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Increasing the Accuracy of Production Allocation from Each Reservoir: Integrating TAML-1 Well Construction Technology and the Dynamic Quantum PLT Method in the Field NP

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Abstract

One of the largest oil fields on the Yamal Peninsula, the Field NP is characterised by complex geological settings. Massive gas caps pose significant complications to the extraction of large oil reserves occurring immediately below them. In such conditions, new approaches are required to achieve economically viable production. This involves well construction based on a fundamentally new configuration and the use of new technologies.

When drilling wells that penetrate more than one target reservoir, the legislation requires performance monitoring and separate production allocation for each reservoir.

The article dwells on the first case of separate production allocation in a multilateral well completed with the TAML-1 solution. The well penetrates two reservoirs with different porosity and permeability, using the dynamic quantum PLT technology. The well was drilled taking into account the properties of the impermeable top of one of the reservoirs.

Introduction

Proven in 1964, the large HC reserves of the Field NP on the Yamal Peninsula remained beyond full-scale development for a long time due to the complex geological settings and non-existent production facilities.

The first wells drilled during field exploration did not penetrate the productive reservoirs and were seen to be water-flooded. Other wells drilled in the dome of the reservoir structure and penetrating the reservoirs at higher elevations showed gas inflows rich in condensate. After tests, the Field X used to be considered a gas condensate field at the beginning. The presence of oil rims was forecast since some slight signs of oil were detected when testing some wells.

Commercially viable reserves of oil, gas, and condensate are mainly observed in terrigenous deposits of the Lower Cretaceous and Jurassic strata at depths from -1,850 to -2,020 m.

The rocks are mainly composed of marine deltaic sandstones interlayered with clays and dense carbonated interlayers with permeability from 1 to 30 mD. Coal deposits of continental origin can be also found in the Upper Jurassic rocks.

The eastern area is marked by numerous tectonic disturbances that lead to high-amplitude layer displacements ranging from single- to double-digit meter distances. Near the top, all productive reservoirs are enclosed in a gas cap with large commercial reserves of natural gas (Figure 1).

