IPTC-23030-EA

Long-Term Productivity Monitoring of Multistage Wells with New Quantum Dot Technology and its Application in Xinjiang Oilfield

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This paper was prepared for presentation at the International Petroleum Technology Conference held in Bangkok, Thailand, 1 - 3 March 2023.

Abstract

Traditional production logging uses cable or coiled tubing for productivity measurement. Such measurement normally requires well to be shut-in, which brings risks for field operation, especially for directional or horizontal wells; it affects normal field production management. Besides, the result only reflects production profile at one time point. The later production system adjustment or changes of water production value need to be measured again, eventually increasing the total cost.

Productivity monitoring technology based on ‘Quantum Dot’ tracers uses nano-size quantum dots to make micron-size quantum signature codes or marker-reporters. As the basic monitoring particle, the quantum signature code can be made to flake quantum dot monitoring tape through polymer materials, this special tape is wrapped around pipe or screen and placed at target location in the borehole. For different layers and fluid phases, quantum monitoring tapes with different codes and affinity properties are utilized to distinguish them. When monitoring tapes come into contact with different fluids such as oil or water in formation, diffusion channels will be generated, from which quantum monitoring particles (marker-reporters) are released and adsorbed on the surface of the material. As fluid flows, quantum monitoring particles in monitoring tapes will be continually released and adsorbed on tapes surface and carried to the wellbore, this achieves a release process proportional to flow rate. The produced liquid collected at wellhead is mixed with quantum monitoring particles with various codes, which can be separated by laboratory analysis. By counting the percentage of marker-reporters with different codes, the production rate percentage of different intervals can be obtained, and then for each stage, oil, gas, and water production can be obtained according to the total wellhead production. The quantity of quantum monitoring particles is massive, and its release rate is in a positive correlation to flow rate. Under normal circumstances, unlimited production monitoring can be achieved within 3 years.

Traditional production logging measure formation and production parameters such as temperature, pressure, density, resistivity, flow rate, water cut etc. logging tools and packers are combined to measure flow volume from each stage and fluid types are identified at wellhead.

Main disadvantage of this method is the requirement for wellbore shut-in and the risk of unsuccessful RIH the tools as the wellbore faces common issue – wellbore deformation.

In addition, it is not normal using packers to isolate other zones while allowing only one stage to produce. Also, production logging can only obtain inflow profile at a specific time or short period of time. If one needs to get information such as later production data or water cut value when producing system is adjusted or changed, logging operation must be done again. It results in higher costs.

How to monitor production profile of each stages any time during normal production process and utilize these data to make timely adjustment is of great significance in terms of operation and efficient development of single well or for a whole block.

Quantum Technology Principle

Different manufacturers produce tracers based on varies technology principles; these impact the method of injection. In China, one type of tracer that commonly used is chemical tracer (or microelement) in liquid phase. Engineers inject this fluid type tracer during hydraulic fracturing though blender truck. It goes inside formation together with operation fluid; tracers are sampled during flowback period. This method has several drawbacks: how to achieve long-term monitoring, as tracer flows back to surface, signals remaining inside target formation gets weaker; this rises the challenges towards analysis equipment precision and shortens monitoring windows to 3-6 months; how to ensure accuracy of tracer data, as there is no any control mechanism for tracer release into the fluid. Besides there are no easy ways to deploy liquid chemical tracers into an existing well. Which limits the area of their usage to newly drilled and completed wells.

However quite often there is demand to understand the work of an existing well after 1-, 2-, 3- years of production.

This paper discuses tracer technology based on Quantum dots, which are semi-conductor nano-structures that bind excitons in three spatial directions. Sometimes referred to as 'artificial atoms', 'superlattices', 'supe-atoms' or 'quantum dot atoms', it is a new concept proposed in the 1990s. This constraint can be attributed to the electrostatic potential (generated by external electrodes, doping, strain, or impurities), the interface between two different semi-conductor materials (e.g., in self-assembling quantum dots), the surface of the semi-conductor (e.g., semi-conductor nano-crystals), or a combination of the above. Quantum dots have a separated quantized energy spectrum. The corresponding wave function is spatially located in the quantum dot but extends over several lattice periods. A quantum dot has a small (1100) integer number of electrons, holes, or pairs of electron holes, that is, the charge it carries is an integer multiple of the primary charge.

