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Long-Term Inflow Profile Monitoring with Markers in Horizontal Gas Wells with Multistage Hydraulic Fracturing

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Summary

Traditional methods of inflow profile monitoring are not always effective, especially when tight reservoirs are considered. One of the most progressive solutions is the use of marker technologies based on the markers' selection and subsequent identification in fluid taken at 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. The main subject of work is a fractured gas well with pumped marked quartz polymer-coated sand.

Introduction

There are no difficulties in developing fields with a relatively simple geological structure and good filtration properties. Such objects have been thoroughly studied and researched. The situation changes when the less profitable projects are considered because of more complicated formation seals with unconventional. 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 estimation 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-saturated shale deposits with all the characteristic difficulties in the development of this type of reserves were presented at in this case. 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 and geological 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: during drilling, 653 m of fine sandstone and 490 m of silty mudstone - argillaceous siltstone were encountered, accounting for 57.1% and 42.9% respectively. 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.

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 tests in the Yan 3G11 well

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 codeQD (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

No.	Data	Fracturing stage	Marker codeQD (GeoSplit)
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	10/30/2019	17	QD15
18	10/30/2019	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.

Yan 3G11 Well Analysis Results

Diagnostics of the inflow profile

There was an 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. To analysis the results, it is also necessary to take into account the technological mode of operation of the well at which sampling was carried out, since this factor can have a strong influence on the profile itself when averaging the inflow rates of each interval.

The sampling was performed in different modes through a filter element in the bypass line with different types of special replaceable membrane and gas stream transmission frequency choosing. In accordance with these parameters, series of the inflow profiles for each case were estimated and analyzed in Figure 1. The sampling was conducted for 2 days (04/24/2020 – 04/25/2020).

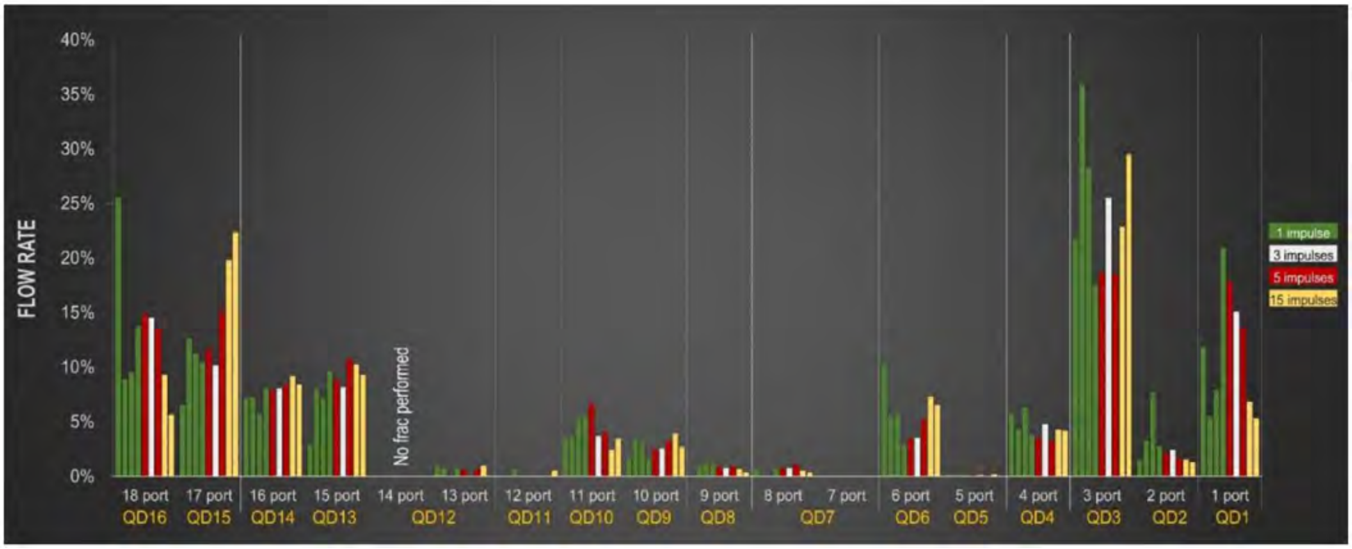

Figure 1—Distribution of well intervals by each sample in different modes (impulses) within 04/24/2020 – 04/25/2020

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 6% to 15% (Figure 1). 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.

