



Experimental Study on Fracturing Fluid Damage of Tight Sandstone Reservoirs Based on Nuclear Magnetic Resonance Technology

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ABSTRACT

This study based on nuclear magnetic resonance (NMR) technology, systematically evaluated the microscopic damage mechanism of fracturing fluids on tight sandstone reservoirs. Through core displacement experiments, combined with permeability tests and T2 spectrum analysis, the impact of fracturing fluids on the pore structure and seepage capacity of the reservoir was quantified. The experimental results showed that the core permeability significantly decreased (35.76% to 66.41%) after fracturing fluid displacement, with an average matrix damage rate of 54.55%. The NMR T2 spectrum indicated that the high-molecular components in the fracturing fluid preferentially invaded and adhered to the medium and large pores, causing their pore size distribution to shift towards micro and small pores, and the overall pore volume decreased. X-ray diffraction analysis revealed that the water-induced swelling of clay minerals further exacerbated the blockage of medium to large pore throats, destroying the seepage channels. The study confirmed that the main cause of damage to tight sandstone reservoirs was the physical blockage of medium to large pore throats by fracturing fluids and the water sensitivity effect of clay minerals, providing key experimental evidence for the optimization of fracturing fluid formulations and reservoir protection.

KEYWORDS

Tight Sandstone; Fracturing Fluid Damage; Nuclear Magnetic Resonance.

1. INTRODUCTION

Due to the complex micro-pore structure and poor porosity and permeability of tight reservoir, fluid migration, fracturing effect and efficient production effect of gas reservoir are severely restricted. Tight sandstone gas reservoir has low permeability, small pore throat and complex pore throat structure, which is easy to cause reservoir damage due to fracturing fluid loss and incomplete flowback during fracturing. The evaluation of fracture fluid damage performance of tight sandstone gas reservoir plays an important role in the development of tight sandstone gas reservoir.

A lot of research on fracturing fluid damage of tight sandstone has been carried out at home and abroad. Ren et al. conducted an experimental study on the imbibition behavior of fracturing fluid, determined the effects of interfacial tension, permeability, oil viscosity and imbibition fluid salinity on imbibition behavior, and analyzed fluid distribution and related changes in imbibition and displacement processes based on nuclear magnetic resonance technology [1]. Tang et al. found that the retention of fracturing fluid residues in fractures is the main cause of permeability damage, and the polymer and salt-out crystallization in fracturing fluid will also cause damage to the reservoir in different degrees [2]. Xu et al. studied formation damage caused by fracturing process and the degree of damage at different times through core flow experiment and low-field nuclear magnetic resonance technology [3]. Through field monitoring and indoor simulation, Liu et al. show that tight sandstone

reservoirs are sensitive to velocity and stress, and fracturing fluid is easy to cause structural damage and affect reservoir performance [4]. Zhang et al. found through experiments that the damage of fracturing fluid to matrix permeability was greater than that of rubber breaking fluid, and the pore throat structure became complicated after intrusion, which affected fluid flow [5]. Wang et al. have shown that the retention distribution and adsorption form of fracturing fluid have a significant impact on the permeability recovery and gas productivity of tight sandstone, and the adsorption characteristics of different types of clay minerals are significantly different [6].

2. EXPERIMENTAL PART

2.1. Experimental Equipment

The experimental content is mainly based on nuclear magnetic resonance technology to evaluate the damage of fracturing fluid to tight sandstone. The instruments used in the experiment include core gripper, ISCO pump, thermostat, pressure gauge, return pressure valve, hand pump, nuclear magnetic resonance instrument, X-ray diffractometer.

2.2. Experimental Materials

Tight sandstone core sample, actual formation water, N₂ with purity of 99.99%, fracturing fluid breaking fluid.

2.3. Experimental scheme and procedure

Fracturing fluid intruding into tight sandstone is easy to induce water locking effect, fluid retention and throat blockage. Nuclear magnetic resonance (NMR) was used to measure the T₂ spectrum and permeability of the core before and after liquid injection, and the influence on the pore structure and seepage capacity of the reservoir was evaluated by analyzing their changes. Specific experimental steps are as follows:

- (1) The core was dried and nitrogen was forward displaced, and the permeability K₁ of the original core was measured;
- (2) The core was evacuated and saturated with KCl solution;
- (3) Nuclear magnetic resonance tests were conducted on the saturated core to obtain the T₂ spectrum;
- (4) Reverse displacement was carried out with fracturing fluid and gel breaking fluid for 15 days. The displacement was stopped, the confining pressure was kept constant, the temperature was maintained at 80°C, and the reaction was fully carried out for more than 12 hours;
- (5) The fully reacted core was taken out, and the core was positively displaced with nitrogen at a displacement higher than that of the atmosphere for 15PV. The gas permeability K₂ after the fracturing fluid and gel breaking fluid displacement was measured, and the damage rate of the fracturing fluid to the core was calculated;
- (6) Saturated KCl solution and conduct nuclear magnetic resonance testing.