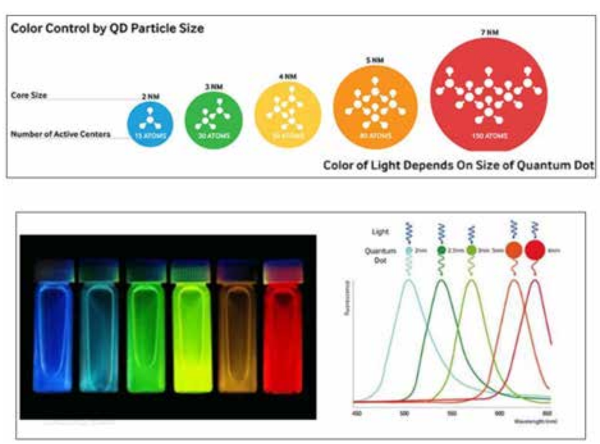

Figure.1—Color Control by QD Particle Size

Micron quantum signature code (marker-reporter) is through the different combination of the particles above. Quantum markers-reporters are polymeric monodisperse microspheres. Their identification is carried out by the method of flow cytometry with the use of algorithms of machine learning. In order to achieve the function of long-term monitoring, two product type can be utilized, that are marker-reporter coated proppant and monitoring tape. One is like normal proppant, that are pumped down during fracking, one works with completion tools.

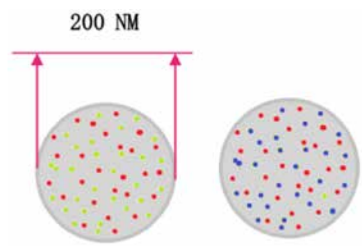

Figure.2—Different Signature Code in Nano Scale

This paper discussed one usage - quantum dot monitoring tape to achieve multi-stage profile monitoring as a retrofit solution on an existing well. This monitoring tape can work with screen pipe and oil pipe. Along with production pipe line to the target location, quantum dots will be released during production stage as hydrocarbon flow through screen pipe.

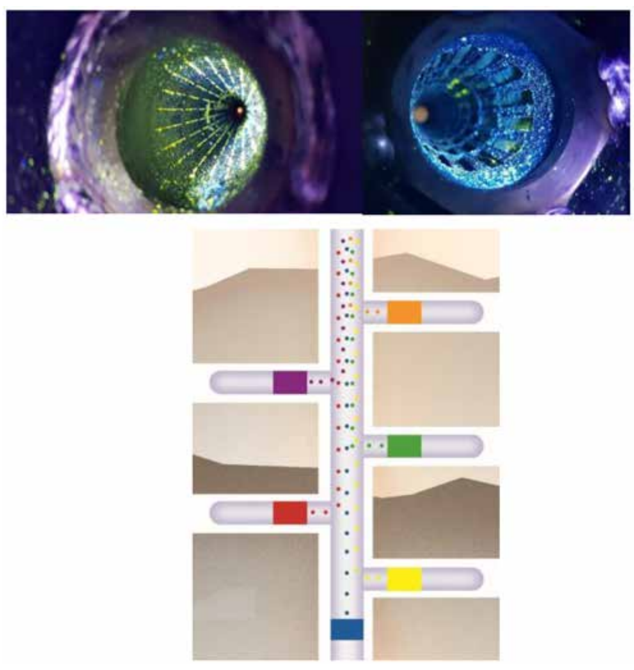

Figure.3—Monitoring Tape

When monitoring tapes meet different fluids either oil, gas or water in formation, diffusion channels will be generated, from which marker-reporters are released and adsorbed on the surface of the tape. As fluid flows, marker-reporters in the monitoring tape will continually to be released and adsorbed on tapes surface and carried into the wellbore, this achieves a release process proportional to the flow rate.

