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Using Markers for Production Logging in Horizontal Gas Wells with Multistage Hydraulic Fracturing

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Summary

The need for the use of modern technologies for diagnosing the work of the developed facilities and clarifying information on the productivity of the target formation arises when making decisions on the control of development, including designing and planning various kinds of technological measures, as well as conducting research to monitor the current state of existing wells. Traditional methods for monitoring the inflow profile are not always effective and cost-effective, especially when it comes to hard-to-recover reserves. One of the most progressive solutions is the use of marker studies based on the selection of markers from the produced fluid and their subsequent identification in samples taken at the wellhead [1]. The main advantage of this technology is that there is no need to suspend work for hoisting operations in order to obtain informative field-geophysical data during well operation. Moreover, the undoubted advantage of marker monitoring is its long-term nature since the technology allows continuous downhole data obtaining within several years. The subject of this work is a gas well with an extended horizontal wellbore, in which the 18-stage hydraulic fracturing using marked quartz polymer-coated sand was carried out.

Introduction

As a rule, subsoil users have no difficulties in developing fields with a relatively simple geological structure and good poroperm characteristics. Such objects have been thoroughly studied and researched, oil engineers have already gained enormous experience in the development of various deposits using a variety of techniques and technologies that ensure efficient production with minimal financial risk. However, the situation changes dramatically when it comes to less profitable projects, in which exploration and further operation of unconventional deposits with difficult to extract hydrocarbon reserves are carried out. The need to search for completely new technological and methodological approaches arises in such situations [2]. One promising solution is the use of reporter markers that can interact with a particular type of fluid. A quantitative assessment of the inflow profile can be carried out on the basis of data on the content of such indicator particles in the composition of the wellhead samples taken [3, 4].

Weak permeable gas-bearing shale deposits with all the characteristic difficulties in the development of this type of reserves were present at the studied object. The operation of such formations is impossible without additional geological and technological measures in the form of multi-stage hydraulic fracturing. The hydraulic fracturing operation with 18 stages was carried out on the studied horizontal Yan 3G11 well with an extended wellbore length of 1143 m. The hydraulic fracturing site of each stage was selected in accordance with the intersection horizon based on the results of geophysical studies. The section was divided into several independent sections according to the opened lithotypes. The upper part of the wellbore ("heel" part) intersects deposits represented by gray fine-grained sandstone. Alternations of interlayers of clayey mudstone with clayey silt lie deeper. The opening of fine-grained sandstone is again noted closer to the "forefoot" part. Such a heterogeneous composition of the development object entails difficulties in determining productive gas-saturated intervals and in the future when choosing the depths of the location of hydraulic fracturing couplings. This feature requires a deeper analysis and careful study of the design of the planned selective stimulation of the target development object.

Thus, the main objectives of the study are to evaluate the effectiveness of multi-stage hydraulic fracturing in shale deposits, as well as careful monitoring of the further operation of the target development. The GEOSPLIT used technology made it possible to give a complete picture of the operation of each interval and to reveal the patterns of formation of the obtained well inflow profile.

Description of the conducting field and laboratory tests in the Yan 3G11 well under investigation

The main source of the analytical signal in the technology used are reporter markers - organic or inorganic polymer microspheres, consisting of a stabilized three-dimensional (mesh) skeleton containing fluorescent substances that are introduced into the body of the microspheres at the stage of their preparation as a result of the polymerisation dispersion process. A different combination of fluorophores, which are introduced at the stage of synthesis, allows to create a large number of unique codes of marker reporters. The use of various technological methods allows to obtain monodisperse particles of a spherical shape with a high content of fluorescent substances. Such particles retain their analytical properties under various operating conditions, as well as under aggressive environmental conditions [5].

The proppant in the form of silica sand coated with a polymer shell acts as a carrier of reporter markers for the Yan 3G11 well in this case.