It should be noted that all representative samples were chosen for further estimation of tested well production. 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 shown in Figure 2 and presented in Table 2.

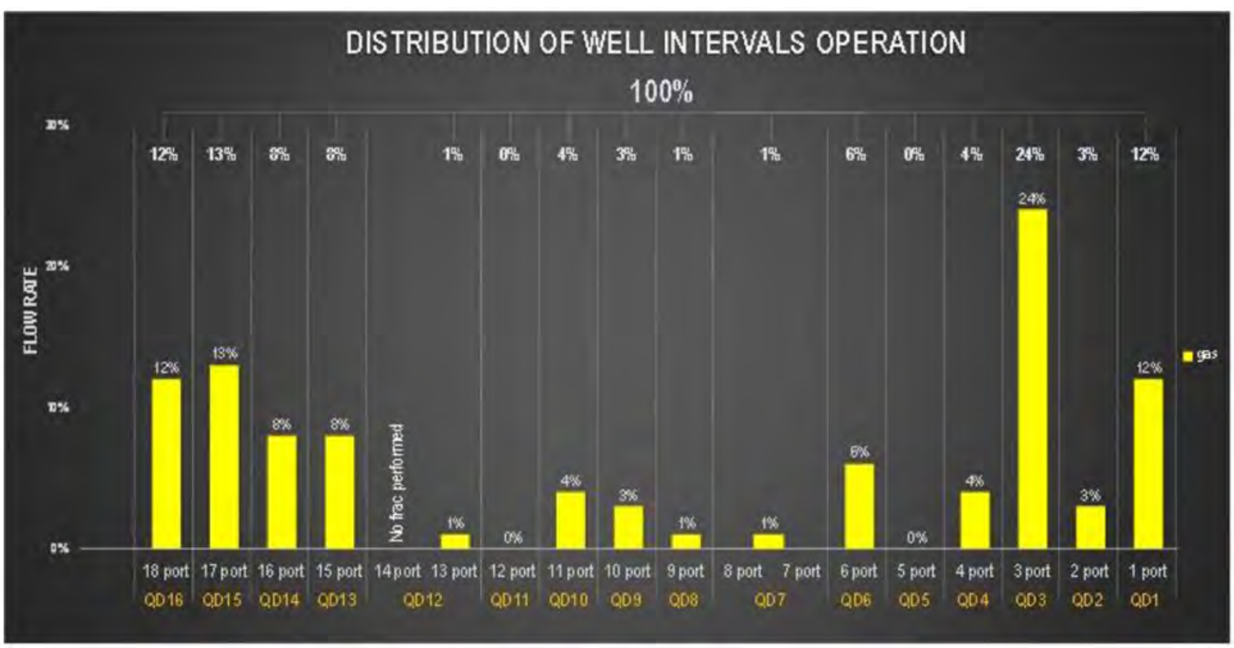

Figure 2—Average distribution of Yan 3G11 well intervals.

Table 2—The results of marker studies interpretation

Interval No.	Location of hydraulic fracturing port (m)	Gas flow rate,%
1	2220	12
2	2167	3
3	2120	24
4	2075	4
5	2010	0
6	1843	6
7	1779	1
8	1709	
9	1655	1
10	1578	3
11	1520	4
12	1480	0
13	1440	1
14	1353	No frac performed
15	1316.2	8
16	1245	8
17	1184	13
18	1131	12
Total		100

The distribution of gas indicates that port 3 makes the largest contribution to the well operation - 24 %. Ports 17, 18 and 1 make a contribution of 13%, 12% and 12% to the well operation, respectively. Port 14 contribution cannot be assessed due to the absence of polymer coated sand of GEOSPLIT brand in the zone. Only qualitative results can be obtained for ports 7 and 8 due to the use of the same code for both intervals and a critically low amount of marked material per interval while fracturing. On the sampling dates most volumes of the gas flow was coming from the «toe» and «heel» parts of the well Yan3G11. The middle part of the horizontal well shows the worst productivity because of lower transmissivity formation zone.

