Research on Gas Drive Front Distribution of Storage in Oil Fields Based on Field Test Monitoring Inversion

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Abstract. The PG2 underground gas storage (UGS) is the first storage in oil fields which rebuilt a waterflooding reservoir. It is important to determine the gas injection front to improve the oil recovery and gas storage space utilization efficiency. Based on the pilot test of PG2 UGS, this paper carried out injection-production well test and production dynamic monitoring test, compared and analyzed the dynamic monitoring results before and after gas injection, and studied the distribution law of gas injection front under different technologies The results show that: (1) The formation pressure test results showed that 78% of wells in the test area responded to pressure, and the pressure diffusion rate is 3.8–11 m /d. (2) Tracer monitoring results showed that the main displacement direction was near the east-west direction, affecting the P25 well to the east and P12 well to the west, and the migration rate reached 3.6–6.8 m/d. (3) Combined with test results of formation pressure, tracer testing, production and absorption profile and saturation testing, the gas drive plane sweep is relatively uniform, and the well control zone plane sweep coefficient is 0.75. The longitudinal sweep range is small, and the longitudinal sweep coefficient is 0.3. The location of gas injection front is determined according to field test monitoring, which provides an optimization basis for the injection and production scheme design of subsequent PG2 UGS construction.

Keywords: injection gas front · gaseous tracer · formation pressure · storage in oil fields · recovery efficiency

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1 Introduction

It has been 20 years since the construction and operation of underground gas storage in China. Currently, there are 28 underground gas storage in operation in China, mainly gas reservoirs with relatively single storage types. The proportion of peak adjustment capacity of gas storage in natural gas consumption is less than 1/4 of that in developed countries [1–3]. With the increasing demand of the natural gas market in our country, high-quality gas reservoir sites are scarce, and the goal of reservoir construction is gradually changing into complex fault block groups, oil reservoirs, hydrocarbon reservoirs and many other types [4, 5]. Reservoir type gas storage is a type of gas storage that implements peak regulation to the market by injecting and producing natural gas into the reservoir, which can greatly improve reservoir recovery and peak regulation and supply protection ability of gas storage [6–8]. Different from the construction of gas reservoir reservoir, in the process of gas oil (water) high-speed interactive displacement, three-phase percolation mechanism, space utilization characteristics and expansion law are complicated, and gas channeling and other phenomena are easy to occur in the process of gas injection, resulting in the loss of reservoir construction space. Therefore, it is more important to study the distribution law of gas drive front in the process of reservoir construction. Wu Zangyuan et al. used microseismic method to monitor the gas injection well in 2005, and obtained the gas drive front, the sweep range of injected gas, the dominant gas injection direction and the gas sweep area of the block [9]. In 2017, Wang Dahai applied microseismic monitoring technology to the monitoring of CO_2 displacement front. Through interpretation and analysis of monitoring results, he could accurately understand the distribution state of gas displacement front, effectively guide CO_2 flooding injection and production parameters, and lay a foundation for remarkable results in the test area [10]. Xu Moyang et al. injected gas tracers into reservoirs developed by gas injection in 2008, which played an important role in studying reservoir connectivity, reservoir physical property, fault sealing, correlation analysis of injection production, corresponding relationship of gas injection, advancing speed of gas injection and determining gas channeling, etc. [11–13]. Based on the pilot test of PG2 UGS, this study defined the distribution location of gas drive front at the present stage by means of injection and production test, production dynamic monitoring and other means.

2 Study Area Profile

PG2 UGS is the target of the first batch of reservoir construction in Jidong Oilfield. The target Es1 is sustrustrine fan deposit. The reservoir thickness is large, the average porosity is 73.7 m, the average permeability is 189.4 mD, the average porosity is 14.9%, the average permeability is 189.4 Md. In the early stage of production, the single well has a high output and large gas capacity, with an average daily oil production of 119 tons per well and an average daily gas production of 115,000 cubic meters per well, demonstrating a good gas injection and production capacity. The preliminary study results show that this block has favorable geological conditions to accelerate the construction of gas storage. Focusing on the key issues of feasibility study such as the gas injection and production capacity of single well in reservoir construction, the formation and expansion law of secondary gas roof, and the effect of gas injection and liquid drainage and expansion, pilot tests will be carried out in May 2021.

3 Gas Injection Front Monitoring Design

The study on the formation and expansion law of the secondary gas top is one of the keys to reservoir construction. In order to grasp the law of natural gas movement in real time and prevent gas channeling, the dynamic monitoring framework scheme of the whole process is established in the pilot test program, and key monitoring items such as saturation, gas tracer and formation pressure are deployed to monitor the gas drive front and displacement interface.