The shell is a polymer composite, consisting of several components, an insoluble polymer network, which is responsible for the strength characteristics of the composition, can be distinguished among them. Since the proppant experiences tremendous loads during operation, the resistance of the coating to such loads is an important parameter. A functional polymer filler in which reporter markers are dispersed is located within this insoluble polymer network. The main function of the filler is that when exposed to gas flows, the functional filler is ablated and reporter markers are removed with the gas flow.

The properties of the composition are selected in such a way that the main functional part is not destroyed by the action of the aqueous phase, or as a result of contact with a water-based gel during hydraulic fracturing.

During each stage of hydraulic fracturing, an individual code is injected, and the number of codes corresponds to the number of multi-stage hydraulic fracturing. The implementation of this approach allows reliable quantitative determination of gas inflows for each interval [6]. Information on the injection of each type of code into the corresponding fracturing interval is given in table No. 1

Table 1—Multi-stage hydraulic fracturing intervals for the Yan3G11 well

No.	Data	Fracturing stage	Marker code QD (GeoSplit)
1	10/26/2019	1	QD1
2	10/26/2019	2	QD2
3	10/26/2019	3	QD3
4	10/26/2019	4	QD4
5	10/27/2019	5	QD5
6	10/27/2019	6	QD6
7	10/27/2019	7	QD7
8	10/27/2019	8	
9	10/28/2019	9	QD8
10	10/28/2019	10	QD9
11	10/28/2019	11	QD10
12	10/28/2019	12	QD11
13	10/29/2019	13	QD12
14	10/29/2019	14	Proppant not injected
15	10/29/2019	15	QD13
16	10/29/2019	16	QD14
17	30.10.2019	17	QD15
18	30.10.2019	18	QD16

Further analysis of the content of reporter markers for each code is carried out by flow cytometry, the main advantage of which is the accurate determination of the number of microspheres of each code.

Unlike traditional fluorometry, which allows to determine the integrated fluorescence intensity for all types of particles, cytofluorometry allows to analyze the fluorescence intensity with specific excitation and emission wavelengths (they are called "channels") for each individual particle. Traditionally, such channels are presented in large numbers, which allows to identify reporter markers of various codes with high accuracy and reliability. Moreover, each analyzed marker represents a point in a multidimensional space under the conditions of cytometry data.

The described method allows to classify markers according to the parameters of interest within a 15-dimensional space with a given accuracy. The quantitative relations of each type of marker in the analyzed mixture are established on the basis of the classification obtained in accordance with the information about the coding of the markers.

In the future, data on the number of markers of each code is used to convert to gas inflows for each stage of multi-stage hydraulic fracturing.

Wellhead sampling procedure

It is necessary to analyze reservoir fluid samples taken from the surface to assess the inflow profile. However, wellhead sampling is not an easy task when it comes to gas samples. It was necessary to take into account many parameters when developing a sampling system: compliance with the safety standards of the oil and gas industry, ensuring the most efficient transportation of samples to the laboratory of GeoSplit LLC, and the possibility of multiple sampling from the well.

Sampling from the Yan 3G11 well was carried out using a filtration device developed by GEOSPLIT, a typical design of which is shown in Figure 1.