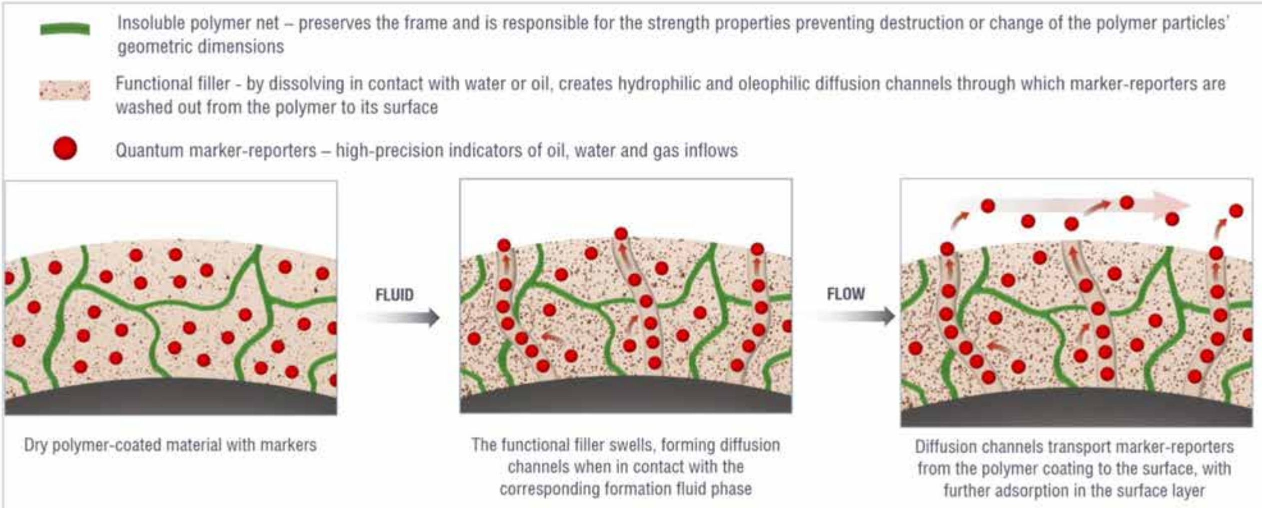

Figure.4—Quantum Signature Code Releasing Principle

Field Application

Well Selection

One well was selected according to following rules: high casing integrity, no leakage point; effective isolation between layers: good cementing quality, no layer channeling and pipe channeling; liquid production is over 10 m^3 per day, average single stage oil and water production greater than the minimum technical requirement. Formation thickness and perforation data is shown in table below.

Table 1—Formation Thickness and Perforation Data

NO.	Interval	Thickness	Perforation	
	(m)	(m)	SD	Shots
3	710~711	1	16	16
	712.5~713	0.5	16	8
	715.5~716.5	1	16	16
2	725~727.5	2.5	16	40
1	740.5~742	1.5	16	24
	748~748.5	0.5	16	8
	763.5~765.5	2	16	32
	767~768	1	16	16

In this case, quantum dots monitoring tape is wrapped around screen pipe and prepared in factory before on-site operation. 6 signature code for the purpose of water and oil production monitoring in this 3 stages vertical well.

Figure.5—Marker Tape Installation

Well Information

This is a vertical well with 3 producing layers. Completion casing using 5.5″, well MD is 788 meters; Date of production: 20th of March, 2013. Since February 2021, the well has experienced a rapid water cut increase while total fluid production decreased. In May 2021, total fluid production remained at around 10 m^3 per day with 78-80% water cut.

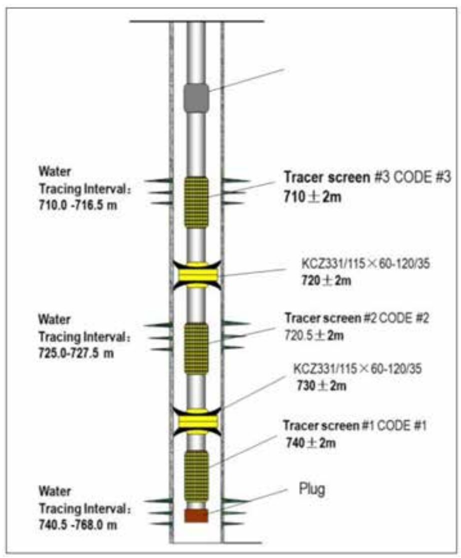

Figure.6—Vertical Well With 3 Producing Layers

The aim of using quantum dot technology is to identify the main water contribution layer. This well was monitored for oil water production at all stages, therefore, later operation such as chemical water plugging, profile control technology can be discussed based on tracer result.

Blind Test

Before installing all monitoring screen pipe inside wellbore, several tests had been done including blind test. Blind test is necessary that allow client mix different codes and provide final mixed sample, only client knows the combination of the mixture. Samples are analyzed in lab and give test results. After that, a comparison will be made between test data and actual data.

Markers-reporters are washed out, through hardware and software system, concentration of markers for each code are detected and quantitative distribution of oil and water phases for each horizontal section are determined. A diagram shows the process.