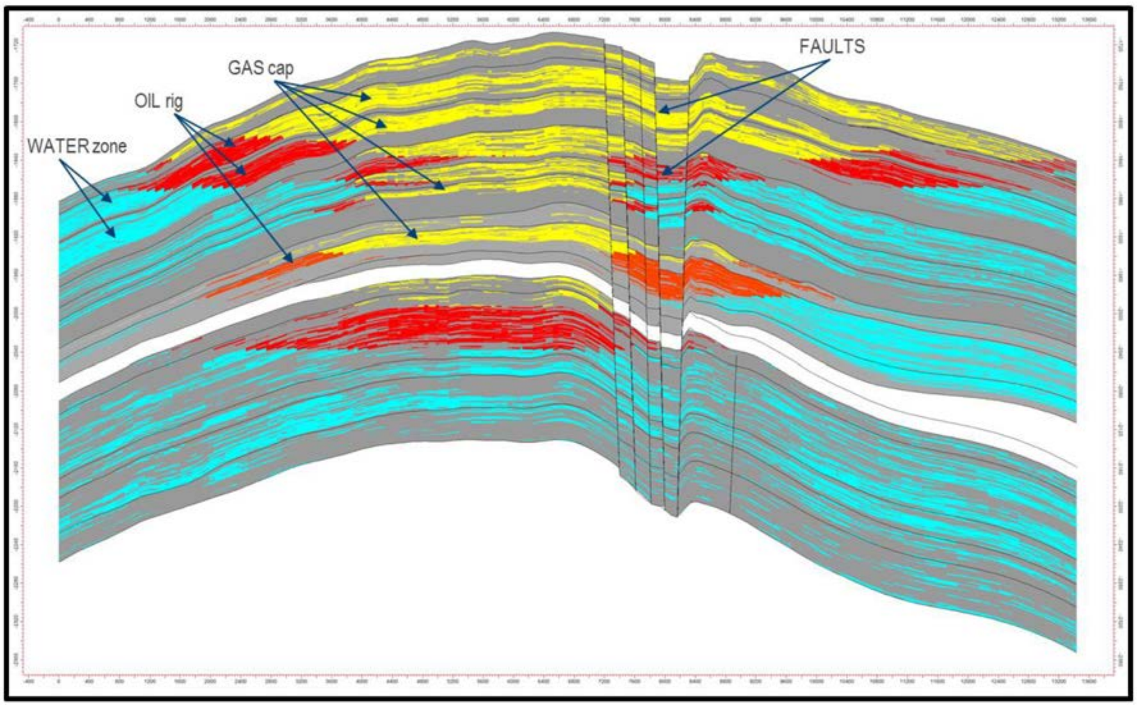

Figure 1—Cross-section of the dome structure of the Field NP

At the beginning of the project, the oil rim development was mainly targeted at productive reservoirs with a high permeability of 25—100 mD and with a reservoir thickness up to 35 m. However, the main amount of the reserves in the formation is concentrated in Upper Jurassic deposits up to 25 m thick characterised by a high degree of vertical geological heterogeneity, reservoir compartmentalisation, and permeability not exceeding 5 mD, as well as in thin Lower Cretaceous formations with a thickness of up to 5 m and a permeability of 10—15 mD.

The development of such complex fields requires new approaches to drilling, exploration, and field development since conventional solutions are uneconomical due to the high cost of drilling technologies. In the current economic settings, such oil and gas production is not economically feasible.

Traditionally, the wells drilled in the Field NP have a multiple-string configuration, with the production string run into the top of the target productive reservoir. The horizontal section is from 1000 to 2000 meters long.

In 1998 a consortium of companies involved in the development of multilateral well construction technologies introduced the TAML (Technology Advancement of Multilaterals) classification. According to it, all multilateral wells are divided into six levels of complexity in terms of the main trunk and a branch junction design. The choice of the TAML level depends on the requirements for sealing of wellbores and their junctions, which are predetermined by the geological conditions.

For purposes of separate production allocation from each wellbore the dynamic marker-based production logging technology (Quantum PLT) is applied. The essence of the method lies in a single-operation placement of high-precision inflow indicators in each wellbore and subsequent formation fluid sampling for analysis in the laboratory with data interpretation. Multiple production logging surveys do not require the well shut-off, operation mode changes and any further well intervention.

Peculiarities of well design

Along with traditional wells, multilateral wells have been extensively drilled in order to expand the drainage area. By the end of 2021, 75 multilateral wells were completed using the TAML-1-level solution. Each well had from two to five cased laterals, with all the laterals located within one productive reservoir.

Given the vertical heterogeneity and the relatively high costs of well drilling, there is no economic viability in drilling individual wells in order to bring low productivity areas into production. The multi-disciplinary team of the operator company was faced with the task of increasing the oil recovery factor while finding the most cost-effective solution. After analysing the existing multilateral well construction technologies, it was concluded that using the TAML 2–5 level technologies would be unreasonable due to their high cost. It was decided to develop a custom solution. As a result, a conceptual design was developed for multilateral well completion using the rock properties in the reservoir top interval and a set of swell packers to create an isolated branching point (Figure 2).

