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The Use of Novel Technology of Inflow Chemical Tracers in Continuous Production Surveillance of Horizontal Wells

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Abstract

The paper describes the use of new generation of inflow chemical tracer application at Salym Petroleum Development Upper-Salym oilfield as a part of Smart Field project. This kind of well surveying using indicators that allow the evaluation of the inflow composition for each hydraulic fracturing port in horizontal wells remotely, without any additional risky and costly downhole activities.

The new inflow chemical tracer technology is based on the use of nano-particle quantum dots, which give a level of high accuracy in quantitative analysis of fluid inflow. Markers, which are micromillimeter in size, are inserted into the polymer coating of the proppant. The technology involves the injection of marked polymer-coated proppant in the process of MHF (multi-stage hydraulic fracturing). Once the MHF is done, and the well is producing, the fluid samples are taken at surface and tested in a laboratory using machine learning software. Once the obtained data is interpreted, a flow profile of oil and water can be generated for each frac stage.

One of the main advantages of marker technologies is that they provide data over a long period of time, with a significant reduction in operating cost. It opens the door for new opportunities in terms of more accurate reservoir characterization and better hydrocarbon recovery. The key element of the technology is the use of specialized intelligent machine-learning software based on Random Forest algorithm to produce production flow profile.

The described methodology was used during the multi-stage hydraulic fracturing operation on oil wells 8105 and 8064 of Upper-Salym field. The volume of proppant injection at each stage was 20 tons, out of which 15 tons were of marked proppant containing a unique code for each stage. As soon as marked proppant has a contact with well fluid markers are emitted into fluid and sampling at the wellhead can be done any time when information required. The results of samples analysis are reports with graph showing quantitative distribution of water and oil production of each fracturing interval.

The new generation of inflow markers allows for continuous production, surveillance and quantitative analysis of oil and water phase from each fracturing stage. This enables better decision making to optimize the production and make better decisions for water conformance interventions. This surveillance method

does not require complex and risky well interventions or production shutdowns, making it substantially more cost effective than the existing conventional methods.

Optimization of oil production, remote monitoring for risks minimization, reduction of operating costs - all these are the results of the introduction of Smart Fields technology systems in the Salym group of oilfields.

Introduction

Due to traditional oil and gas reserve depletion, the share of unconventional, hard-to-recover oil and gas reserves is constantly expanding. The cost of horizontal well stimulation used to increase oil recovery rate using multi-stage hydraulic fracturing is significantly higher. Addressing this requires the implementation of new technologies and services to facilitate optimal drilling, completion and stimulation returns, thus shifting the focus to analyzing well productivity increases.

Historically, the analysis of multi-stage hydraulic fracturing operations efficiency was based on geological and hydrodynamic modeling that considered petrophysical features, including the analysis of reservoir characteristics such as 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 capital workover operations [1].

At the same time, there is an emerging trend both in Russia and abroad of using various tracer-based study methods to obtain data on the horizontal well intervals operation. 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, thus providing new opportunities for well and reservoir management and increasing the cumulative production.

Tracer-based production logging technologies involve the placement of flow indicators along the horizontal well. When they come into contact with the target formation fluid (oil, water, gas), the tracer particles are injected and move along with the flow. Fluid samples are taken from the wellhead and analyzed in order to identify the number of tracers of each code. Data on the oil and water inflow distribution over each interval are interpreted based on the test results [2].

Geological specificities of Upper-Salym oil field

The Upper-Salym oil field is located in the Nefteyugansk district of Khanty-Mansi Autonomous Area of the Tyumen region. The field development is a very complex project as there are no effective operational best practices [3]. The oil deposits are not controlled by common geological features and do not contain any free water, so in order to find a reservoir, with or without using well interventions, most of the geological risks and uncertainties would be required to be eliminated. The main reason is that the reservoir units behave unpredictably. Indeed, two wells can often be drilled very close to each other in similar geological conditions and produce completely differently. Developing reliable geological models is a major challenge faced by geologists when planning a cost-effective field development. During the last three years Salym Petroleum Development carried out extensive studies to reduce the geological uncertainties of developing the Upper Salym reservoir. The study enabled SPD specialists to define the requirements for surface infrastructure and oil recovery methods [4].