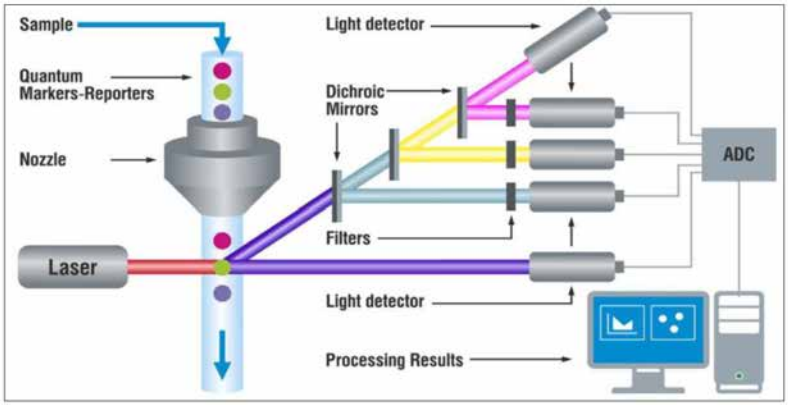

Figure.7—Analytical hardware-software complex, implementing the identification of markers- reporters by a flow cytometry method

Table 2—Blind Test Result

Mixed Sample	Client Measurement		Percentage, %	Lab Test		Deviation %
	Code	Volume, mL		Code	Testing Percentage, %	
	1	60	30	1	18.7	-11.3
#A	2	100	50	2	44.4	-5.6
	3	40	20	3	36.9	16.9
Total	200	100		100		
	1	40	20	1	9	-11
#B	2	70	35	2	28.9	-6.1
	3	90	45	3	62.1	17.1
Total	200	100		100		
	1	100	50	1	61.7	11.7
#C	2	60	30	2	17.4	-12.6
	3	40	20	3	20.9	0.9
Total	200	100		100		

Sampling & Monitoring Results

First Batch Results. During late July 2021, 20 samples had been taken from wellhead. Sampling time and corresponding oil water percentage data is shown in the table below.

Table 3—First Batch Sample Information

NO.	Date	Sample Time	Water, %	Oil, %
Sampling Period 21.07.2021 - 30.07.2021				
1	21.07.2021	10:30	89	11
2	21.07.2021	11:00	82	18
3	22.07.2021	16:18	92	8
4	22.07.2021	16:48	97	3
5	23.07.2021	15:25	93	7
6	23.07.2021	15:55	92	8
7	24.07.2021	12:45	96	4

NO.	Date	Sample Time	Water, %	Oil, %
8	24.07.2021	13:15	93	7
9	25.07.2021	11:30	93	7
10	25.07.2021	12:00	93	7
Average			92	8
11	26.07.2021	15:00	89	11
12	26.07.2021	15:30	91	9
13	27.07.2021	11:30	66	34
14	27.07.2021	12:00	88	13
15	28.07.2021	12:35	87	13
16	28.07.2021	13:05	72	28
17	29.07.2021	15:50	89	11
18	29.07.2021	16:20	88	12
19	30.07.2021	11:00	86	14
20	30.07.2021	11:30	91	9
Average			84.7	15.4

From those samples, details data were analyzed, and contribution from each stage is listed below.

Table 4—1st Batch Results

NO.	Date	Sample		Oil, %			Water, %			Water Cut, %		
		Total Oil %	Total Water %	Stage 1 Code 1	Stage 2 Code 2	Stage 3 Code 3	Stage 1 Code 1	Stage 2 Code 2	Stage 3 Code 3	Stage 1	Stage 2	Stage 3
1	2021.07.21	11	89	29	40	31	26	48	26	88	91	87
2		18	82	35	35	30	24	52	24	76	87	78
3	2021.07.22	8	92	37	47	16	29	51	20	90	93	93
4		3	97	21	58	21	23	57	20	97	97	97
5	2021.07.23	7	93	18	57	25	27	46	27	95	91	93
6		8	92	32	45	23	28	51	21	91	93	91
7	2021.07.24	4	96	33	46	21	24	55	21	95	97	96
8		7	93	36	47	17	23	58	19	89	94	94
9	2021.07.25	7	93	37	45	18	24	57	19	90	94	93
10		7	93	30	44	26	28	51	21	93	94	91
	Average	**8**	**92**									
11	2021.07.26	11	89	25	44	31	29	48	23	90	90	86
12		9	91	27	46	27	29	49	22	92	92	89
13	2021.07.27	34	66	30	41	29	23	55	22	60	72	60
14		13	88	26	37	37	25	53	22	87	91	80
15	2021.07.28	13	87	21	42	37	24	50	26	88	89	82
16		28	72	38	34	28	26	50	24	64	79	69
17	2021.07.29	11	89	15	41	44	22	46	32	92	90	85
18		12	88	20	60	20	19	50	31	87	86	92

