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Experimental Study on Gas Breakthrough Prevention by Flue Gas Drive

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Abstract. The heterogeneity of glutenite reservoir is serious, and breakthrough is easy to occur in the process of water drive and gas drive, which reduces the sweep efficiency. The serious vertical heterogeneity in the H well area of Xinjiang oilfield led to the rapid gas breakthrough during gas injection test. Water alternating gas flooding and foam profile control are often used to seal breakthrough. In this paper, based on the actual reservoir characteristics, vertical heterogeneous planar model is made for flooding experiment. The experimental results show that after gas breakthrough caused by water alternating gas flooding, the flue gas foam can effectively block the high permeability layer and develop the low permeability layer, improve the sweep efficiency and recovery percent, and provide reference for the development adjustment of actual reservoir after gas breakthrough.

1 Introduction

Most of the oilfields in China belong to continental sedimentary type, with great difference in permeability and serious heterogeneity. The glutenite reservoirs are widely distributed in Xinjiang. The preferential seepage channel is formed by long-term water flooding, which leads to low swept range of injected water; the subsequent injected gas flows along the preferential channel and gas breakthrough occurs earlier, which significantly reduces the gas injection effect. The interlayer heterogeneity is serious in H well area of Xinjiang oilfield, and the difference of vertical producing degree is wide. Nitrogen injection test was carried out in the test site, and gas breakthrough occurred 8 days later. The existing research shows that water alternating gas flooding and foam profile control are often used to slow down gas breakthrough and enhance oil recovery.

Compared with the core experiment, the physical simulation experiment of 2D planar model is closer to the actual situation of the reservoir, and can reflect the law of the water and gas breakthrough and the effect of measures to control gas breakthrough to a greater extent. In addition, a large amount of flue gas was produced after heavy oil thermal recovery and in-situ combustion in Xinjiang oilfield. The selection of flue gas for injection medium can save cost and realize the recycling and effective storage of flue gas. Therefore, based on the planar model flooding experimental equipment and planar sand packed model, the laboratory physical simulation experiment of the control of gas breakthrough during flue gas drive is carried out in this paper, which provides reference for the development and adjustment measure of heterogeneous reservoir after flue gas breakthrough.

2 Experimental Preparation

2.1 Injection Gas

The flue gas on site was sufficient, which has been selected for injection. The sample gas was prepared using standard pure gas according to the flue gas composition on site. Flue gas molar composition is shown in Table 1.

Table 1. Composition of flue gas

Components	N_2	CO	CO_2	O_2	CH_4	H_2
Mol , %	83.913	0.24	14.67	0.49	0.42	0.267

2.2 Simulated Oil

By adjusting the mass ratio of lead isooctanoate to n-iodobutane, the viscosity of simulated oil is consistent with that of crude oil under formation conditions. A set of formula was obtained to adjust the viscosity of the simulated oil by controlling the mass ratio of the first two. The simulated oil sample was made with this formula, and then the viscosity of the sample was tested to verify the formula.

The formula of the simulated oil is shown in Table 2. The viscosity of the simulated oil is 15.15 mPa·s, which matches the viscosity of crude oil 15.2 mPa·s under

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formation conditions (temperature 42.0 ℃, current formation pressure 8 MPa), which can be used for subsequent experiments.

Table 2. Simulated oil formulation

	lead isooctanoate	n-iodobutane
mass ratio	1.139	1

2.3 Production of 2D Planar Model

The model of large-scale planar sand packed model (40cm × 30cm × 3cm) is made by mixing quartz sand, seaming glue and water in the mold under normal temperature and pressure.

In the production process, the proportion of quartz sand and seaming glue was constantly adjusted to optimize the porosity and permeability of the planar model, and then the core was cut from the planar model for verification. The formula of planar model is shown in Table 3.