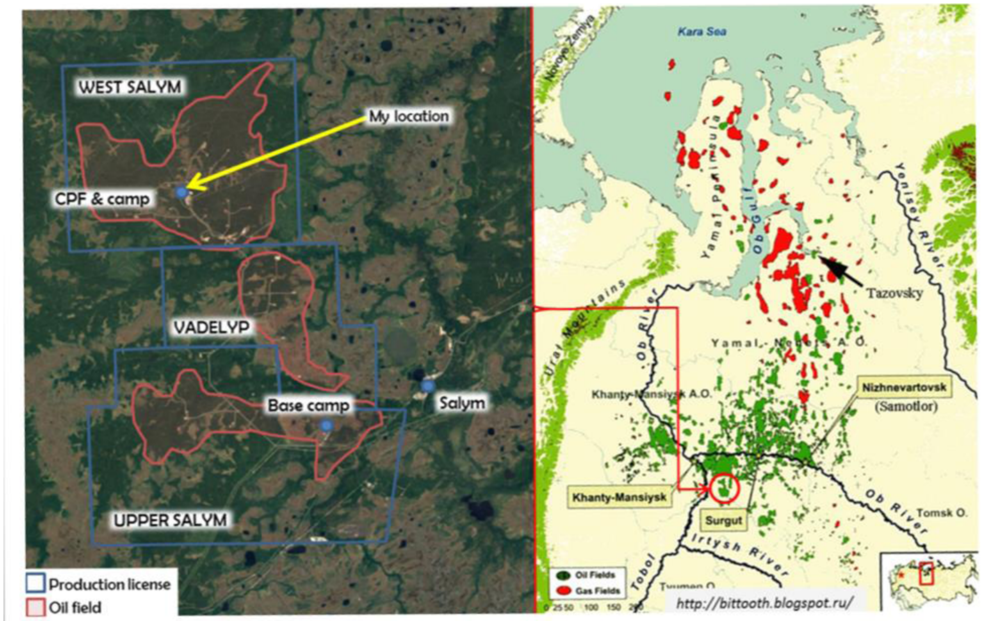

Figure 1—Location of the Verkhne-Salymskoye Oil Field

Smart Field Technology implementation at Upper-Salym oil field

Smart Field technology is a part of the major project in SPD on well and reservoir management, focusing on the development of a comprehensive approach to field development. [5].

As part of "Smart Fields" project, for the first time in Russia, the oil producing company has implemented an innovative marker-based technology, which allows for remote monitoring of the entire well stock of the Salym oilfield.

Traditional well logging technologies limitations

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 [6]. 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 well production logging usually involves two basic methods for delivering downhole equipment, which involve flexible tubing systems and downhole tractors. So, in most cases PLT operations in horizontal wells require drilling of MFrac ports and, consequently, are associated with technical difficulties, such as the risk of downhole equipment getting stuck or lost in the well. Besides traditional logging methods imply mobilization of human resources to a field to perform the services which cause an additional HSE risks.

Moreover, conventional logging operations can be performed only in medium and high-production wells, and their operation can cause alterations in the horizontal well formation fluid flow rate thus leading to ambiguities and difficulties in data interpretation due to multiphase flow. Moreover, the cost of such logging operations is very high.

Production logging methods without well intervention have been steadily growing in popularity, such as the technology of well production logging using markers (chemical tracers) in the global oil industry. Significant advantages of these methods include the elimination of well intervention operations during production logging, the ability to obtain data on the selective inflow of water and liquid hydrocarbons for each interval in the remote monitoring mode over a long period of time, and no need of well shut-in that involves expensive equipment and numerous personnel.

Marker-based well logging technology without downhole operations

Marker-based well logging technology is based on the application of quantum marker-reporters, which precisely indicate the formation fluid inflows [6]. This technology requires the placement of markers along the horizontal well or in the reservoir using several alternative options:

1. application of marked polymer-coated proppant pumped during multi-stage hydraulic fracturing;
2. placement of marked composite materials in special downhole cassettes, integrated to well completion equipment.

Option 1 is the method under discussion in this paper, which has been implemented in the Upper-Salym field. The method of including markers in the polymer coating of proppant for well production logging has highly accurate correlations to the formation fluid inflow. Marker-reporters are polymer microspheres (Figure 2 and 3) doped with a set of quantum dots. Combinations of quantum dots with different spectrums in one marker are assigned as a particular code.

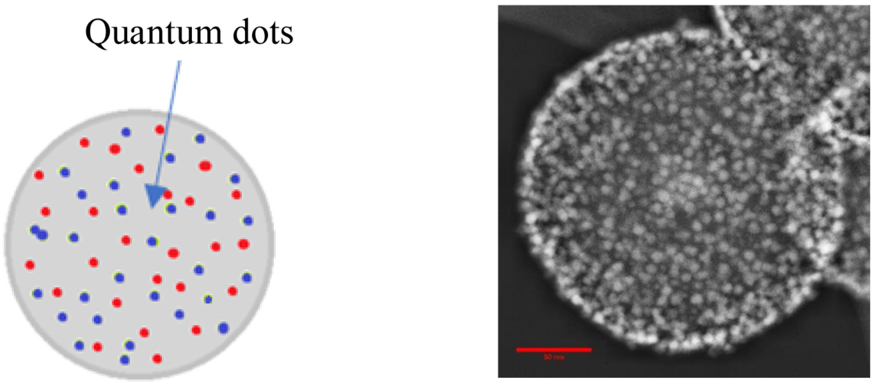

Figure 2—Spherical Marker. Left - a visual demonstration of the composition. Right – a picture from the electronic microscope.

