Typical case analysis of oilfield tracer testing technology

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Abstract. The development history and principle of interwell tracer testing and single-well tracer testing were investigated, and the application conditions and application advantages of different tracer testing were analyzed through the analysis of two types of tracer testing technologies and test results in the production process of SMi oilfield with medium porosity and low permeability, so as to provide reference for the study of tracer development in the same type of oilfield. Tracer testing technology can master the connection between injection well and production well, effectively judge the connection relationship between Wells, and provide a basis for well pattern adjustment; The seepage velocity of injected fluid in the formation can be directly observed, and the dominant injection direction can be determined, which provides reference for solving the plane contradiction. It can judge whether there is fracture system or high permeability strip, which provides ideas for high precision numerical simulation to avoid risks. It can master the remaining oil situation of single well and judge the washing efficiency of chemical agents effectively on the basis of saving investment.

Key words: Interwell tracer test; Single-well tracer test; Plane contradiction; Hypertonic band; Oil saturation

1. Introduction

Tracer testing technology was introduced in China in the 1980s. The early oilfield tracer technology only qualitatively described the subsurface movement direction of the injected fluid and the nonhomogeneity of the reservoir. With the development of technology and the increasing demand of oilfield development, oilfield tracer technology has gradually become an important reservoir engineering means in the process of secondary and tertiary oil recovery, and has been rapidly popularized and applied. [1]

Due to different development concepts and national conditions, foreign oil fields tend to pursue extreme benefits, and pay more attention to where there is oil, which layer of oil, how to quickly recover oil. The SMi field is a large onshore sandstone reservoir with medium porosity and low permeability. Production peaked in 1989, then began to decline, and stabilized for some time after adjusting the well pattern. In 2006, the water content exceeded 90%, and the effect of extracting liquid decreased gradually. From 2009 to 2013, a large range of multi-well group interwell tracer test was carried out to determine the advantageous waterflood direction and solve the interzonal waterflood contradiction, which provided support for the follow-up flood control and stable production and suppressed the production decline. In 2017, the oilfield has entered the ultra-high water cut stage. In order to prolong the life cycle of the oilfield, three times of oil production has been attempted in the plot block. On the basis of the preparation of the reagent, a single well tracer test was carried out to verify the oil washing efficiency of the reagent and judge the economic benefits of the three times of oil recovery. The tracer test of this oilfield is comprehensive in the development process, which can provide reference for other domestic oilfields in the same development process.

2. History, principles and classification of tracer testing

In the 1950s, chemical tracers such as inorganic salts, dyes, halocarbons and low molecular alcohols were used to qualitatively understand the movement of underground fluids. In the 1970s, the radioisotope tracers represented by tritium and tritium compounds appeared. In the 1980s, the stable isotope tracers represented by deuterium and its compounds were studied and applied. Due to their shortcomings, the first three generations of oilfield tracers could not meet the requirements of oilfield exploitation, which promoted the production of trace substance tracers. Since the mid-1960s, oilfield tracer technology has made great progress in many countries in the world. [1]

Tracers are substances that are easily soluble and can be detected at very low concentrations to indicate the presence, flow direction and flow velocity of the dissolved fluid in the porous medium. Commonly used tracers can be divided into distributive tracers and non-distributive tracers. Non-distributive tracers are only soluble in water, while distributive tracers are soluble in both water and oil. [2] Field tracer testing can be divided into two categories: interwell tracer testing and single-well tracer testing. Interwell tracer testing is used to determine interwell connectivity and permeability anomalies, while single-well tracer testing is used to study remaining oil saturation near the well.

2.1 Interwell tracer testing

The interwell tracer test (FIG. 1) involves injecting a tracer slug into the injection well and continuously monitoring the tracer production in the surrounding production well. The tracer concentration curve over time is called the tracer production curve. The production curve of the tracer was analyzed to gain knowledge of the reservoir. [2] The early analytical methods of interwell tracer testing could only be used to qualitatively judge the reservoir ground connectivity and the existence of deep bands. In 1984, Briham et al. used analytical methods to quantitatively analyze the tracer production curve, and the parameters were the average formation parameters between oil and water Wells. In 1997, the numerical simulation method was used to solve the formation parameters in China with objective accuracy. In 2001, a semi-analytical method combining numerical and analytical methods appeared. In recent years, on the basis of semi-analytical method, combined with reservoir modeling, profile analysis, numerical simulation and other methods to take advantage of each other to form a comprehensive interpretation method. [3]

Cross-well tracer testing can determine and analyze the heterogeneity of the reservoir in both horizontal and longitudinal directions. Determine whether there is a high permeability layer in the formation and calculate its permeability and other formation parameters; It can also be used to determine the type and dosage of profile control agent; If a distributive tracer and a non-distributive tracer are injected at the same time during the interwell tracer test, the non-distributive tracer is only soluble in water, because the two tracers differ greatly in oil solubility. However, distributive tracers are soluble in both water and oil and produce late. According to the production time difference and distribution coefficient of the two tracers, the remaining oil saturation in the study area was obtained.