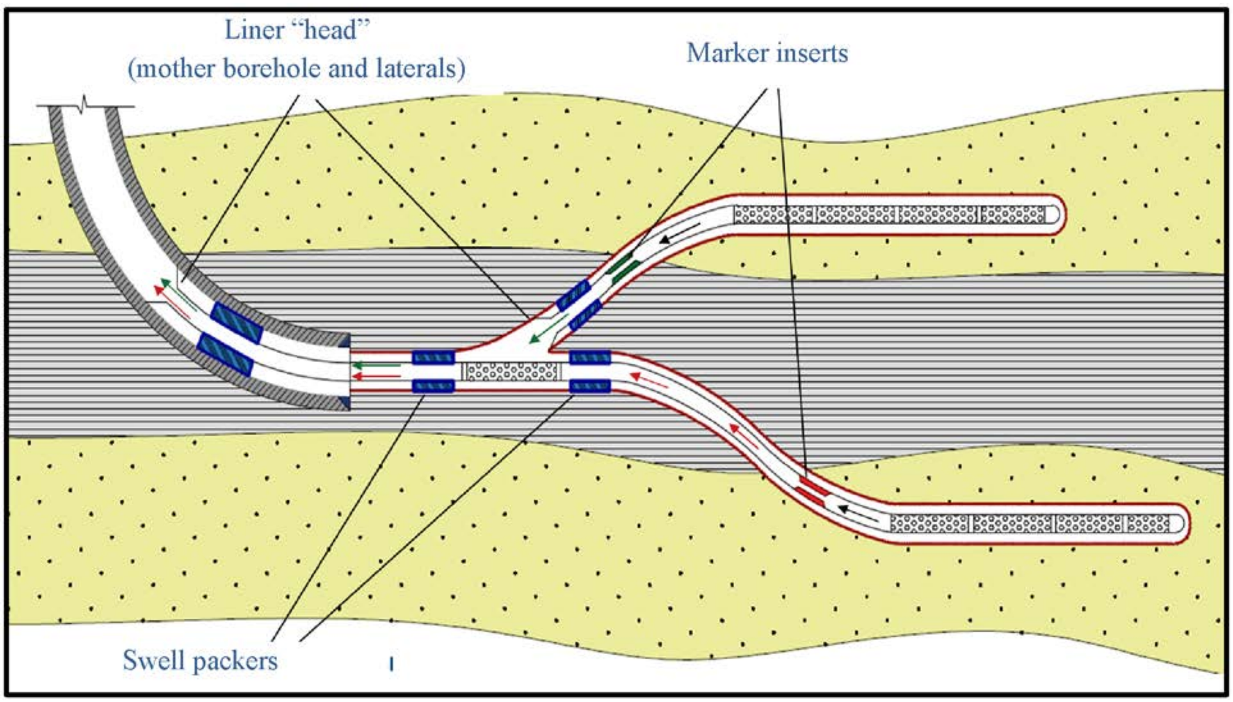

Figure 2—Conceptual TAML-1 well completion design

In this approach, the shoe of the production string is first placed into an impermeable interlayer between two target productive layers. Then the first lateral is sidetracked toward the upper layer and is subsequently fixed with a filter liner. The design of the liner includes blind pipes, a swell packer and an insert with marker tapes. The "head" of the liner is a left-right thread sub providing for reliable and cheap disconnection with the running string.

Sidetracking toward the underlying layer is done using the BHA for subsequent drilling by keyseat reaming without involving additional equipment. Once the target depth is reached, the BHA is lifted and the sidetrack is completed with a liner. The liner consists of (bottom-up) a shoe, well screen pipes in the reservoir interval, and blind pipes in the transition area to an impermeable layer having an insert with marker tapes. The branching point interval consists of a single perforated pipe and blind pipes with a standard liner hanger in the production string and is isolated by swell packers. This design enables measuring the contributions of each lateral individually (by cutting off one or another lateral).

If a well penetrates more than one reservoir, production from each of them must be accounted for individually in accordance with the legislation. For these purposes, dynamic quantum PLT was selected, since it has no limitations with this well design, unlike conventional logging methods.

Dynamic quantum PLT without well interventions

The dynamic quantum PLT technology involves the use of quantum marker reporters — high-precision indicators of reservoir fluid inflow. A composite material with markers is placed into special downhole inserts installed in the lower completion of a multilateral well (Figure 3). The marked material is a plastic composite, i.e. marker tapes that release indicators into the reservoir fluid at a stable rate and duration. Different types of marker tapes – oleophilic and hydrophilic – are combined, so the markers are released exclusively into the target reservoir fluid phase – oil and water, respectively. An individual marker code is responsible for providing data to evaluate the individual contribution of each lateral.