Figure 3—Quantum Dots fluorescence in the visible spectrum

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 [2, 5]. Figure 4 demonstrates the grain of the marked proppant where the markers are inside the polymer coating. A great number of marker-reporters are packed into the proppant polymer coating.

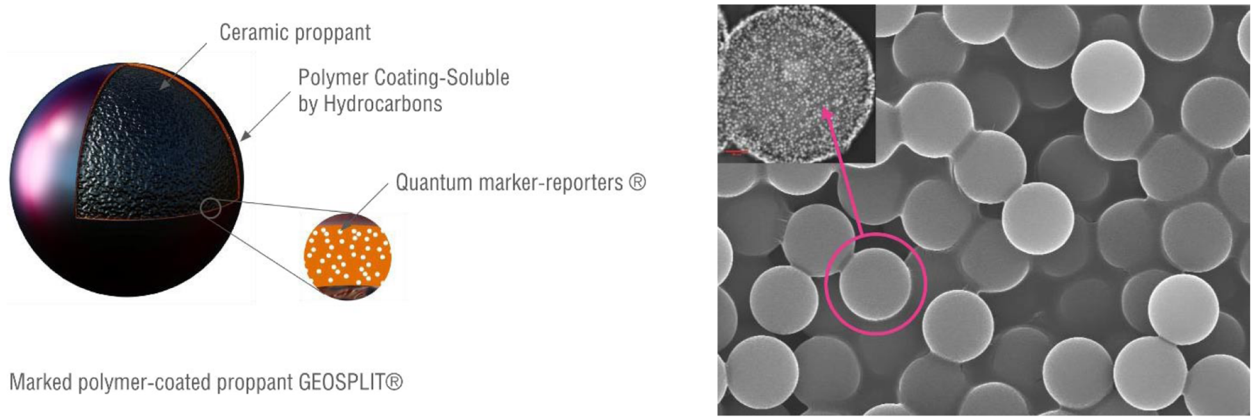

Figure 4—The grain of polymer-coated proppant with quantum marker-reporters

To keep the fractional composition of the proppant at the same level, the thickness of the polymer coating does not exceed several tens of microns. By being in contact with the target formation fluid (gas, water or oil), marker-reporters are freed from the polymer shell of the proppant and moved by flow to the wellhead. The markers, being captured by gas, water or oil, have no force to overcome phase boundaries due to their small size and physicochemical inertness.

During the multi-stage hydraulic fracturing job, marked proppant with a specific code unique to each stage is injected into each stage, with the last proppant pack (near-well bore). The concentration of 'marked' proppant is higher in the tail of each pumped stage to ensure the proppant pack at the near wellbore contains a higher density of chemically marked proppant to increase potential contact area and thereby the chance of flowing formation fluid/gas coming into contact with them.

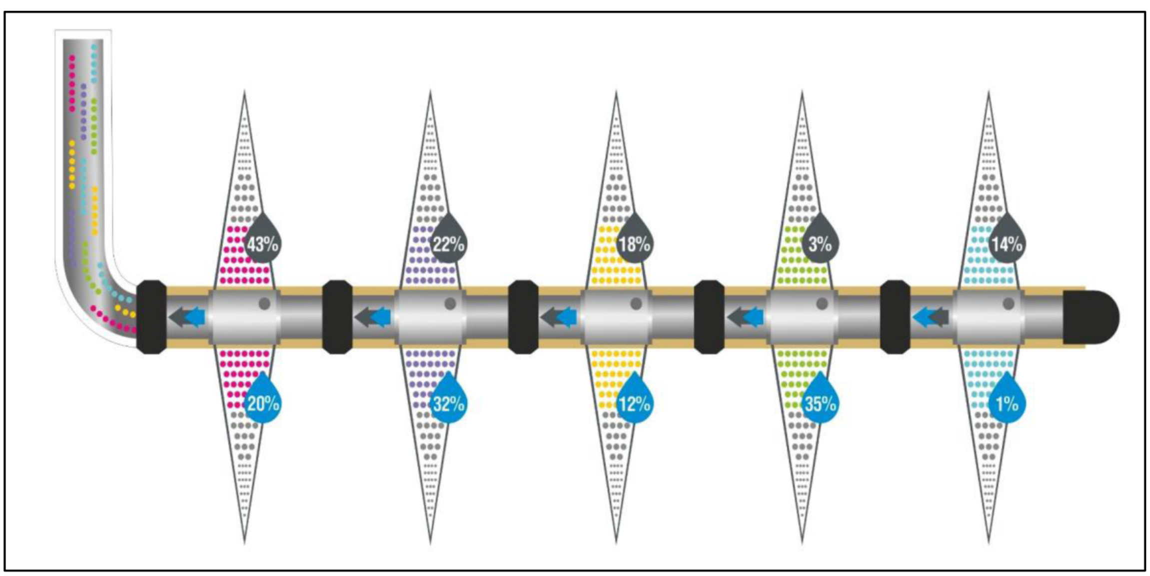

Figure 5—Multi-stage hydraulic fracturing scheme with the marked proppant at each stage

Polymer coatings have three types of responsiveness, oleophilic, hydrophilic and gas sensing. An oleophilic coating focuses on interaction with liquid hydrocarbons, while a hydrophilic coating focuses on interaction with water, gas sensing coating are based on an ablation process.