It should be noted that such behavior of gas rate probably deals with formation depletion on the tested area. This feature can influence on distribution of well intervals because of anomalously low permeability and complicated geometry of each mining-induced fracture.

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

Well Yan 3G11 has been launched into production on November 23, 2019, with an average gas rate of 22 000–23 000 m3/day. The history of gas production during the study was further analyzed for an in-depth understanding and identification of the relationships of formation of the obtained inflow profile. After a short period of production time (670 hrs) it began to decline and at the end of the test it was about 11 000 m3/day (Figure 3). Water cut also decreased at the beginning of exploitation (hydrofracturing fluid washing out). Bottom hole pressure (BHP) dropped down from 4 MPa to 0.55 MPa and on June 19, 2020, it was still declining due to low filtration properties of a formation.

On the assumption that formation pressure is about 3 MPa at the end of test (19.06.2020), the productivity index (PI) of Yan 3G11 Well is 4.4 Mm^3/(MPa day).

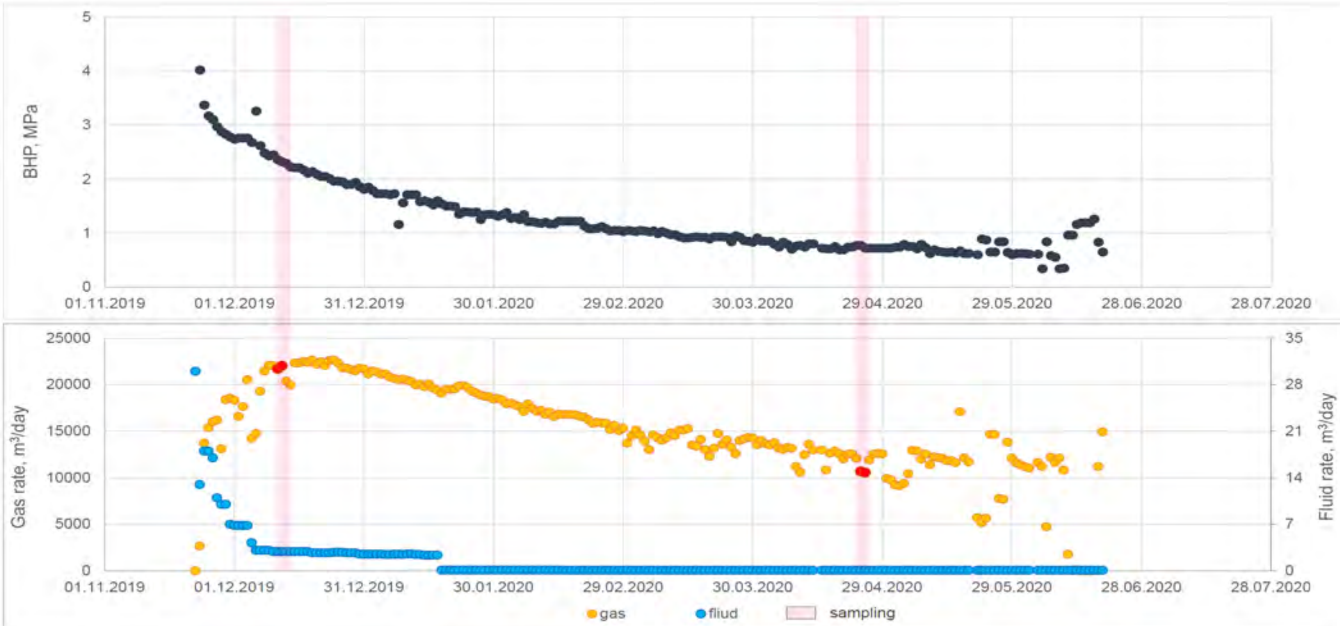

Figure 3—History of gas production from the Yan 3G11 well within November 2019 – June 2020 (the sampling period is marked with purple colour)

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.

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. The formation pressure declines during the time because of depletion and absence of formation-pressure maintenance system on the tested area.

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 4): 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).