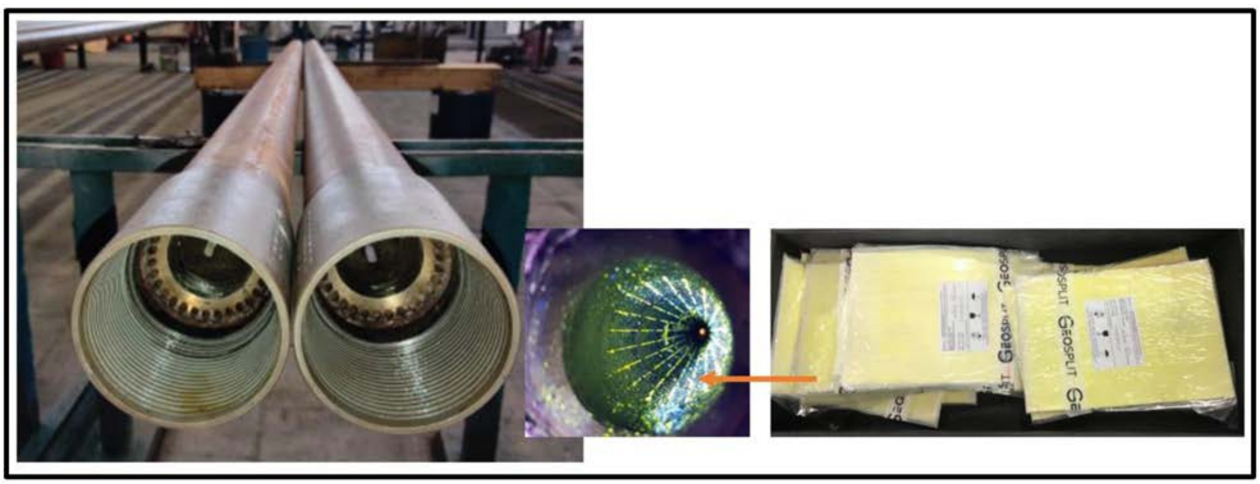

Figure 3—Downhole quantum marker inserts with marker tapes

After the liners with quantum marker inserts are run downhole, the latter are used then in subsequent production surveillance. Reservoir fluid is sampled from the wellhead and the samples are analysed using a flow cytometry analytical complex. According to this method, dispersed media are analysed on a particle-by-particle basis using light scattering signals. It helps identify the quantitative distribution of oil and water markers of each code with high accuracy.

The data of long-term dynamic quantum PLT in a producing well, coupled with the analysis of the historical performance of the target well and the nearest-neighbor wells, provides a basis for developing recommendations on how to optimise development of complex fields.

Dynamics of the inflow profile for a one-year surveillance period

Dynamic quantum PLT in a bilateral well of the Field NP was conducted from December 2020 to October 2021. Horizontal laterals of the well pierce a fault trap bounded by two faults forming a structure in the shape of a step fault (Figure 4). The target layers are separated by impermeable interlayers predominantly composed of clay. Due to this, production can be accounted for separately for each lateral. Since the trajectory of the lower horizontal lateral passes near the water-oil contact, there are risks of water-flooding during production.