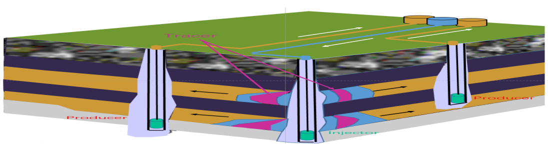

FIG. 1 Schematic diagram of tracer testing between Wells

2.2 Single-well tracer test

Single-well tracer tests (Figure 2), which measure remaining oil saturation with tracers injected and produced from the same well. Usually, a low molecular ester is injected as the first tracer, and then dissolved in water to form an alcohol as the second tracer. The distribution coefficients of the two tracers in oil and water are different. The first tracer is oil-philic and the second tracer is water-philic. The two tracers are separated during mining, and there is a time difference when their peaks reach the surface, according to which the remaining oil saturation can be obtained.

The determination of residual oil saturation by tracer method using the chromatographic effects of the formation was first proposed by Cooke. This method was successfully used by H.A. Daans to determine residual oil saturation in a model in the laboratory in 1967, applied to field tests in 1968, and tested three times in the same well in 1969 with success. Exxon Production Research patented the technology in 1971. From 1968 to 1993, more than 200 Wells were logged in the United States, Canada, Venezuela, North Sea and other oil fields. [4] Shengli Petroleum Administration Bureau began to study the single-well method to test residual oil saturation in 1981, and determined the technological process and interpretation method in 1987. Later, it was popularized and applied in Xinjiang Petroleum Administration Bureau and Yumen Petroleum Administration Bureau successively. [5] At present, the interwell tracer testing technology can not only store energy to determine the thickness and permeability of water-salt layer, the diameter of large pore, the channeling of injection well pipe and the perforation in the pipe, and the orientation of fractures, but also reflect the change of water injection quantity inside the waterflood layer, the contradiction between each waterflood layer and the distribution of remaining oil in water drive oilfield. [6]

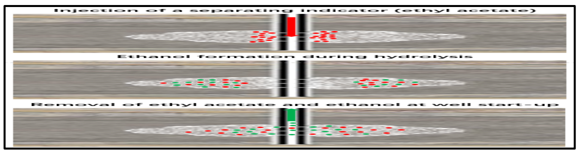

FIG. 2 Schematic diagram of single-well tracer testing

3. Case analysis

SMi Oilfield began to be put into production in 1982, and the reservoir saw water immediately after it was put into production. Most of the producing Wells had a short period of water-free oil production, and the water cut rapidly increased from 17.2% in the initial period to 80% (Figure 3). Production peaked in 1989, when water content remained below 40%, and then production began to decline. Water cut exceeded 80% in 2004 and 90% in 2010 (Figure 4). Comprehensive analysis shows that there may be hypertonic bands, which lead to this development phenomenon.

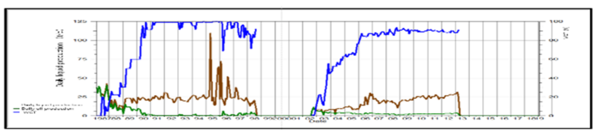

FIG. 3. Typical well production curve

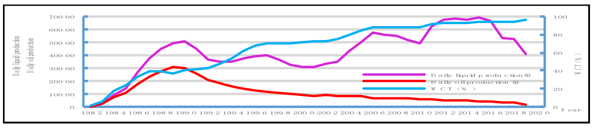

FIG. 4 Production curve of SMi oilfield

3.1 Interwell tracer testing

From 2009 to 2013, a total of 146 oil-well interwell tracer studies were conducted on 25 well groups in three target zones to investigate and study reservoir physical properties and assist in determining reservoir geological conditions. It plays a key role in the follow-up plugging and postponing production decline. Select injection Wells with injection rates greater than 100m³/d and inject tracers (e.g. Urea, guanidine thiocyanate, ammonium nitrate, sodium fluorescein) that are pre-dissolved in water into the Wells. 4-10 production Wells were selected around the injection well as monitoring Wells, and samples were taken within three months after the tracer injection. The reservoir physical property parameters were studied based on the tracer test. (Take layer 1# as an example)

Based on the tracer study results in well S, the following conclusions can be drawn: There is a good hydrodynamic connection between the S injection well and the surrounding Wells. The main flow line traced in the first 90 days percolated along the abnormally high conductivity interval. The average permeability of the seepage channel through which the tracer flowed was 6.96μm2, several hundred times higher than the designed level (0.187μm2). In the direction of Wells D, N and A, most of the tracers (58-66%) were percolated through channels with abnormally high conductivity (15-200μm2). Throughout the study period (90 days), tracer production accounted for approximately 71% of the injected volume (1000kg), and the total permeability of the tracer dominant channel was 137m3/d, accounting for 74% of the average daily injected water in well 5292. The main flow directions in the studied reservoir are as follows: northwest (13% of the injected water); Northeast direction: (44% of water injected); Southeast direction: (15% of the injected water); Southwest direction: (2% of water injected).