NO.	Date	Sample		Oil, %			Water, %			Water Cut, %		
		Total Oil %	Total Water %	Stage 1 Code 1	Stage 2 Code 2	Stage 3 Code 3	Stage 1 Code 1	Stage 2 Code 2	Stage 3 Code 3	Stage 1	Stage 2	Stage 3
19	2021.07.30	14	86	15	60	25	25	47	28	91	83	87
20		9	91	13	32	55	18	44	38	93	93	87
	Average	**15**	**85**									

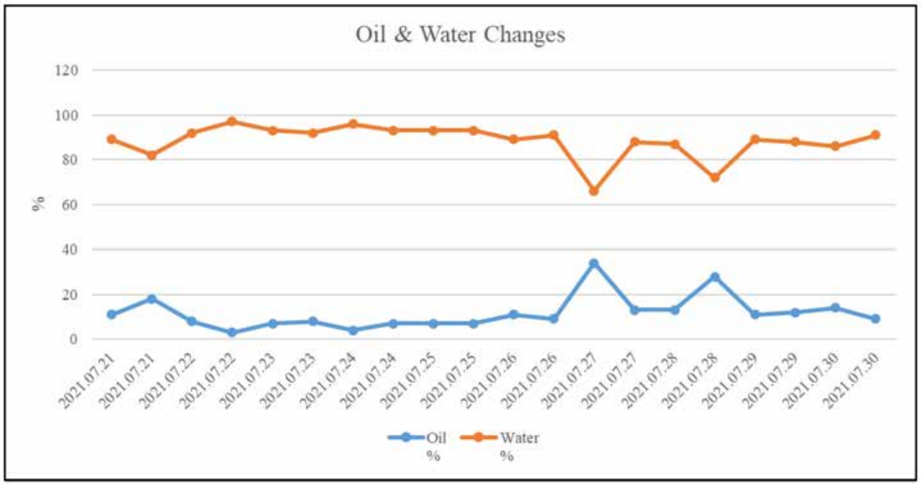

Figure.8—Oil and Water Changes

Oil and water separated from each sample were extracted with tracer respectively. Through the analysis of tracer content, the percentage of oil production and water production in each stage was obtained.

Data for 2 samples on same day were averaged; the distribution and change of oil production are consistent with the trend of water production. The higher the oil production a layer has, the higher the water production as well. Water content from stage 2 decreased from 55% (26.07.2021) to 39% (28.07.2021) during sampling period, with an average of 47%. The water production from stage 3 showed a gradually increasing trend in the later period, analyzed below.

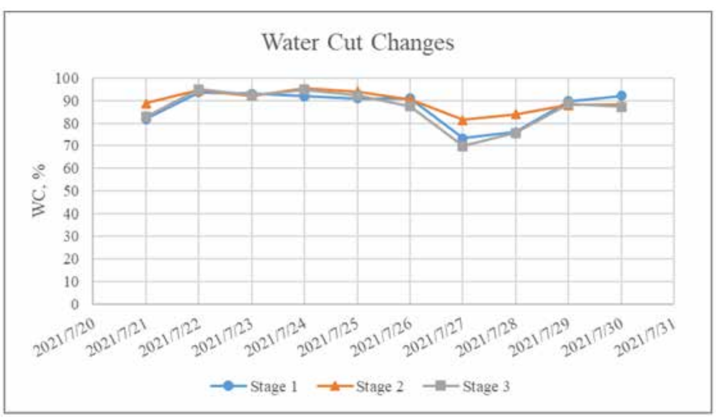

Figure.9—Water Cut Changes

Based on oil and water composition of each sample, as well as the distribution data of oil and water in these three intervals, the water content of the produced liquid in each interval was calculated.