Table 3. Formula of planar model

Permeability / mD	Thickness / cm	Quartz sand mass / g (40-70 mesh)	Quartz sand mass / g (80-160 mesh)	Seaming glue / g	Water / g
1000	1	130	30	32.5	1
500	1	130	30	34.7	1
200	1	130	30	35.2	1
100	1	130	30	36.1	1

3 Experimental Equipment and Procedures

3.1 Experimental Equipment

The 2D planar model experimental equipment used in this experiment is mainly composed of injection pump, intermediate container, planar model holder, confining pressure pump, temperature control system, gasometer and liquid fraction collector.

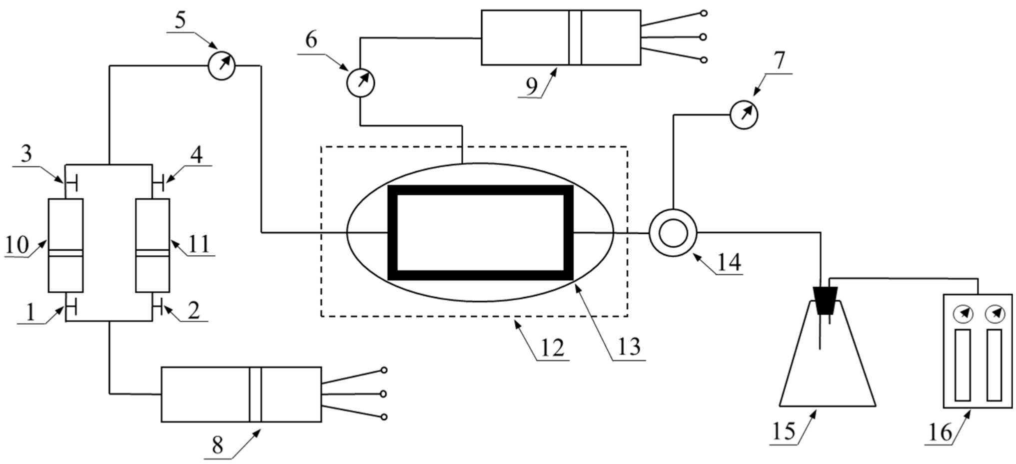

Fig 1. The experimental flow of gas breakthrough control in the planar model

In the Figure 1: 1, 2, 3, 4 - valve; 5, 6, 7 - pressure gauge; 8 - injection pump; 9 - confining pressure pump; 10 - gas intermediate container; 11 - liquid intermediate container; 12 - temperature control system; 13 - planar model holder; 14 - back-pressure valve; 15 - gasometer; 16 - liquid fraction collector.

3.2 Experimental Procedures

Two groups of experiments are carried out in the planar model.

The first experiment is flue gas / water alternative flooding (WAG) after water flooding.

The second experiment is WAG + flue gas foam flooding after water flooding.The experimental flow is shown in Figure 1.

(1) Prepare the equipment

Assemble the planar model and the planar model holder, calibrate the instrument, clean and dry the pipeline, vacuum after temperature test and pressure test, and keep it constant to the current formation temperature of 42 ℃.

(2) Establish irreducible water saturation

When the formation water is saturated at constant pressure, oil displaces water until no water is produced, establishing irreducible water saturation. The water injection rate and water production rate are recorded in the whole process.

(3) Saturate oil sample

Set the pressure to 8MPa, and the oil samples with several times of pore volume are used for displacement. When the fluid composition at the outlet is basically consistent with the displacement oil composition, gas oil ratio and other parameters, the oil sample is saturated.

(4) Experiment

The first experiment and the second experiment are tested.

The first experiment: when water flooding reaches 95% of water cut, switch to WAG until a certain well gas breakthrough is closed, continue production and close gas breakthrough wells one by one until all production wells are closed, and stop experiment.

The second experiment: when water flooding reaches 95% of water cut, turn to WAG, until a certain well finds gas breakthrough, turn to flue gas foam flooding, close gas breakthrough wells when breakthrough occurs in a certain well, continue production and close gas breakthrough wells one by one, and stop experiment after all production wells are closed.