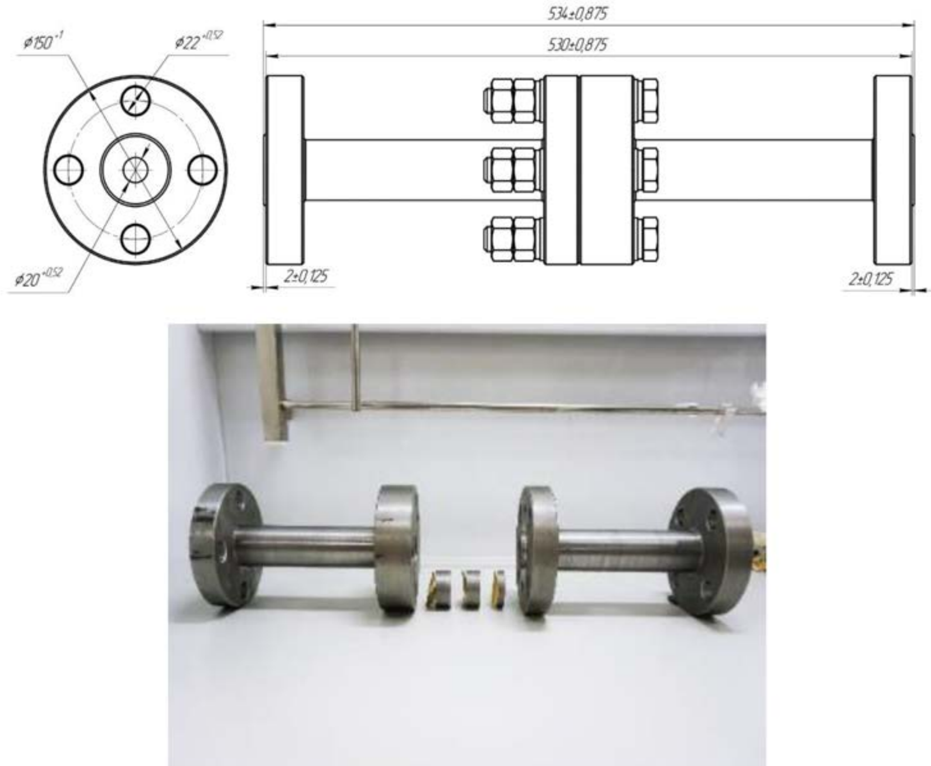

Figure 1—A typical GeoSplit filtering device

The device was designed and manufactured individually for a specific customer, taking into account his wishes and well operating conditions, it can be used in the pressure range of 1-10 atm, is oil and petrol resistant and completely tight. The filtration device consists of two main elements on a flange connection, between which there is a filtration compartment, where the most important structural element - a membrane filter, the task of which is to trap gas markers is located (see the figure below). A characteristic design feature is the possibility of varying the number of filters for one sampling (one to three) depending on the size of the plug used (Figure 2).

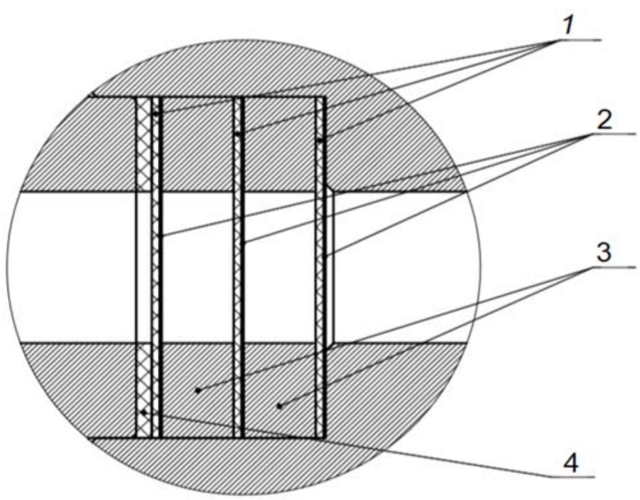

Figure 2—Filter compartment
1 - membrane filter, 2 - metal filter, 3 - plug, 4 - O-ring.

The filtering device was installed on the bypass line, previously cut into the piping of the Yan 3G11 well, according to Figure 3.