(1) **Gas tracer monitoring**

Gas tracer, as a gas injection monitoring method, is used to inject a gas tracer into the injection well, take gas samples from the surrounding monitoring Wells, analyze the concentration of the tracer samples, and show the tracer production curve. The tracer interpretation software is used to analyze the tracer production curve, so as to judge the connectivity of the reservoir, estimate the gas channel time, and determine the location of the gas drive front. Gas tracer CH2FCF3 is injected after stable gas injection in gas injection well INJ, and gas samples are taken from Wells P11, P12, P13, P14, P15, P16, P21, P22, P23, P24, P25, P26, P31, P32, etc. According to the tracer situation in monitoring Wells, Dynamic tracking of injected gas movement in the formation to determine the direction of injected gas advance, inter-well connectivity, and the current injection gas displacement front.

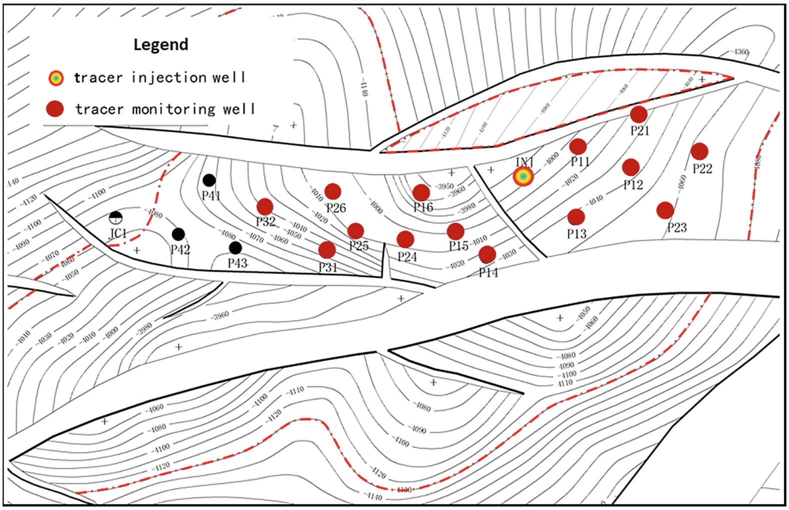

Fig. 1. Deployment diagram of the gas tracer monitoring

(2) **The fluid saturation monitoring**
Saturation monitoring: pulsed neutron full spectrum deep logging is performed by using pulsed neutron full spectrum logging tool (RPM). A single logging can complete the functions of two-sources-to-oxygen ratio and neutron lifetime logging, and directly evaluate the residual oil and gas saturation in the formation. By comparing the gas saturation values before and after gas injection, the gas drive front location can be determined. During the pilot test, two Wells, P12 and P24, were deployed to monitor the saturation of the formation fluid at different time points to determine the location of the gas drive front (Fig. 2).

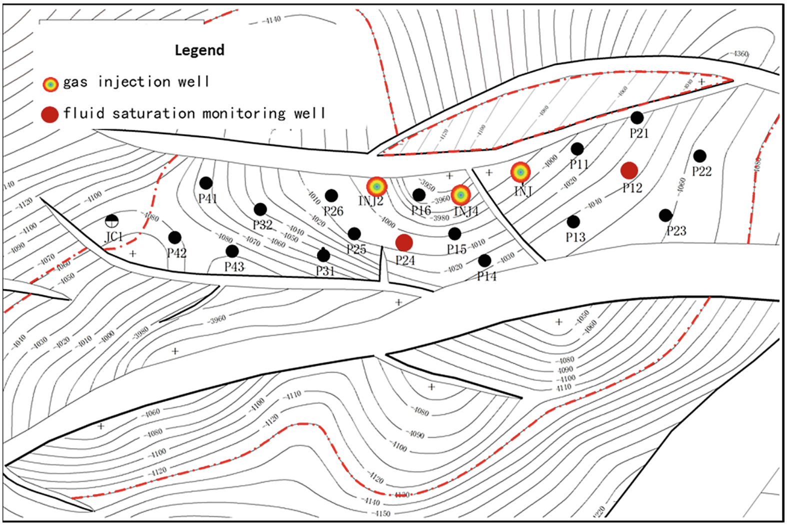

Fig. 2. Deployment diagram of the fluid saturation monitoring

(3) **Formation Pressure Monitoring**
Through gas injection, the formation energy can be continuously restored, and the formation pressure change at different times can be monitored by point measurement of formation pressure, and the pressure propagation speed and direction can be determined to implement the position of the gas drive front. A total of 22 Wells are deployed in the program (Fig. 3).