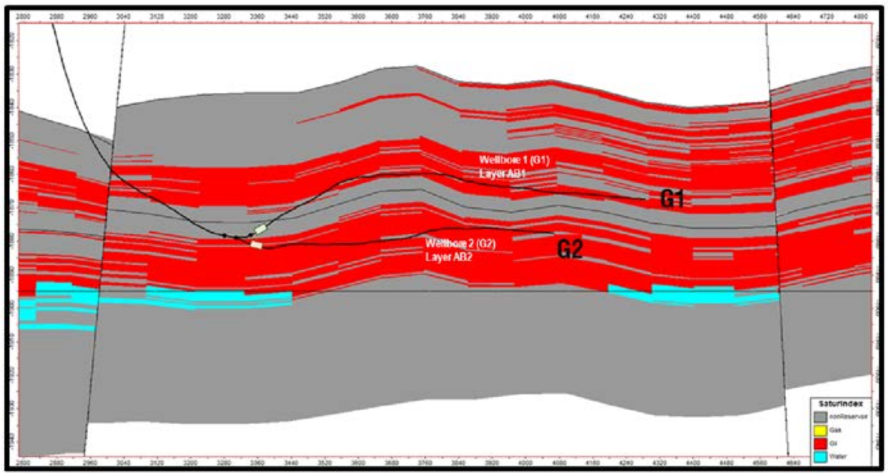

Figure 4—The subject horizontal well profile according to the saturation cube

During the entire time of surveillance, 8 surveys were conducted to obtain the distribution of the laterals' contribution for each period (Figure 5).

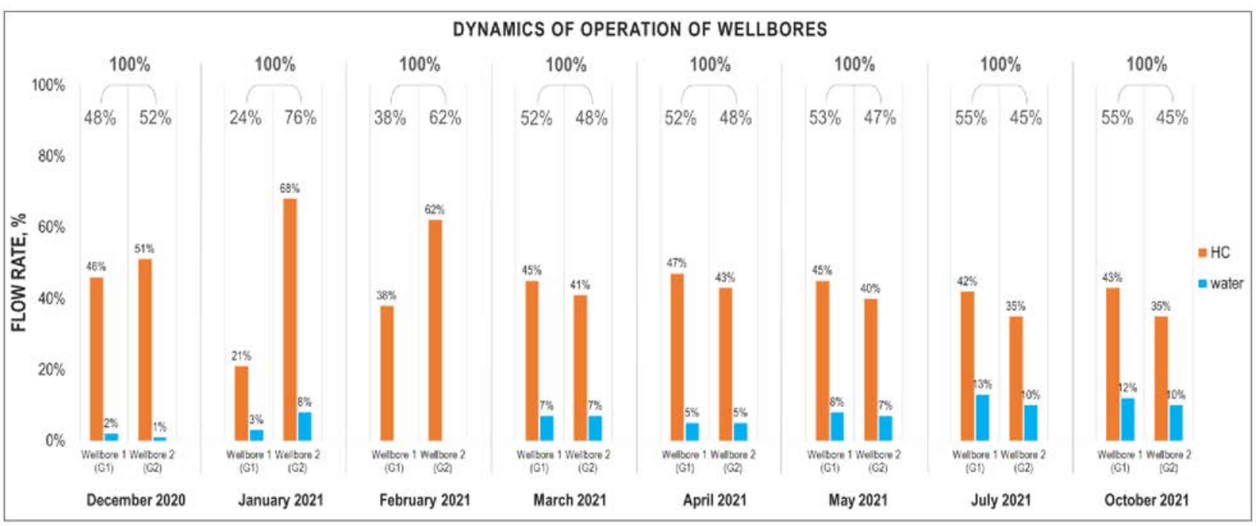

Figure 5—Dynamics of the performance of well No. XXX1 laterals

According to the data of dynamic quantum PLT and the analysis of the field geological settings, including the reservoirs, the following observations were formulated. Uneven performance of the laterals was observed in the first three months of surveillance with a predominant contribution of horizontal sidetrack 2, which is due to a non-steady fluid flow along the reservoirs. A relatively uniform production starts from the next quarter, with a slight predominance of the contribution from horizontal lateral 1. At the same time, water cut in the formation fluid is growing gradually during well operation.

The marked subject well No. XXX1 extends over the area marked by multiple faults. A water-oil contact is located to the east of the subject area. A probable system of conductive cracks could trigger a water flow process as reservoir pressure in the eastern part of the subject field was decreasing, inter alia, in the marked well drainage area.

Turning from relative values (the percentage distribution of the performance by laterals) to absolute figures (cubic meters per day), reservoir energy tends to decline in the course of well operation (Figure 6).