To register a strong signal from each signatures the technology requires the injection of 15 tons of marked proppant into each stage of the hydraulic fracturing job. Depending on the required objectives, the pack contains proppant in different ratios of hydrophilic, oleophilic and gas sensing. Unlike solutions based on the use of natural fluorophores, quantum dot technology involves the synthesis of an unlimited number of codes. At the moment, the oilfield services company operates with 63 marker codes that meets the needs of the market. Each marker code can be used for any type of fluid. Therefore, it is possible to mark more than 60 analyzed intervals in a single well. Moreover, an unlimited number of production logging operations can be conducted while the well is under monitoring period.

Methodology of markers identification in formation fluid samples

When the hydraulic fracturing operation is completed and the well is in production mode, formation fluid samples need to be taken from the wellhead, they are then analyzed in a laboratory based process. Markers in the samples are identified by an analytical hardware-software process (Figure 6). In this process, a stream of small-diameter liquid is formed. Markers line up in a row by the flowing fluid, a laser irradiates it and a scattered light signal is measured, both directly and laterally. This individually identifies the marker of each code. Therefore, through the analysis of the total volume of samples it is possible to identify the quantitative ratio of the fluid phases in the total flow rate.

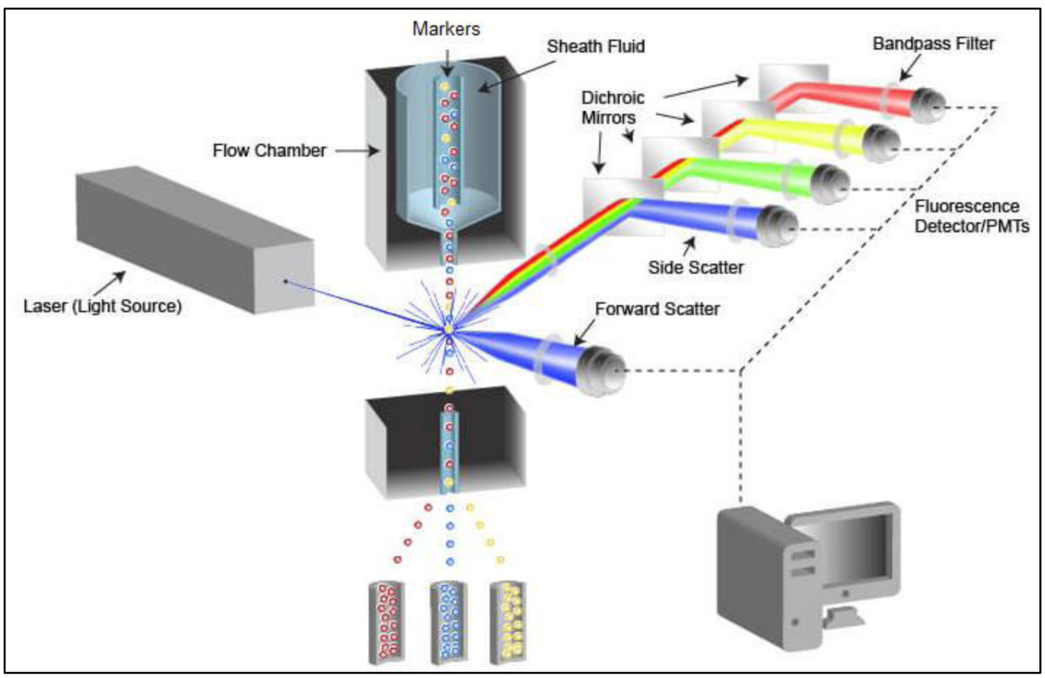

Figure 6—Analytical hardware-software complex based on the method of flow cytometry

The important part of this technology is the use of artificial intelligence and machine-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 at 15-dimensional space of coordinates (15 detection channels), so any manual calculations will be extremely laborious. Unique intelligent software was developed to involve machine-learning with the "Random Forest" algorithm (Figure 7).

Figure 7—The random forest algorithm

Random forest consists of a large number of individual decision trees that operate as an ensemble. Each individual tree in the random forest spits out a class prediction and the class with the most votes becomes our model's prediction. The fundamental concept is - a large number of relatively uncorrelated models (trees) operating as a committee will outperform any of the individual constituent models. The trees protect each other from their individual errors. While some trees may be wrong, many other trees will be right, so as a group the trees are able to move in the correct direction.

The combination of precisely adjusted hardware and software processes provides a high accuracy in data counting in a short timeframe, unlike the manual counting with the lower quality due to limitations of operating with big data.