(5) Clean the planar model

After the experiment, clean the planar model with petroleum ether and anhydrous ethanol.

During the experiment, the gas and liquid displacement rate is 4ml / min. The WAG is flue gas and water injection alternately. The injection slug volume is 0.1HCPV, and the gas - liquid ratio is 1:1. The flue gas foam flooding is flue gas and foaming agent solution injection alternately. The injection slug volume and the gas - liquid ratio are the same as the former.

4 Results and Discussion

According to the actual reservoir characteristics, two kinds of planar models with vertical permeability ratio of 10 are made for experiments, as shown in Fig 2, Fig 3 and Table 4. At present, three - level separate injection is implemented in the field, and the main layer may be injected separately in the later stage. Therefore, the main body of the planar model is divided into three layers, with the thickness of 8cm, 14cm and 8cm respectively.

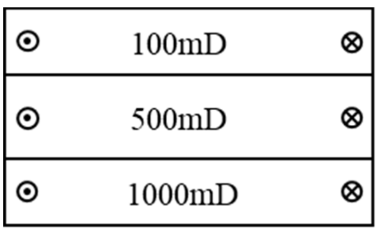

Fig 2. Schematic diagram of the 1st planar model

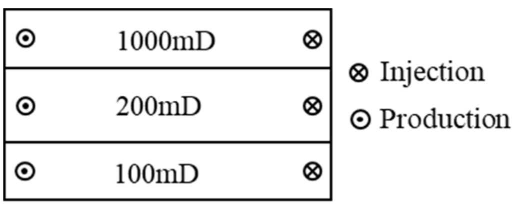

Fig 3. Schematic diagram of the 2nd planar model

Table 4. Parameters of planar models

Planar model parameters	1st	2nd
Total volume, ml	3600	3600
Porosity,%	30.81	28.67
Pore volume, ml	1109	1032
Irreducible water saturation,%	25.88	40.21
Irreducible water volume, ml	287	415
Oil volume, ml	822	617