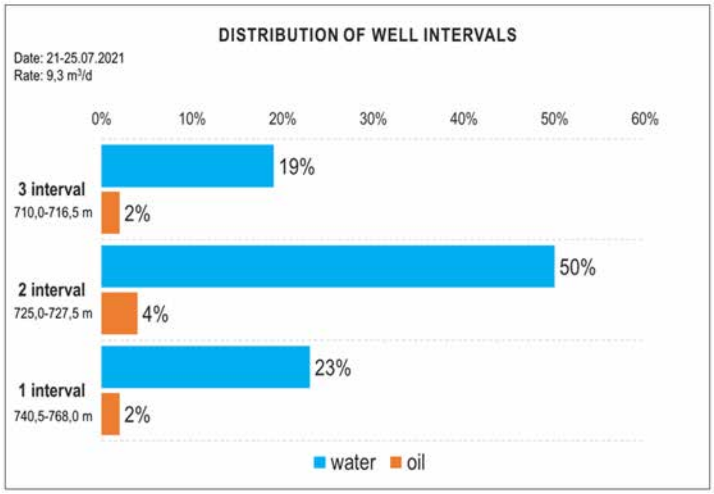

Figure.10—Distribution of Well Intervals (21-25.07.2021)

The average oil content of the whole well is 8% and the water content is 92%

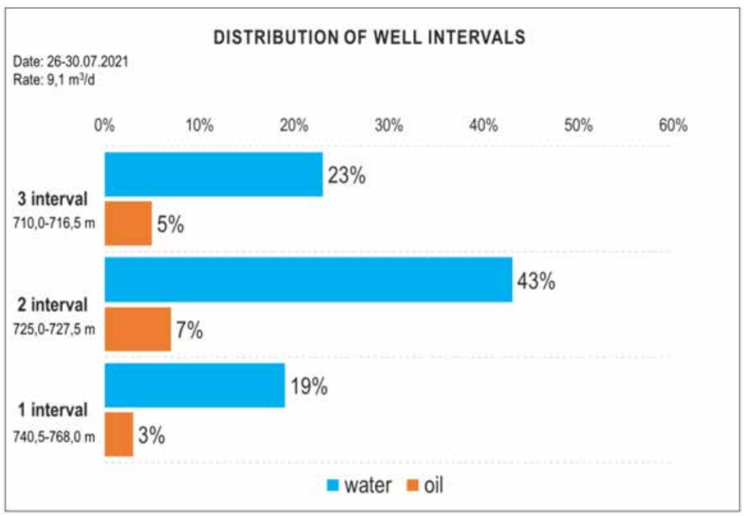

Figure.11—Distribution of Well Intervals (26-30.07.2021)

The average oil content of the whole well is 15% and the water content is 85%

Second Batch Results. Free water was detected in all samples. Individual samples have low oil content (4%-9%). Between 2-11 August 2021, Samples are 70-96% water. The average total water cut was 84% and the oil was 16%.

From 13-22 August 2021: The sample contains 79 -95% water. The average total water content is 87% and the oil content is 13%.

Table 5—2nd Batch Results

NO.	Date	Sample		Oil, %			Water, %			Water Cut, %		
		Total Oil %	Total Water %	Stage 1 Code 1	Stage 2 Code 2	Stage 3 Code 3	Stage 1 Code 1	Stage 2 Code 2	Stage 3 Code 3	Stage 1	Stage 2	Stage 3
1	2021.08.02	20	80	19	40	41	12	42	46	72	81	82
2		10	90	17	41	42	14	38	48	88	89	91
3	2021.08.04	30	70	16	40	44	13	37	50	65	68	73
4		25	75	17	37	46	15	38	47	73	75	75
5	2021.08.06	4	96	17	37	46	14	38	48	95	96	96
6		17	83	17	40	43	14	41	45	80	83	84
7	2021.08.08	18	82	15	26	59	12	40	48	78	88	79
8		9	91	16	30	54	12	39	49	88	93	90
9	2021.08.11	19	81	18	36	46	13	32	55	75	79	84
10		11	89	23	28	49	13	37	50	82	91	89
	Average	**16**	**84**									
11	2021.08.13	8	92	16	32	52	18	33	49	93	92	92
12		5	95	16	39	45	15	37	48	95	95	95
13	2021.08.15	21	79	10	39	51	16	34	50	86	77	79
14		19	81	12	36	52	15	39	46	84	82	79
15	2021.08.17	6	94	15	38	47	17	33	50	95	93	94
16		13	87	17	39	44	15	38	47	86	87	88
17	2021.08.19	13	87	15	39	46	18	34	48	89	85	87
18		10	90	14	42	44	13	38	49	89	89	91
19	2021.08.22	16	84	15	33	52	15	36	49	84	85	83
20		18	82	22	29	49	17	36	47	78	85	81
	Average	**13**	**87**									