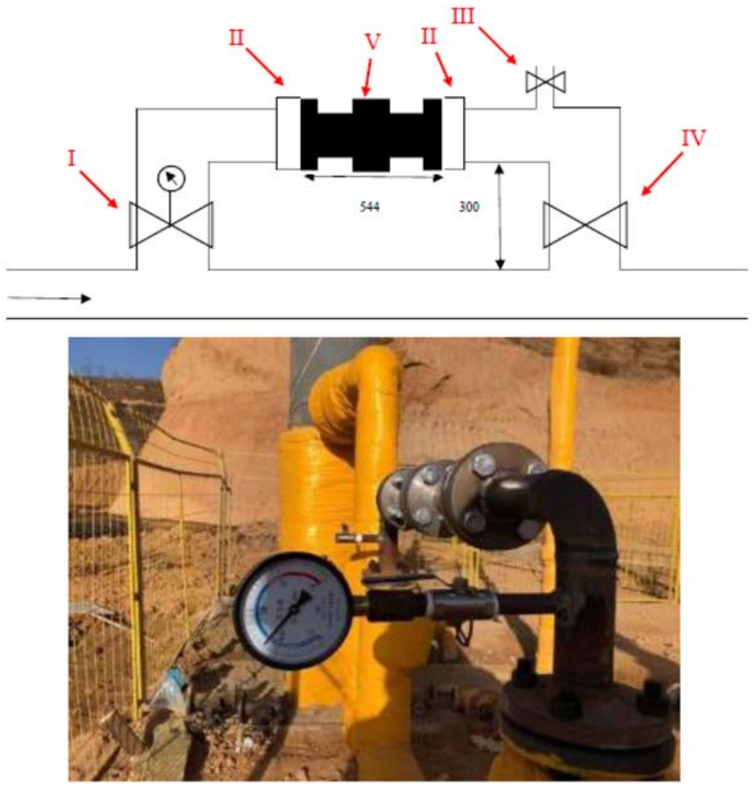

Figure 3—Bypass line diagraml - valve with pressure gauge, II - flange, III - ball valve, IV - valve without pressure gauge, V - filtration device

Samples were taken according to a pre-approved schedule. One of the parameters varied for each sample: time, type of membrane filter, number of pulsed gas supplies to the filtration device. A similar technique was applied to identify optimal conditions for gas sampling at a given well.

The filtering device was removed from the bypass line with each new sampling, and all elements of the filtration compartment (with the exception of plugs) were removed for further analysis.

A sample package of 8 samples was taken within 48 hours for further analysis, which involves identifying and counting the number of detected markers.

Yan 3G11 Well Analysis Results

Diagnostics of the inflow profile according to laboratory analysis

The interpretation of the results with a sample of the most representative samples from the entire data array was carried out after analysis of the samples using the cytofluorometry method. A similar procedure is necessary to minimize ambiguities in the further calculation of the inflow profile of the investigated well. To interpret the results, it is also necessary to take into account the technological mode of operation of the well at which sampling was carried out (whether the nozzles were changed), since this factor can have a strong influence on the profile itself when averaging the inflow rates of each interval.

A separate sampling mode, implying a different type of replaceable membrane and the frequency of transmission of the gas stream along the bypass line through the filter element, was applied for each sample. Several variants of the inflow profile were calculated and analyzed for each case in accordance with these parameters.

The results of the analysis of the operational efficiency of multi-stage hydraulic fracturing ports for the Yan 3G11 well are presented in Figure 4.