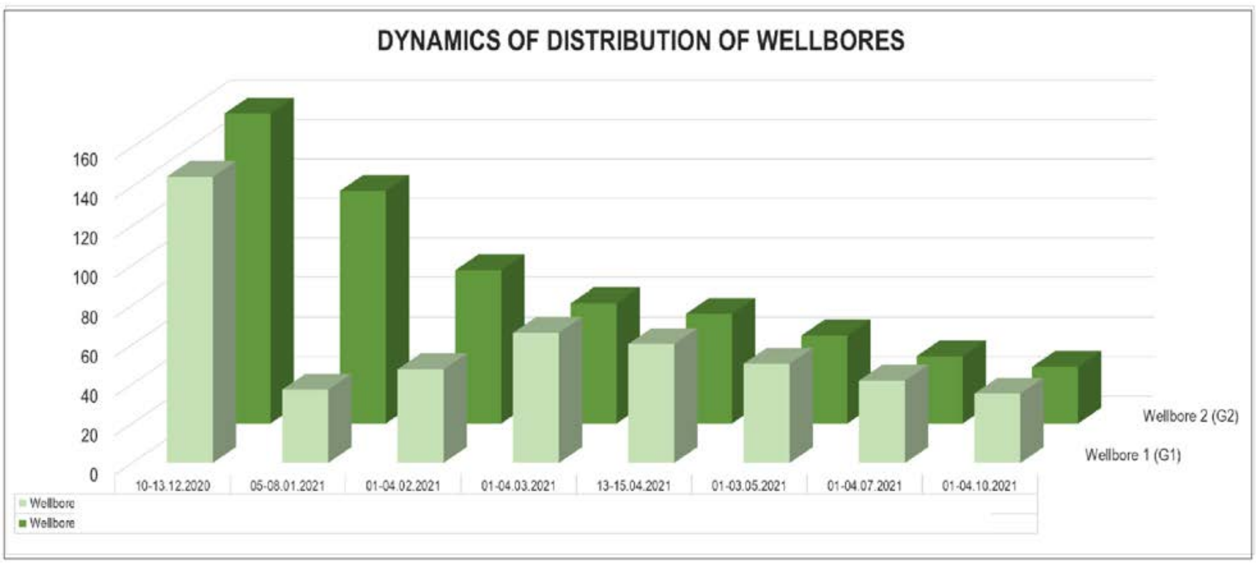

Figure 6—Dynamics of lateral performance in absolute values

Absolute figures of the production dynamics reveal a significant discrepancy in the performance of the laterals in the initial months of production. Thus, a sharp drop in the fluid flow rate in January 2021 (subsidence) observed in the performance of lateral 1 piercing the AB1 formation indicates the non-stationary nature of fluid flows in the drained area.

The dynamics of the performance of horizontal lateral 2 piercing formation AB2 demonstrates a gradual decrease in the fluid flow rate due to the presence of gas cap drive, in which oil is mainly propelled by the energy of the gas cap pressure. In this case, oil is displaced by the pressure of the expanding gas, which is in a free state in the top part of the deposit. The high permeability of formation AB2, several times the permeability of formation AB1, is a precondition for the most effective manifestation of the gas cap drive.

Production is complicated in such a case due to the fact that gas breakthroughs lead to uncontrolled waste of gas energy while reducing the oil flow. Therefore, it is recommended to continuously monitor production in the object under study and wells located near the gas cap.

The dynamics of reservoir performance (decreasing fluid flow rate and bottom-hole pressure) indicates a clear depletion effect in the well drainage area (Figure 7). This conclusion is also confirmed by the starting pressure after a long well shutdown, which has significantly decreased from the initial one.