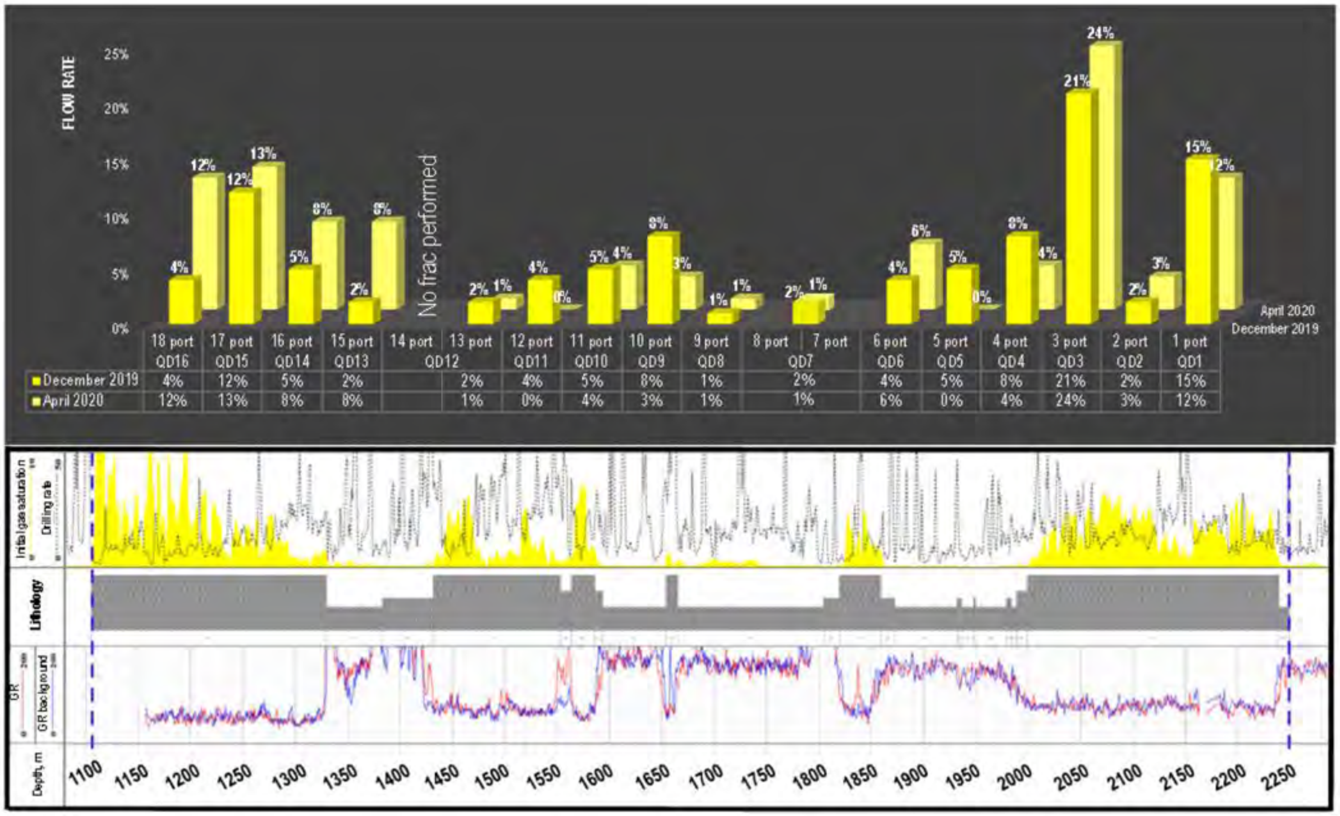

Figure 4—Comparison between the dynamics distribution of well intervals according to marker diagnostics and the data of open wellbore geophysical surveys for the Yan 3G11 well

When comparing the received inflow profiles for two the study period from November and April 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. 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. The production level of «heel» part of a horizontal well has increased by the second sampling period. 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 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.

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.

It should be noted that another series of samplings planned as part of the research program will allow to trace the dynamics of the 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

An unconventional research showing the horizontal part production 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 substance can be carried out for 3-5 years by gas flows, which makes it possible to trace the inflow profile changes while production period and diagnose problem zones of the horizontal well (identification impermeable intervals). Such an approach can contribute to the further optimization of resources without additional costs for expensive well tests.

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