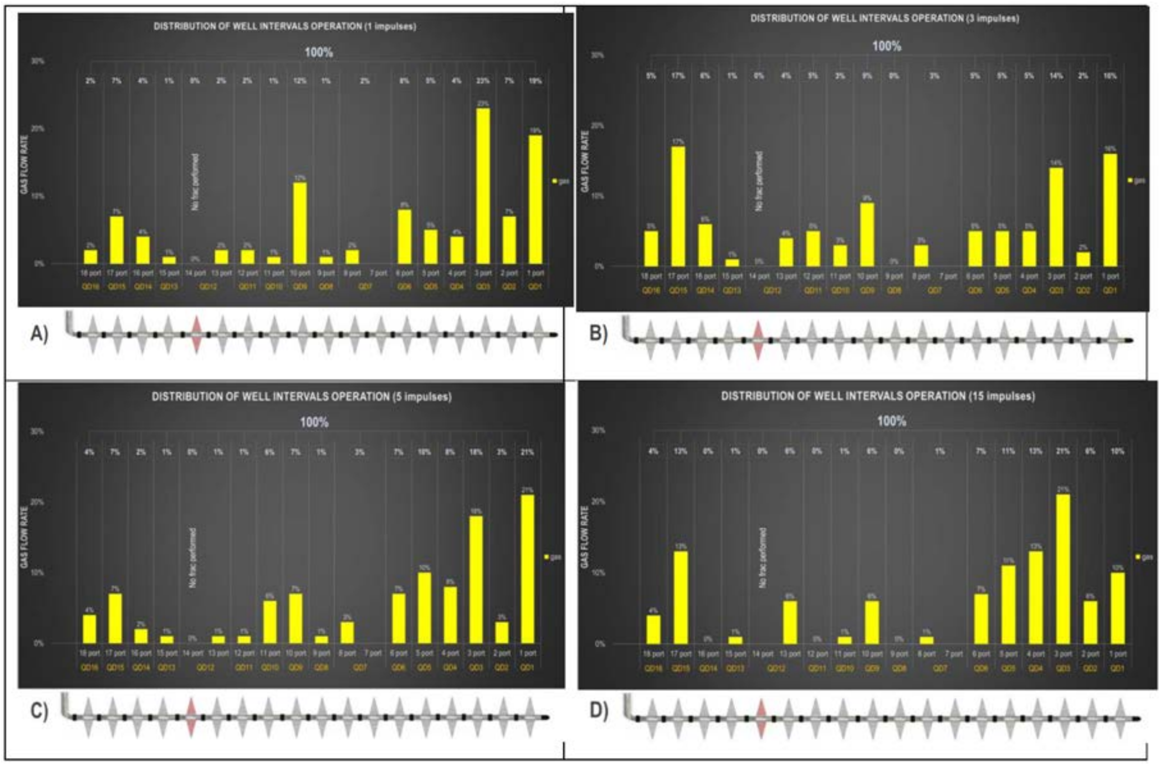

Figure 4—A series of inflow profiles characterizing the intervals dynamics within 12/11/2019 – 12/12/2019

When comparing the received inflow profiles for the study period from 12/12/2019 to 12/12/2019, a similar development of the target object is observed at a qualitative level - the ports included in the work show similar productivity if we group them in separate zones. So, for example, ports 1 and 3 in the "forefoot" of the horizontal wellbore are distinguished by high readings, while the value of their inflow is well correlated in percentage ratio for different pulse variations (transmission frequency of the gas stream during sampling). Intensive filtering of a group of ports in the "heel" part of the wellbore (ports 15, 16, 17, 18) with the most intensive filtering in port 17 was also noticed, which may indicate the presence of a stable technogenic crack formed during hydraulic fracturing. It is worth noting that the central part of the wellbore shows the inclusion to the ports work. However, only 10 and 11 ports stand out among all in the considered area (a group of 7, 8, 9, 10, 11, 12, 13 ports). The operation of other ports is rather unstable.

The fact is obvious that samples have a discrepancy between themselves, which is especially evident when comparing the distribution of inflow over each interval (port). For example, if we consider the operation of port 1 at different pulses (from 1 to 15), then the estimated intensity in it will vary from 10% to 21% (Figure 4), the standard deviation in this case is 4.2%, which generally does not go beyond margin of error. This parameter remained below the specified value for the other ports included in the operation. Such an insignificant variety in the share of each port may be due to the fact that some unsteadiness of the filtration process was reflected in the production, since the water component was present in addition to the light phase in the inflow. As noted above, the distinguished zones ("forefoot", central and "heel" parts) retain their productivity at a qualitative level when comparing the received inflow profiles with each other.

Averaging over each port among the entire array of informative samples was carried out for a generalized assessment of the efficiency of ports based on the presented results of laboratory analysis. The final distribution of the work of the hydraulic fracturing intervals for the Yan 3G11 gas well under study is presented in Table 2, and also shown in Figure 6.