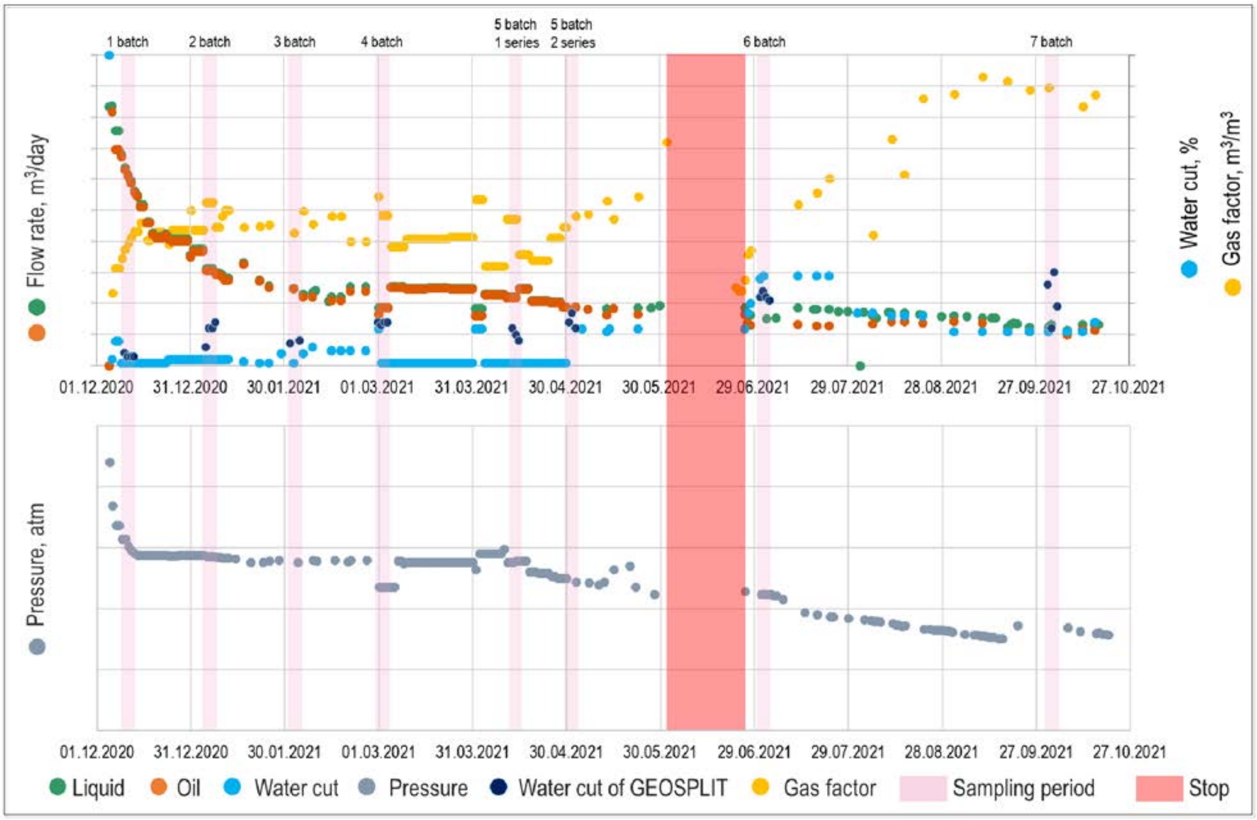

Figure 7—The history of the marked well No. XXX1 operation

The rapid increase in the gas factor since the well restart after shutdown is characterised by a decreasing gas-oil contact level. As the contact level decreases, the gas breaks through to the wells located closer to the gas pool boundary. In this case, it is important to optimise the energy loss from the expansion of the gas cap for the sake of cost-effective oil well operation.

A rapid increase in the gas factor may also be attributed to a change in the reservoir drive mechanism, namely, the transition from the gas cap drive to the dissolved gas drive. In the second case, oil is forced through the reservoir to the well bottoms by the energy of expanding gas bubbles as gas is released from oil. The reservoir drive mechanisms may naturally change due to a changing equilibrium in the reservoir, caused, in turn, by a decreasing bottom hole pressure.

In addition to identifying the sidetrack performance distribution in the subject well for the purpose of split production accounting for two reservoirs with different porosity and permeability, data obtained using dynamic tracer-based production profile surveillance enables monitoring production indicators without well shutdown, as well as developing recommendations for its optimisation.