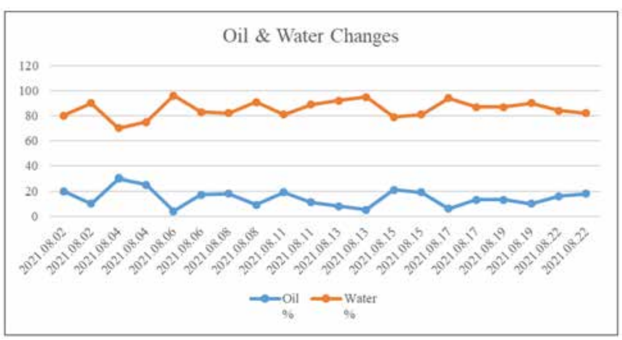

Figure.12—Water Cut Changes

Compared with the first batch, the water cut of this batch was slightly decreased.

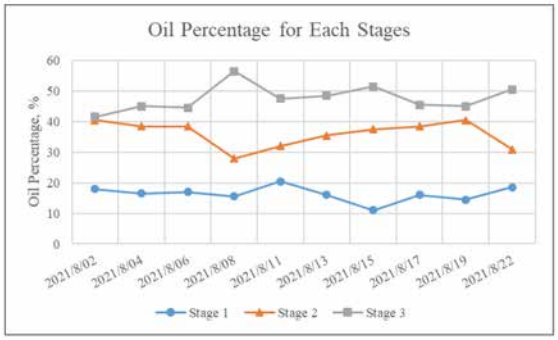

Figure.13—Oil Percentage for Each Stage

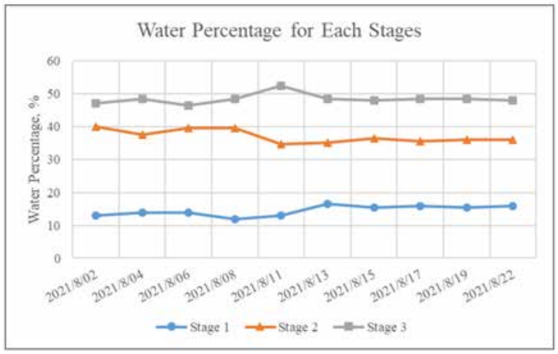

Figure.14—Water Percentage for Each Stage

In the second batch of sampling, the proportion of water produced in each stages tends to be stable, indicating that the output contribution rate of each section has reached a stable state.

The third stage produced majority of water, accounting for 42% of the wellbore fluid production. The proportion of oil production in each section is consistent with the overall trend of water production. The higher the oil percentage, the higher the water percentage.

The proportion of water produced in stage 3 was the highest, which was consistent with the trend of the first batch of sampling and the later data.

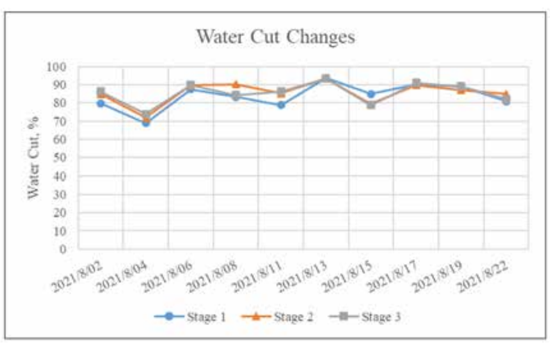

Figure.15—Water Cut Changes

Based on oil and water composition of each sample, as well as the distribution data of oil and water in all three intervals, the water cut of the produced liquid in each interval was calculated. The variation trend of water content in each section is similar.

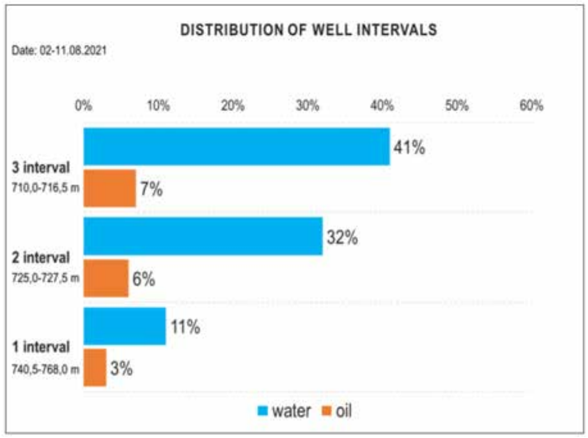

Figure.16—Distribution of Well Intervals (02-11.08.2021)

The average oil content of the whole well is 16% and the water content is 84%.