Table 2—The results of marker studies interpretation

Interval No.	Location of hydraulic fracturing port (m)	Gas flow rate,%
1	2220	15%
2	2167	2%
3	2120	21%
4	2075	8%
5	2010	5%
6	1843	4%
7	1779	2%
8	1709	
9	1655	1%
10	1578	8%
11	1520	5%
12	1480	4%
13	1440	2%
14	1353	0%
15	1316.2	2%
16	1245	5%
17	1184	12%
18	1131	4%
Total		100%

The analysis shows that the "forefoot" and "heel" parts of the wellbore work intensively, while the middle of the horizontal section works less intensively. The uneven profile is mainly due to the heterogeneity of the developed object, since these deposits are classified as hard-to-recover reserves. Uneven productivity along the wellbore is characteristic with such an abnormally low permeability of the formation.

A comprehensive assessment of the intensity of the well under study, taking into account a priori data

The history of gas production during the study from 11/21/2019 to 12/24/2019 (Figure 5) was further analyzed for an in-depth understanding and identification of the relationships of formation of the obtained inflow profile. The dynamics of sampling showed an unstable mode at the initial stage, which varied from approximately 14,000 to 20,000 m^3 / day, since productivity mainly occurred through fractures formed during hydraulic fracturing (linear filtering mode along an extended horizontal wellbore). Beginning in mid-December 2019, the gas flow rate stabilized and began to reach a constant level (# 22,000 m^3 / day). Sampling was carried out on the surface through the previously described filtration device, which was installed on the wellhead according to the developed methodology at the stage of stationary sampling (without changing the technological depression) of gas, which ensured obtaining the inflow profiles of the studied well with the established filtration mode.

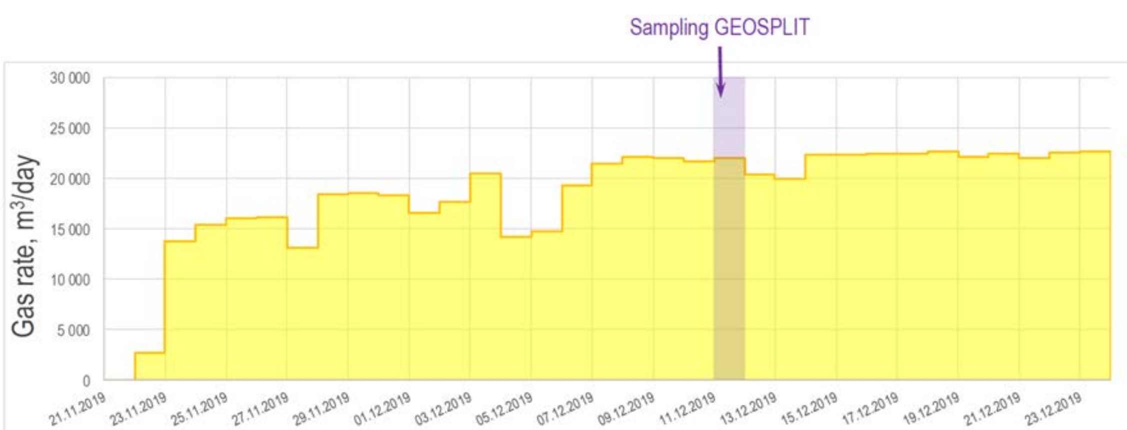

Figure 5—History of gas production from the Yan 3G11 well within November 22, 2019 – December 23, 2019(the sampling period is marked with purple colour)

The timing of formation fluid sampling is an extremely important factor when planning work and drawing up a research program, which also includes a schedule for sampling from the surface, since the non-stationary process during production can be accompanied by technological effects associated with external influences and not reflect the characteristic features of the developed object.

Additionally, baseline information on field geophysical data was studied for the well under study. The geophysical complex of recorded data provided by the subsoil user was simplified and mainly included radioactive methods, which were later used to calculate the basic filtration characteristics and estimate the current saturation. Several productive intervals are identified along the wellbore according to the lithological column and the initial gas content at relative elevations (Figure 6): 1100-1350 m, 1430-1600 m, 1820-1860, as well as 2000-2250 m. Such an uneven profile along the wellbore is due to the trajectory of the well, since the most curved sections along the penetration fell just into the impermeable or low-permeable areas, where the inflow was not detected at all, or it was quite low (up to 5% of the wellhead flow rate).