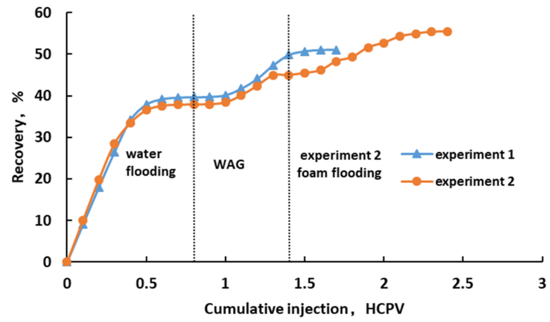

Fig 4. Recovery curve

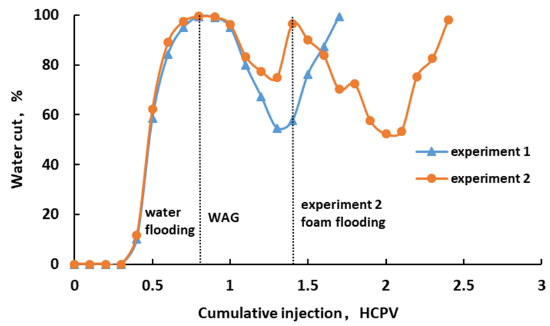

Fig 5. Water cut curve

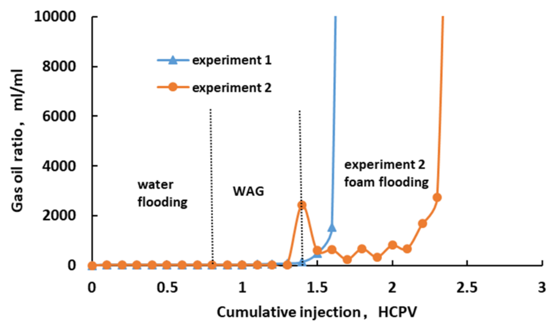

Fig 6. Gas oil ratio curve

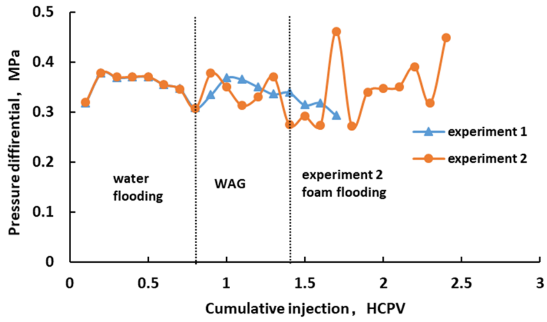

Fig 7. Pressure differential curve

Table 5. Results of planar model experiment

Recovery,%	Group 1	Group 2
Water drive	39.66	37.88
WAG	11.41	7.01
Flue gas foam flooding	—	10.53
Cumulative	51.07	55.42

The experimental results are shown in Fig 4 ~ Fig 7. In the first experiment, the pressure differential decreased gradually during water flooding. When water flooding was converted to WAG, the pressure differential increased from 0.308MPa to 0.368MPa, and the water cut decreased from 100% to 54.64%. Then, the pressure differential gradually decreased. In the experiment, when the cumulative injection of 1.5HCPV, the gas oil ratio rose sharply and the well was shut in quickly.

In the second experiment, when the cumulative injection of 1.4 HCPV, the gas breakthrough, water cut and gas oil ratio increased. After the flue gas foam flooding, the water cut and gas oil ratio continued to decrease, the water cut decreased to 52.3%, the gas oil ratio remained at a low level, and the pressure differential showed a fluctuating upward trend. When the cumulative injection of 2.2 HCPV, the gas breakthrough, water cut and gas oil ratio increased rapidly, and finally shut in after the cumulative injection of 2.4 HCPV.

In the first experiment, the injection water quickly formed a preferential seepage channel along the high permeability layer, resulting in the gradual decrease of pressure differential. The three-phase flow of oil, gas and water was formed by WAG, which improved the seepage resistance and pressure differential, and expanded the sweep efficiency. However, after the breakthrough of flue gas, the water cut and gas oil ratio increased rapidly, and the subsequent injection medium was ineffective circulation. The WAG has limited effect on the planer model with large permeability ratio.

In the second experiment, after WAG and gas breakthrough, the recovery factor was increased by 10.53%, and the gas oil ratio and water cut were optimized. The results show that the flue gas foam entered into the high permeability layer preferentially, reduced the mobility ratio, improved the pressure differential, significantly prolonged the gas breakthrough time, and the subsequent injection medium flowed to the low permeability layer and displaced the remaining oil. The experimental results show that under the condition of large permeability ratio and gas breakthrough caused by WAG, the flue gas foam can effectively block the preferential channel and improve the sweep efficiency and recovery factor.

5 Conclusions

(1) In reservoirs with high permeability ratio, water and gas were prone to cross flow along high permeability channel, which was ineffective circulation. Based on the actual reservoir characteristics, vertical heterogeneous planer model was made for displacement experiment, which could truly reflect the water and gas breakthrough laws and foam flooding control gas breakthrough effect compared with core experiment.

(2) In the experiment of planer model displacement, three - phase flow of oil, gas and water was formed by WAG, which improved the seepage resistance and pressure differential to a certain extent, and expanded the sweep efficiency. However, the gas oil ratio and water cut increased rapidly after gas breakthrough, and the producing degree of WAG to the planer model with high permeability ratio was limited.

(3) In the case of large permeability ratio and gas breakthrough caused by WAG, the flue gas foam could effectively block high permeability layer and develop low permeability layer, improved sweep efficiency and recovery percent, and provided reference for development adjustment after gas breakthrough in actual reservoir.

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