Fracture modeling

An 8-stage multistage hydrofracturing was planned for formation BS8 in well № 8064 (pad 82) of Verkhne-Salymskoye field. The BS8 formation is represented by interlayering of sandstones and siltstones with a total thickness of 19 m, permeability ~ 10 mD, average porosity 17%, and temperature 115 °C. The design of the multi-stage fracturing program was considered with a crosslinked gel and flow rate of 2.6 m^3/min (max concentration – 1200 kg/m^3), volume of a buffer stage is 33 m^3, a total volume of injected fluid is 140 m^3 and following proppant sizes: 16/20 – 10 tons, 12/18 – 5 tons and marked proppant with fraction 12/18 – 15 tons.

In general, the hydrofracturing operations were carried out as planned, without complications, all proppant mass was placed in the reservoir according to design. The geometry of the hydraulic fracture and proppant tracking for one stage is shown in Figure 8. |The maximum concentration of marked proppant was supplied at the final stage of the hydrofracturing operation. The purpose of pumping marked proppant at the final stage is to maximize the contact area of the formation fluid flowing into the well.

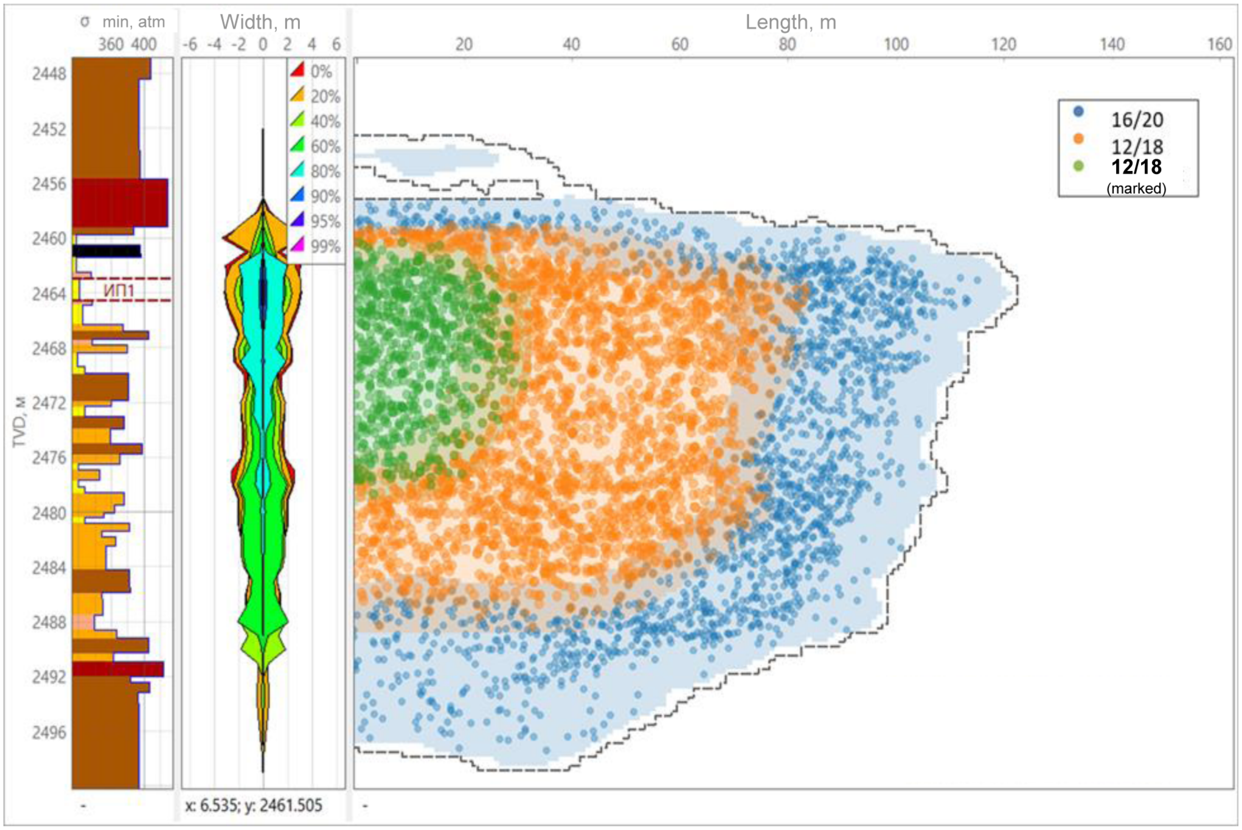

Figure 8—Geometry of the fracture and proppant tracking for stage №4

Results of interval productivity analysis, using a marker-based diagnostic system

In order to carry out a production capacity dynamics analysis of the target facility BS8 two horizontal wells of 600-700 meters long were chosen to be injected with marked proppant. The integrated approach has been applied to the analysis comparing the inflow profile with geological and reservoir data, including production history of the well under study.

Well 8105

The samples of the fluid in the well under study were taken in accordance with a dedicated schedule considering its performance peculiarities. The 15 samples were taken during five days (three times per day). This sampling frequency ensures sufficient analytical response for a proper analysis followed by an evaluation of inflow profile both in quality and quantity terms.

