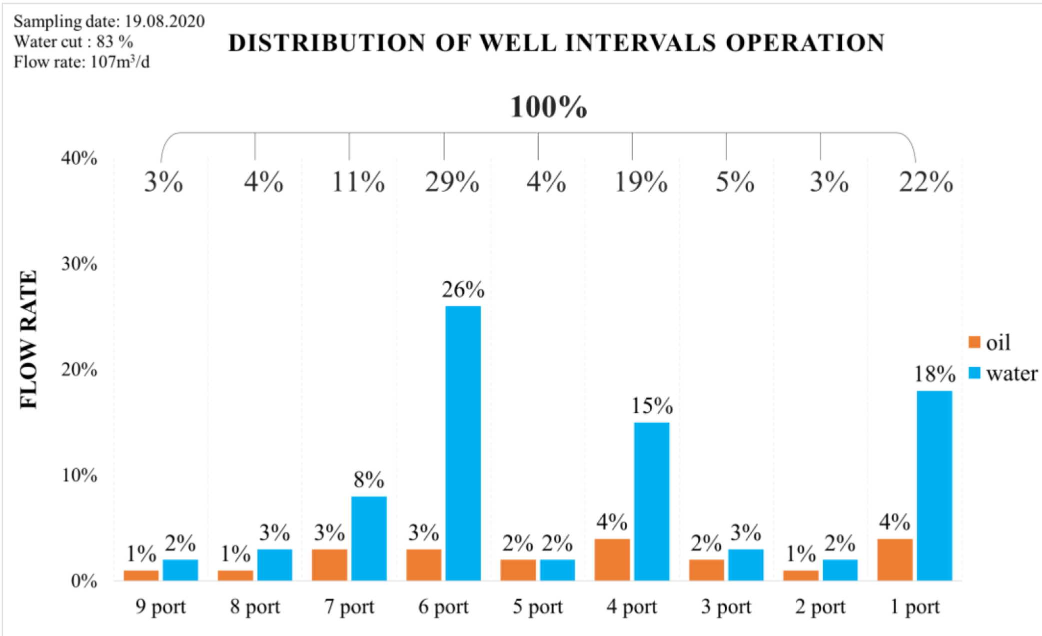

Figure 7—Flow rate distribution for oil and water according to the well No.1 ports, as of 19.08.2020

Ports 1, 4 and 6 are extensively involved in the operation, when comparing flow profiles of the well No. 1 for August and March 2020.

A high water cut of the extracted product was observed due to penetration into the overlying aquifers, based on the well No. 1 monitoring. Water comes mainly from Ports 1, 4, and 6. A drop in the reservoir's energy condition was noted during the well's survey. Production is carried out with a pressure below the bubble point pressure that may lead to adverse effects, contributing to an even more considerable decrease in fluid production.

Figure 8 shows the distribution of operating intervals over a period from November 2019 to March 2020.