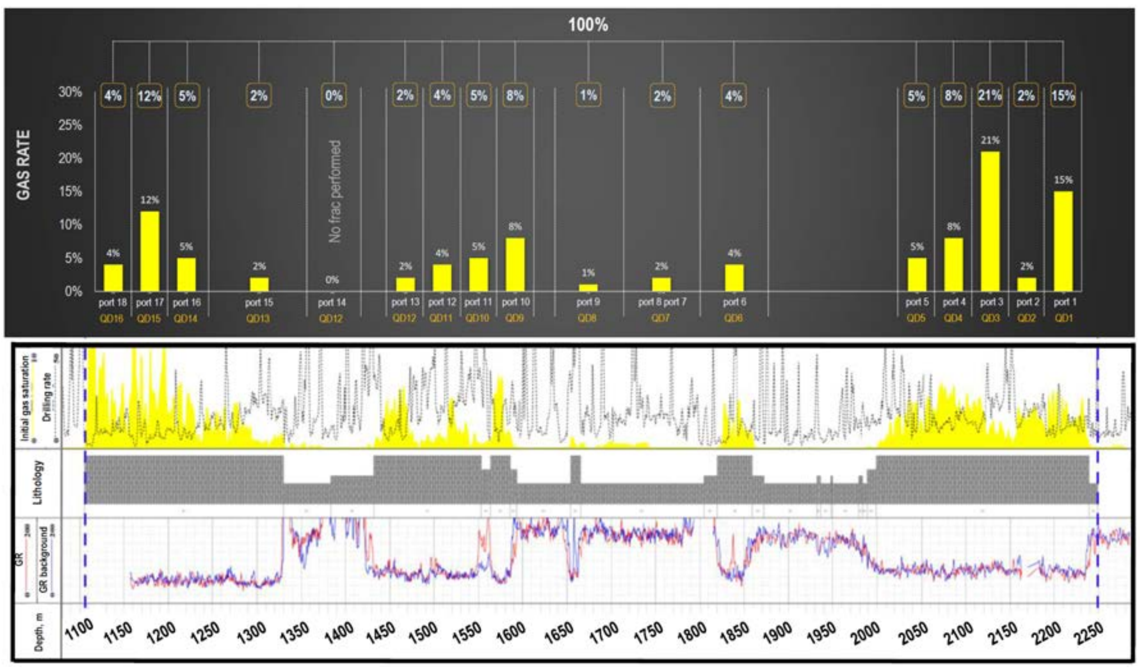

Figure 6—Comparison between the results of ports performance according to marker diagnostics and the data of open wellbore geophysical surveys for the Yan 3G11 well

The estimated inflow profile for the short-term Yan 3G11 well development shows good convergence when compared with the interpretation results of open wellbore geophysical surveys, which indicates a sufficient degree of reliability of the estimated performance indicators of each included interval at the initial stage of sampling.

It should be noted that another 3 series of samplings planned as part of the research program in 2020 will allow to trace the dynamics of the entire wellbore. At the same time, stopping the operation of the well and conducting any additional technological operations for the implementation of such control is absolutely not required. So, for example, it is possible to visualize the formed drainage zone of the studied well in the considered area by the average daily cumulative production for each port, as well as analyze the change in productivity of each port over time to assess reservoir productivity and identify the likelihood of possible interference with the producing environment [7]. Such an analysis is very effective in updating hydrodynamic models for a more reliable forecast of reserves productivity. In addition, this dynamic data can be critical when it becomes necessary to make operational decisions in emergency situations.

Conclusion

A unique study showing the of the horizontal part of a gas well under unusual conditions with a low gas flow rate allowed to identify working ports at the initial stage with a high degree of reliability. The marked agent can be carried out for several years by gas flows, which makes it possible to trace the dynamics of changes in the inflow profile for a long time using regular sampling and diagnose problem areas of the horizontal section of the well. Such an approach can contribute to the further optimization of resources without additional costs for field research.

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