The interpretation of data with a selection of the most representative samples from the entire volume was carried out after special cytofluorometry analysis. A similar procedure is necessary to minimize ambiguities in the calculation of the inflow profile of the well. To interpret the results, it is also necessary to take into account the well process flow pattern at which sampling was carried out. This factor can change the profile significantly when averaging the inflow rates of each running interval. In this case all surveys with 5 sets of fluid samples taken can be roughly divided into 2 parts.

The first period (April - October 2019) differs by active production with increased pressure drawdown. There were two short-term build-ups while production period that may have an effect on filtration flows in bottom hole zone of BS8 formation. It is observed after quantitative estimation of the inflow profile. The second one differs in production at a lighter draw-down, an insignificant increase in bottom-hole pressure that are correlated well with fluid rate change is also in evidence. It should be noted that starting with

June 2019 the operation was carried out at borehole pressure below saturation pressure followed by gradual increase in gas/oil ratio (GOR). With high volumes of liberated dissolved gas there is a possibility of field blowdown degradation in the near-field area of a reservoir (this effect is observed by gradual increase of mechanical skin factor). The water cut of the produced media remains at 80% level on average during the survey.

The results of inflow profile assessment correlated well with the well historical events and give an insight into the performance of the production interval in the area under discussion.

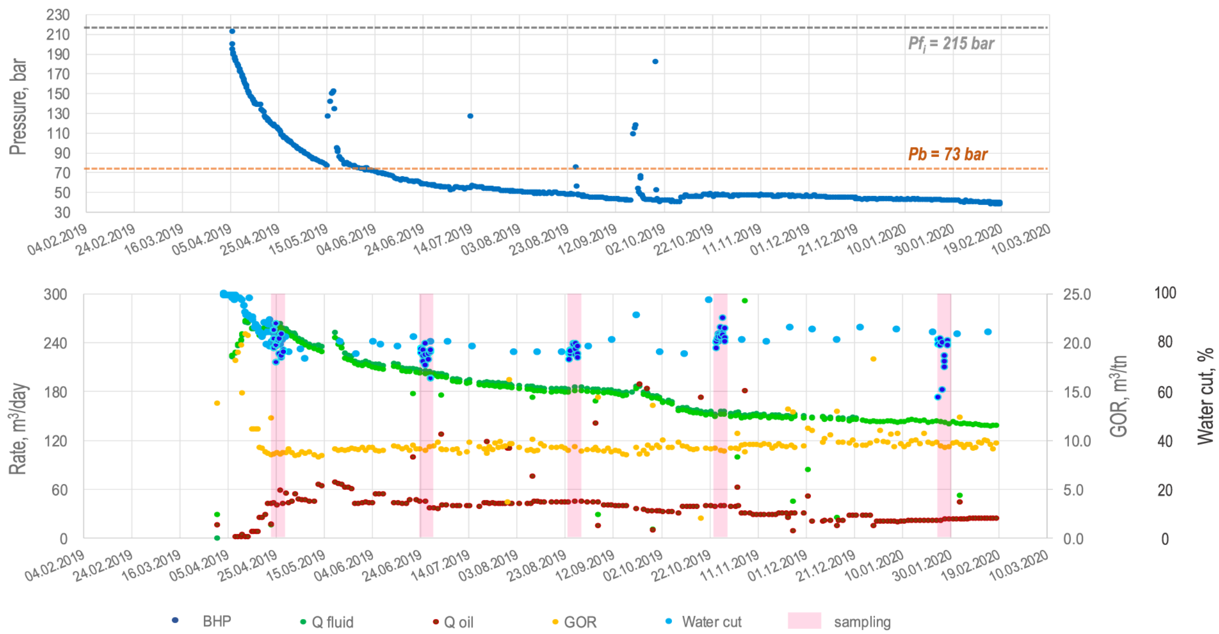

Figure 9—Well 8105 operation history for the period of April 2019 to February 2020