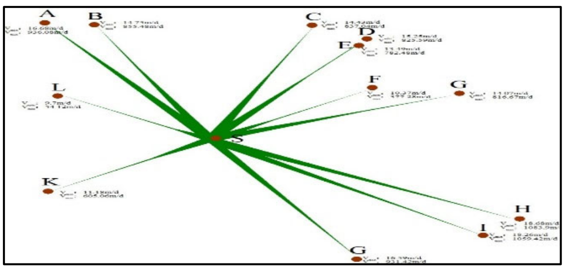

FIG. 5 Flow velocity and flow direction of the tracer in well S of Layer 1#

Table 1 Calculated permeability of small layer

Pound sign	Maximum permeability, μm²	Minimum permeability, μm²	Mean permeability, μm²	Calculated permeability value, μm²
A	187.2	3.3	11.4	
B	152.7	2.6	6.5	
C	146.7	2.5	5.7	
D	177.3	3.3	8.4	
E	135.4	2.3	5.0	
F	58.1	1.6	3.4	
G	145.3	2.5	5.8	0.187
K	274.6	4.7	11.4	
L	287.5	5.0	11.2	
N	202.7	3.6	9.7	
O	103.3	1.9	3.7	
Q	6.5	1.2	1.5	

The results of zone 1# tracer study showed that there was good connectivity between the injection well and the surrounding production well, and in most cases, the communication was through high conductivity channels. The distribution characteristics of seepage fluid and velocity indicate that the plane heterogeneity is serious. The average permeability of the pervious channels through which the tracer flowed varied from 4.6μm2 to 7.03μm2, which was several hundred times higher than the designed level (0.187μm2). The main distribution directions of low resistance seepage channels are northwest and southeast. The results of the interwell tracer test were consistent with permeability ranges from core, logging, and well testing studies, and the data were mutually verified.

3.2 Single-well tracer test

In 2018, the combined water content of the field exceeded 95%. In order to continue the field development cycle, the field is looking for a tertiary production partner. 2021 Partners successfully developed a polymer agent compatible with the formation on the basis of laboratory tests. To verify the efficacy of the agent, single-well tracer testing was conducted on selected Wells in late 2022.

Its work flow includes:

① Well selection: The study area should be located above the oil-water interface, without single-layer outburst, well casing seal condition, adequate formation energy, 2-6 meters near the well, 10 meters of effective thickness, and unfractured; (2) Select the appropriate tracer, verify its composition of five elements in laboratory, determine the hydrolysis rate and obtain the separation coefficient; ③ large dose injection of formation water; (4) Injection of tracer into the formation; (5) technical shut-in and interval sampling; ⑥ Interpretation of research results.

Site construction can be roughly divided into four stages: the first stage is the technical settlement of single well and the injection of a large amount of formation water into the formation; The second stage is to inject tracer into the formation. The third stage of chemical reaction technology settlement stage; Phase IV single well recovery and sampling phase. (Figure 6)

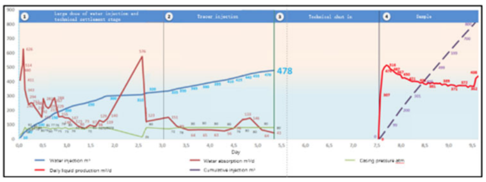

FIG. 6 Schematic diagram of single-well tracer test construction technology

The calculation formula is:

$$S_{oil} = \frac{((Q_{ethyl})/(Q_{ethanol} - \partial) - 1)}{((Q_{ethyl})/(Q_{ethanol} - \partial) - 1 + K_d)}$$

Among them:

Q_{ethyl} Is the extreme value of the ethyl acetate concentration curve, m³;

$Q_{ethanol}$ Is the peak of ethanol concentration curve, m³;

∂ Is wellbore volume, m³;

K_d Is the separation coefficient。

Single-well tracer test results showed an 8.2% decrease in near-wellbore residual oil saturation from the initial stage of production, translating to 15.5% enhanced oil recovery. The increase in oil recovery by chemical flooding was 13%-22%. The two results are consistent, which proves the reliability of the single-well tracer test and verifies the feasibility of the agent.

4. Conclusion

1) Interwell tracer test can master the connection between injection well and production well, effectively judge the connection relationship between Wells, and guide well pattern adjustment and new well exploration and deployment;
2) The dominant injection direction can be determined according to the different seepage velocity and water absorption of the injected fluid in the formation, which plays an auxiliary role in adjusting the development strategy;
3) Cross-well tracer testing can determine whether fracture systems and high-permeability bands exist in the formation, which can provide strong support for numerical simulation;
4) Single-well tracer test can measure multiple parameters such as residual oil saturation, bound water saturation and formation water salinity in the near-well zone. The reserve and distribution of residual oil plays an important role in determining whether an enhanced oil recovery method is economically viable.
5) With the continuous progress of tracer testing technology, the testing methods are diversified and the application scenarios are more convenient, which provides a broader prospect for the field research of tertiary oil recovery technology.

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