4 Monitoring Results and Analysis

(1) **Analysis of Gas Tracer Monitoring Results**
The gas tracer monitoring of LNJ well group involved 14 monitoring Wells. The monitoring target of this well group is Es1, and the distribution of injection Wells and monitoring Wells is shown in Fig. 1. The LNJ of the tracer injection well started gas injection in May 2021 with an average daily gas injection volume of 100,000 m^3 and injection pressure of 19.5 MPa. 20 kg of gas tracer CH2FCF3 was injected on July 21, 2021. By June 22, 2022, after 336 days of monitoring, Of the 14 monitoring

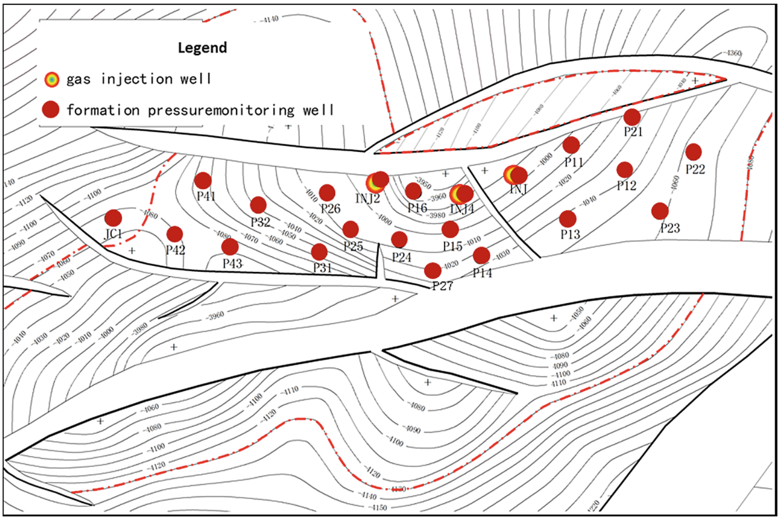

Fig. 3. Deployment diagram of the formation pressure monitoring

Wells, four Wells P11, P12, P15 and P25 produced the tracer injected by LNJ well. The detailed monitoring results of the well group are shown in Table 1. Gas tracer monitoring results showed that: The main displacement direction in the test area is near the east-west direction, spreading to the P25 well in the east and to the P12 well in the west. The breakthrough time of tracer is between 60 and 224d, and the migration rate reaches 3.6–6.8 m/d. The gas drive front location predicted by the gas tracer monitoring results is shown in Fig. 4.

(2) **Analysis of monitoring results of fluid saturation monitoring**
By 2022, 54 million cubic meters of gas has been injected in the test area. The saturation test results of two Wells show that the maximum gas saturation of P12 well has increased by 80% from 15% before gas injection to 27%. The maximum gas saturation in well P24 increased from 16% before gas injection to 33%, an increase of 106%. At the same time, the numerical simulation results also showed that the gas saturation in the high part of the structure increased gradually after gas injection, ranging from 20 to 32%. Saturation test results demonstrate that the injection front location has reached well P24 to the west and well P12 to the east.

(3) **Analysis of monitoring results of formation pressure monitoring**
Before the injection, the formation pressure of 21 Wells was applied in the pilot test area. During the gas injection process, 78% of the wellhead pressure in the test area responded with the response time of 35–170d, the pressure diffusion rate of 1.0–11.5 m/d, and the oil pressure increased by 0.7–8.4 MPa. Wells P41 and P43 had no water injection, but the formation pressure dropped after gas injection was stopped and converted to production. The rest of the 16 Wells can be compared with each other, and the pressure near the well has increased. The pressure in the high part of the structure has increased obviously (1.2–4.9 MPa), the pressure in the waist of the structure has increased 0.8–2.4 MPa, and the pressure in the low part has increased 0.3–1.3 MPa. The average formation pressure in the current injection volume of the

Table 1. INJ well group tracer monitoring results table

Serial number	well	Distance from injection well (m)	Date of first sighting of the tracer	Number of days (d)	Concentration (μg/L)	Gas drive velocity (m/d)
1	P15	400	2021.09.19	60	0.972	6.67
2	P11	267	2021.09.30	71	0.654	3.76
3	P12	462	2021.10.19	90	0.934	5.13
4	P25	811	2022.03.02	224	0.632	3.62
5	P13	278	No tracer was found during monitoring			
6	P14	409				
7	P26	890				
8	P21	571				
9	P22	783				
10	P23	636				
11	P31	951				
12	P32	1182				
13	P24	622	The well has been stopped for the duration of the survey			
14	P16	471				