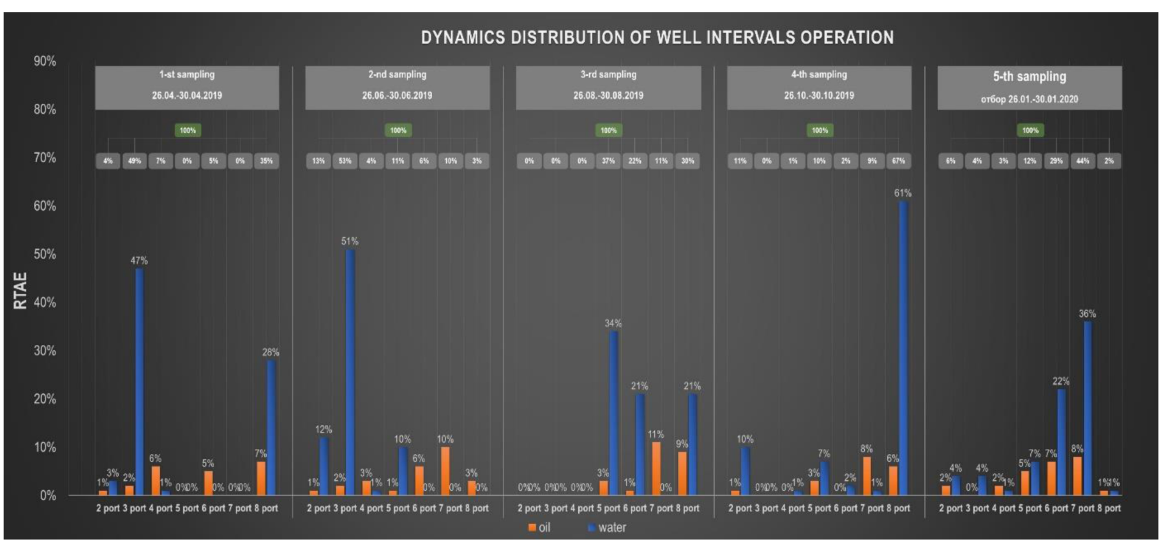

Figure 10—Well 8105 operation history for the period of April 2019 to February 2020

The comparative evaluation of producing interval performance according to the results of interpretation of five series of samples shows that at steady-state starting with April 2019 the bulk of water comes from the lower portion of the horizontal well (ports 5, 6, 7, 8), this area is marked by intensive field blowdown. The results of the inflow profile assessment for 6 months (from August 2019 to January 2020) of monitoring shows that the upper part is slightly engaged in operation, the ports 1, 2, 3, 4 total to 11-13% inflow of total liquid rate. This is subject to the fact that there is not enough compensation of energy stated from injection ringing of the field under discussion for effective field blowdown. There are also several producer wells in close proximity that may have a strong impact on well 8105 performance. This in turn requires a certain exploitation process optimization and also selection of the proper patterns that would increase oil production.

Well 8064

The survey scenario is the same for this well: the fluid sampling schedule has been designed before monitoring. The samples were also taken over 5 days, three times per day in a half an hour range.

Based on the results of flow cytofluorometry sample analysis in accordance with the above mentioned approach, the combined interpretation with quantitative evaluation of the inflow profile was carried out. Firstly, the history of the well No8064 has been examined highlighting process and reservoir effects that are shown in bottom-hole pressure (BHP) and produced fluid rate historical data. At close consideration 2 short-term build-ups may be singled out that imply rapidly and continuously formation pressure decline (Figure 11).

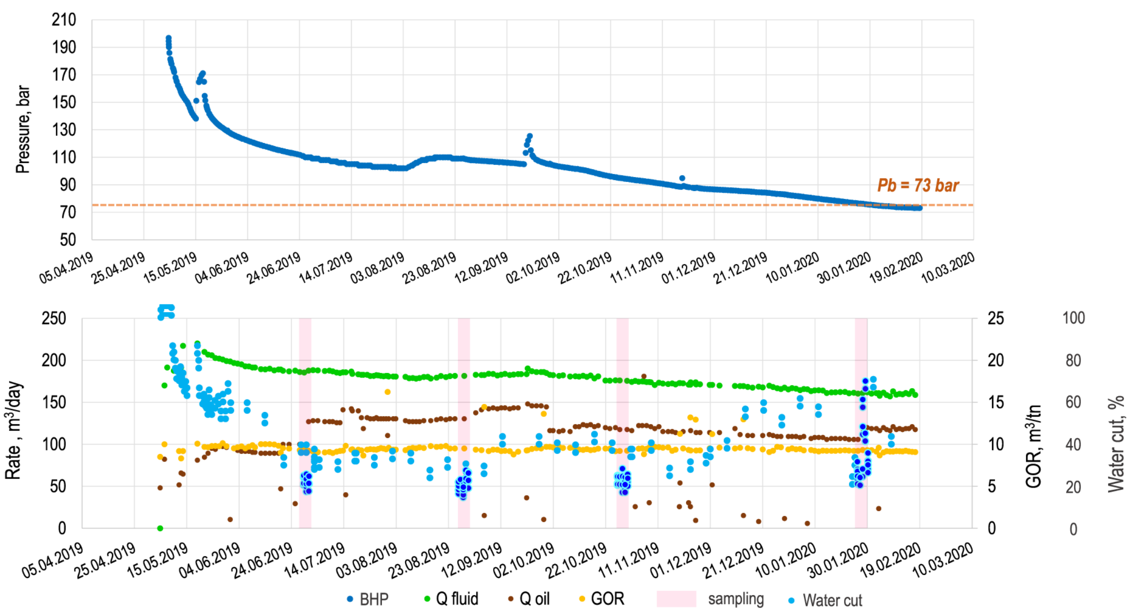

Figure 11—Well 8064 operation history for the period of April 2019 to February 2020

Insufficient pressure support from nearby injection well stock has also impacted the pattern of change in the production profile. The fluid rate declines steadily from 220 to 160 m³/day. Throughout the survey the process flow pattern has been changed (draw-down reduction) finally resulting in filtration flow redistribution during production.