To reduce the water cut of reservoir products and the gas factor, it is recommended to consider the possibility of changing the reservoir drive mechanism in subject well No. XXX1 by slightly reducing depression, as well as controlling the bottomhole pressure to prevent well operation at the bottomhole pressure below the saturation pressure.

Comparison with reservoir model data

One of the main ways to improve the quality of design, management and control over oil and gas field development is the use of reservoir flow models. Digital field and reservoir models provide the possibility to monitor the dynamics of the amount of remaining HC reserves and make more accurate oil and gas production predictions. They also help simulate well interventions to improve oil recovery and operational efficiency, as well as facilitate reasonable analysis of the most rational and cost-effective reservoir development options.

In order to verify the dynamic quantum PLT method in the oil and gas condensate field NP, a comparison was made with a coupled sector model of reservoirs AB1 and AB2. This model was developed taking into account the basic geological settings and engineering factors and describes the real reservoir processes occurring in hydrocarbon deposits with the required accuracy. The simulation involved evaluating various options for adapting the model. Eventually, the option showing the best convergence of the model with the production history was selected.

After the integral setup of the sector and the adaptation of the model, the production distribution according to the reservoir model was compared with the results of dynamic quantum PLT. Table 1 shows the results of the data comparison.

Table 1—Comparison of the reservoir model results and the data yielded by dynamic quantum PLT

Wellbore №	Layer	Flow rate (liquid), %		Flow rate (oil), %	
		Hydrodynamic modelling data	GeoSplit LLC	Hydrodynamic modelling data	GeoSplit LLC
December, 2020 (1 batch of samples)					
1	AB1	68	48	67	46
2	AB2	32	52	29	51
January, 2021 (2 batch of samples)					
1	AB1	46	24	46	21
2	AB2	54	76	48	68
February, 2021 (3 batch of samples)					
1	AB1	48	38	48	38
2	AB2	52	62	45	62
March, 2021 (4 batch of samples)					
1	AB1	54	52	54	45
2	AB2	46	48	40	41
April, 2021 (5 batch of samples 1 series)					
1	AB1	52	52	52	47
2	AB2	48	48	41	43
May, 2021 (5 batch of samples 2 series)					
1	AB1	48	53	46	45
2	AB2	52	47	44	40

The comparison reveals a satisfactory correlation between the data obtained using dynamic quantum PLT and the reservoir model calculations. Deviations during the first several months are associated with a non-stable reservoir flow, which, in turn, correlates with the well reaching a steady-state production mode.

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Conclusion

The TAML-1 multilateral well in question was drilled for the first time in Russia based on a fundamentally new design. For this purpose, the properties of the impermeable roof of one reservoir were used along with the dynamic quantum PLT technology to ensure separate production allocation for each reservoir. The total production of a multilateral well is the sum of the flow rates of two individual wells for the same purposes. The well was drilled no major issues ecountered with a 38% reduction in capital expenditures (CAPEX) and construction time.

Its design enables separate production allocation without well shutdown. The results of dynamic quantum PLT can be used to control the production parameters of reservoirs AB1 and AB2 of the oil and gas condensate field. Based on a monthly analysis of the reservoir performance dynamics for each reservoir, gas cap drive was identified in reservoir AB2, i.e. the main energy propelling oil is the pressure of the gas cap. Continuous monitoring of the gas factor provides the possibility to detect the depletion of the gas cap. This, in turn, can help choose the optimal well operation mode.

The dynamic quantum PLT technology in multilateral wells penetrating different reservoirs is especially promising in the case of dual completion wells. This is due to the fact that operator companies consider the task of reducing costs for drilling, construction, and field development a top priority. The technology delivers more value if used within an integrated approach to the study of a reservoir with several marked wells. In such a case, a number of processes are optimized, leading to economic synergy in several disciplines simultaneously: drilling, production, stimulation, and field development, in general.

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