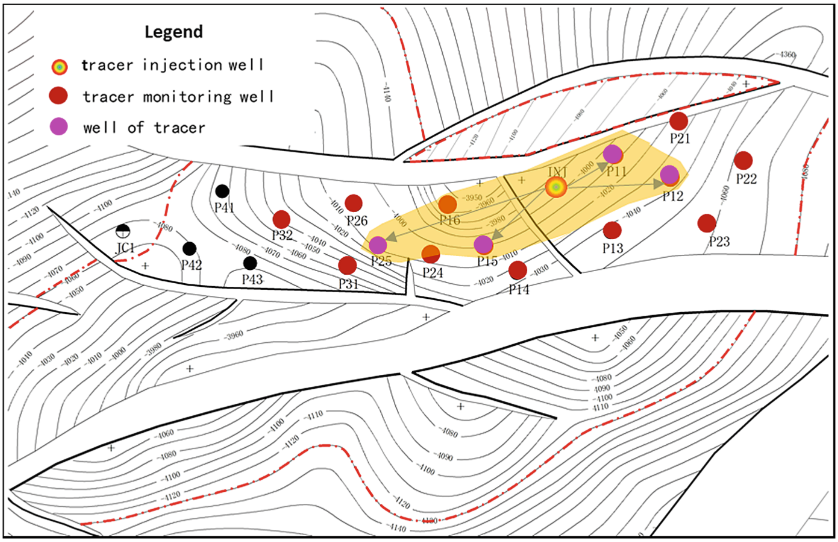

Fig. 4. Position of the gas drive front monitored by the gas tracer

test area has increased 2.0 MPa. The position of gas drive front predicted according to formation pressure monitoring results is shown in Fig. 5 (Table 2).

Table 2. Formation pressure test results

Type of well	Well	position	Formation pressure before gas injection (MPa)	Formation pressure after gas injection (MPa)	Difference value (MPa)
Oil well	P27	Low structural position	24.3	25.6	1.3
	P14		24.6	25.5	0.9
	P41		31.6	27.3	−4.3
	P43		30.2	28.1	−2.1
	P23		25.2	26.1	0.9
	P22		25.2	25.5	0.3
	P31		26	untested	
	P32		28.5	untested	
Gas injection well	INJ2	Structural elevation	22.3	27.2	4.9
	INJ4		21.9	25.1	3.2
	INJ		23	25.6	2.6
Monitoring well	P16		19.2	22.9	3.7
	P11		21.8	24.9	3.1
Oil well	P21		23.8	25	1.2
	P26		18.5	20.2	1.7
	P42		29.9	untested	
	P25	Structural loin	23.9	26.2	2.3
	P24		23	25.3	2.3
	P15		23.1	25.5	2.4
	P12		23.6	26	2.4
	P13		25.2	26	0.8

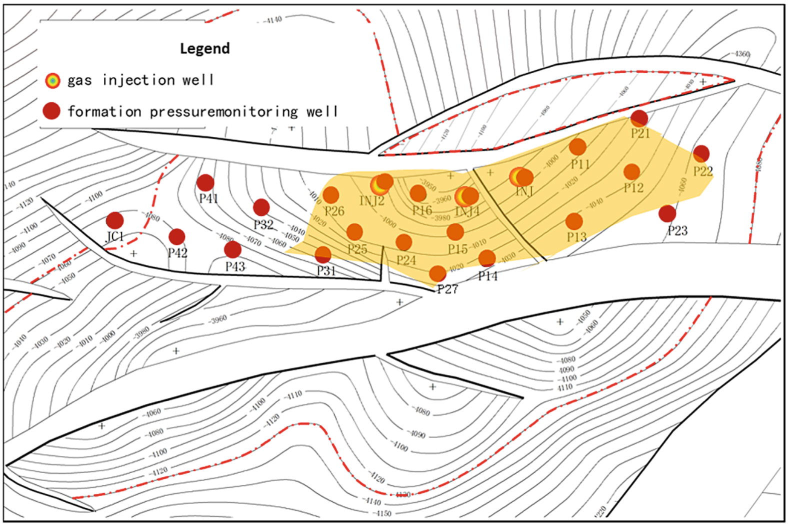

Fig. 5. Position of the gas drive front monitored by pressure test results

5 Conclusions

(1) The distribution of gas injection front under different technology can be determined by field test.

(2) The formation pressure test results showed that 78% of wells in the test area responded to pressure, and the pressure diffusion rate is 3.8–11 m/d.

(3) Due to the limited gas injection, it is recommended to continue the injection production test, and further determine the location of the gas injection front to consolidate the foundation of feasibility study.

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