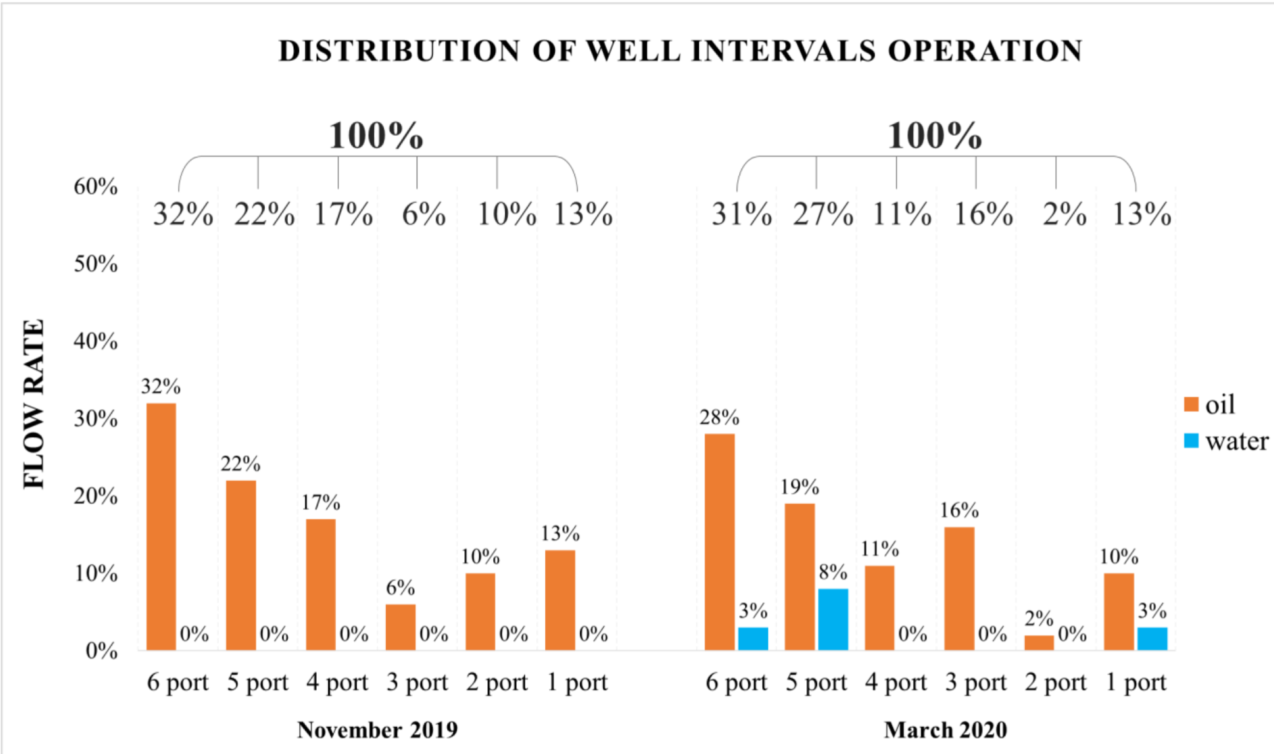

Figure 8—Distribution of the well No.2 intervals operation for oil from November 2019 to March 2020

Based on the well No.2 intervals operation analysis for November 2019, Port 6 makes the most considerable contribution to the well's production (32%). The percentage of the Port 5 contribution to the well's production reaches 22%. Port 4 contributes to the well's production at 17% of the total production rate. The contribution of Ports 1 and 2 to the well's production is 13% and 10%, respectively. The lowest contribution to the total well production rate is made by Port 3 (6%).

An insignificant change in the operation of ports was observed in March 2020. The Port 2 production reduced by 8%, while the contribution of Port 3 increased by 10%.

According to the marker diagnostics performed in the well No. 2, an intensive depletion of the reservoir was noted, mainly in the "heel" part of the horizontal wellbore. An insignificant decrease in production had been observed since April, presumably due to the lack of reservoir energy condition compensation. Given the systematic decline in production rates, it is recommended in the future to consider the possibility of transferring the immediate well to the reservoir pressure maintenance, and if any candidate wells are lack, consider the possibility of drilling an injection well.

RESULTS

Due to the lack of a reservoir pressure maintenance system in the study area, production rates are gradually declining, and production was carried out with a pressure below the bubble point pressure, which in turn reduces the operational efficiency during long-term development under the current mode. In the future, such an approach may lead to an adverse impact that contributes to an even more considerable decrease in production. Hence, a comprehensive study helped to identify the factors that affect the performance and approaches that contribute to an increase in the target reservoir development, which in turn would contribute to increased oil recovery within the area in study.

Using the long-term inflow profile monitoring, it is possible to evaluate production and refine the geological conditions (identify impermeable boundaries and highly conductive channels), when performing the diagnostics of every interval performance fluctuation in time, considering the changes in the produced fluid inflow composition.

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