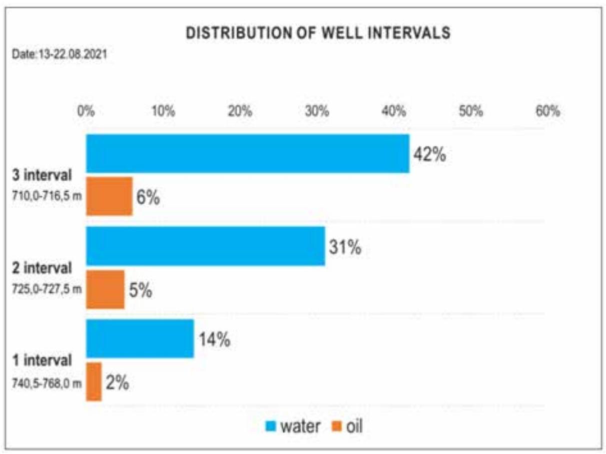

Figure.17—Distribution of Well Intervals (13-22.08.2021)

The average oil content of the whole well is 13% and the water content is 87%.

Analysis & Suggestions

Cause Analysis - Higher Water Production from Stage 3

During target well operation, two adjacent water injection wells stopped injection between 14 - 18 July. This well was affected by the contamination of well shut-in and workover fluid, which made it take a long time for well production to recover to the pre-monitored production after the operation, and the dynamic change process was 13 days.

Different stages have different influences on water injection effect, pressure diffusion after stopping injection, workover fluid pollution and so on.

During first inspection period, the proportion of water produced in stage 3 increased gradually as production resumed after workover, demonstrating the tracer's ability to monitor dynamic changes in the production profile in a short term.

During the second long period monitoring, wellhead pressure remained stable and consistent with the occurrence before monitoring operation. It can represent the oil and water production profile of this well during stable production period.

Suggestions

1. Analysis was carried out by using the existing tracer string and combining with injection adjustment

   Using the existing tracer string, by adjusting the water injection volume in the small zone of adjacent well #67 and #66, the dynamic changes of each small zone in well #49 are adjusted and tracked one by one, and the corresponding liquid production, oil production and dynamic reaction time of each small zone are determined to qualitatively identify the residual oil in each small zone. The disadvantage is that it can only be applied to target well, and other wells in the well group cannot be accurately analyzed.

   Residual oil identification: after two wells are stopped and then opened, there is a process of water cut falling and rising. The analysis shows that there is oil/water replacement in the well group unit, but the excessive water injection strength causes the oil / water replacement is not timely. By controlling the water injection volume of the water channel, the oil production of a single well can be increased
2. Use well group chemical tracer monitoring, comprehensive analysis of remaining oil distribution. It is suggested that water injection tracer monitoring should be carried out first for the two well groups to further clarify the oil-water relationship and analyze the remaining oil situation.

   At present, tracer interpretation includes qualitative and quantitative aspects. The results of qualitative analysis are obtained directly by using the test data. The quantitative calculation is to use the numerical simulation method to fit the output curve and get the parameters between wells. Or, other technology needs to be also utilized to identify residual such as using wide-field electro-magnetic monitoring technology.
3. Profile control and water plugging were carried out in two water injection Wells #67 and #66 to block the high permeability layer and use the remaining oil of the low permeability and no water absorption layer.

   From the situation of water cut rise in this well, the water injection of high permeability layer refers to the water intake mode. It is suggested to adopt profile control measures to block the high permeability layer, control the water absorption of the high permeability layer, increase the water injection pressure to the starting pressure of the low permeability layer, use the low permeability layer, and displace the remaining oil.
4. In similar wells, a water - controlled proppant can be used to retrofit fracture-mouth water-controlled production. (Sand production is controlled at the same time)

Conclusion

Within the specified contract period, complete the technical service content of the project and meet the relevant technical service requirements;

Two batches of field sampling were conducted in target well, and four sets of liquid production profile test data were obtained. The contribution rates of oil and water in each section were clear, and the main water-producing zones were effectively identified.

The sampling data from July 21 to 30 showed that the liquid production profile presented a dynamic change process, and the water production from stage 3 increased and gradually stabilized.

The sampling data from August 13 to 22 showed that the liquid production profile was stable with little changes. The proportion of liquid production in each section is as follows: 48% in the stage 3; 36% in the stage 2 and 16% in stage1. The water cut of each stage is around 86.1% - 87.5%, and there is no obvious difference in water percentage.

The tracer monitoring results in this well are consistent with the development of thin layer and water injection effect.