The analysis of the first series of samples shows a relatively even production capacity on each interval. The following samples sets demonstrate the change in horizontal well operation: reduced draw-down pressure resulted in gradual deactivation of ports 3 and 5. However the bottom part keeps working at high-intensity. Starting with February 2020 the bottom-hole pressure was reduced below saturation pressure resulting in fluid filtration degradation thanks to gradual increase of GOR. In accordance with the assessed inflow profile for the given period it is apparent that alongside with ports 3 and 5, port 6 has also lowered production capacity (Figure 12). This may also have a critical effect on other intervals in the future. As such it is necessary to choose the process flow pattern and control performance parameters of the well under study during further production.

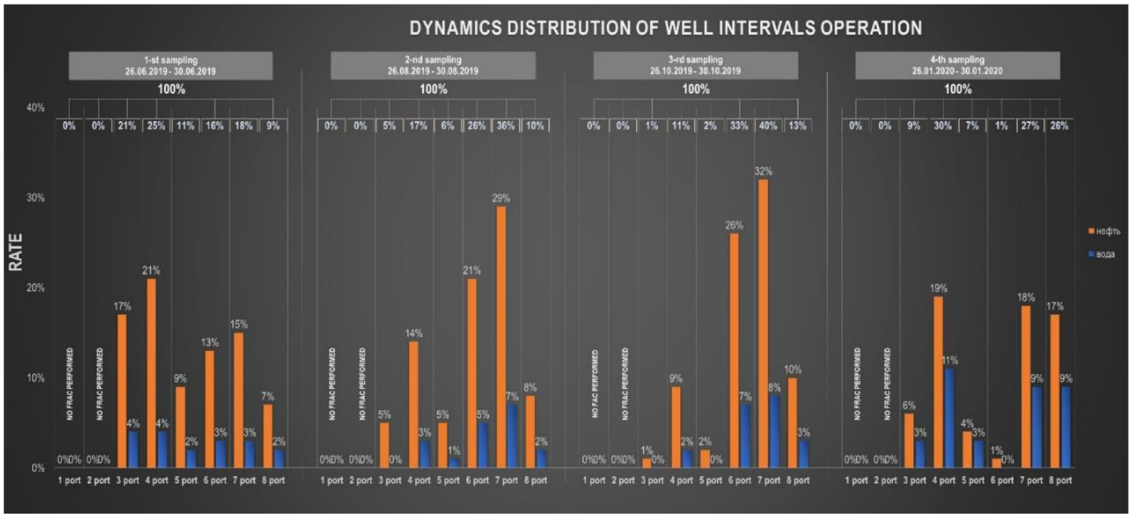

Figure 12—Well 8064 operation history for the period of June 2019 to January 2020

Conclusion

The analysis presented carried out by means of marker technologies of inflow profile assessment allowed the trends in BS8 facility performance both in fluid composition quality and integral (well-head) rate index to be quantified. Two wells located in different areas of one field show a certain production intensity of a reservoir that may be bound to its performance pattern. Certain features showing interference with producing ringing proving presence of good pressure communication in the target reservoir. These results have great practical importance as with information of a performance distribution nature along the well, allows the well management to be optimized for further production, not only in one area but the entire field.

Therefore, the marker technology has proved itself as the effective tool in the field developlment, enabling the solving of standard problems with well logging and cuts the survey expenses significantly, avoid risks of HSE due to minimal attendance of the field personnel and the reduced need for driving instruments to a well It also enables operators to carry out well monitoring off-line using innovative methods of machine learning. It is safe to call the technology a next step to implementation of the "Digital Field" project relating to well surveying.

References

1. Rudnitsky S.V., Ananenko S.V., Kravets V.A. Marketing research of the Russian multistagehydraulic fracturing monitoring market. ERP Eastern European LLC, 2017. Barber E., Shippe M., *Neftegazovoe obozrenie*, 2007–2008, URL: https://www.slb.com/~/media/Files/resources/oilfield_review/ors07/win07/optimizing.pdf
2. Complex studies of tracer-based technologies in reservoir conditions / M. Dulkarnayev, K. Ovchinnikov, A. Guryanov, A. Anopov, E. Malyavko. SPE-192564-RU, report at the AnnualCaspian Technical Conference and Exhibition SPE, October 31 – November 2, 2018, Astana, Kazakhstan.
3. Salym Petroleum Development N.V. official site, URL: https://salympetroleum.com/
4. URL: https://rogtecmagazine.com/wp-content/uploads/2014/09/06_SPD_Smartfields.pdf
5. Rudnitsky S.V., Ananenko S.V., Kravets V.A. Marketing research of the Russian multistagehydraulic fracturing market. ERP Eastern European LLC, 2017
6. A.V. Guryanov, A. Yu. Katashov, K.N. Ovchinnikov. Production logging with the application of quantum dots tracers. – *Coiled tubing times*, 2017, No. **2** (60), P. 42–51