2.4. Experimental results and analysis

2.4.1. Core basic physical properties

After the selected core is pretreated, its basic physical properties are tested, and the experimental results are shown in Table 1.

Table 1 Basic core information

Sample ID	Length/cm	Diameter/cm	PV/cm ³	Permeability/mD
1#	9.43	2.49	0.65	0.0937
2#	9.25	2.51	2.74	0.1978
3#	8.74	2.51	2.86	0.5421
4#	9.08	2.51	0.72	0.0153

XRD clay mineral test was carried out on the core, and the relative content of clay minerals was obtained. The experimental results are shown in Figure 1.

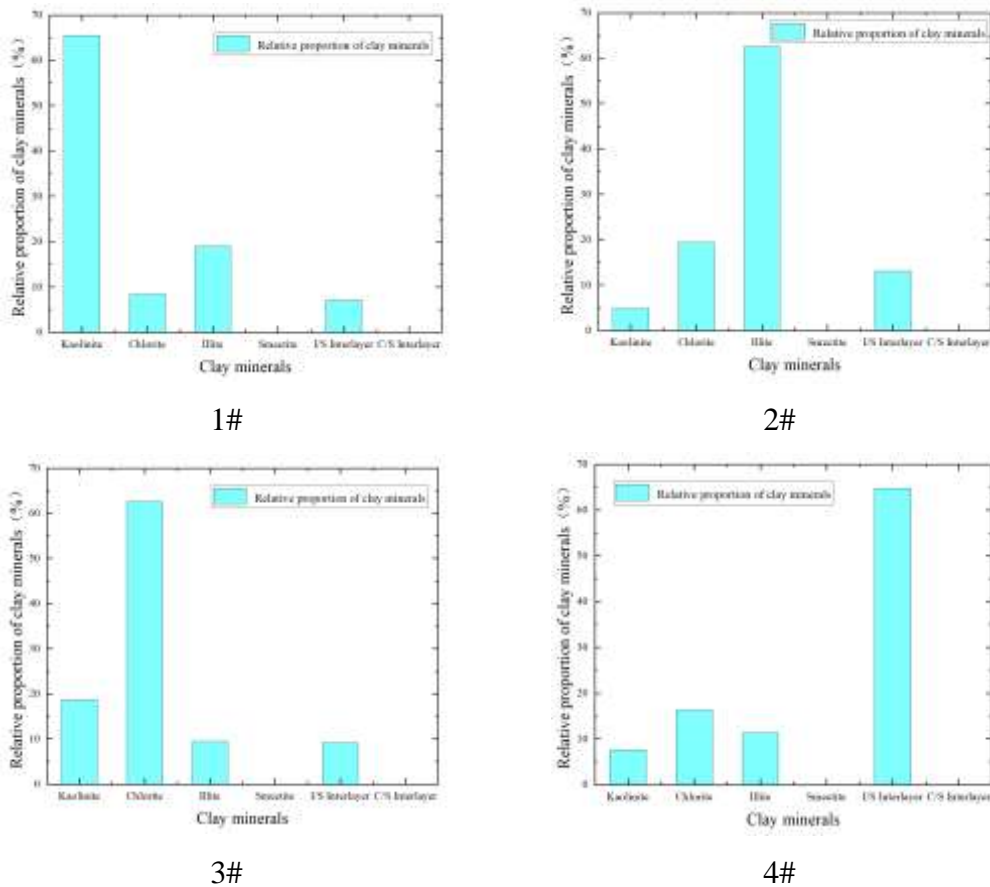


Figure 1. Relative content of clay minerals in core

The highest content of kaolinite in clay minerals of 1# rock sample is 65.3%, followed by 18.2% illite. The highest illite content in the clay minerals of rock sample 2# is 62.7%, followed by chlorite content is 18.9%. The highest content of chlorite and kaolinite in clay minerals of rock sample 3# is 62.3% and 18.6%. The content of kaolinite in clay minerals of 4# rock sample is 7.8%, followed by illite content of 11.7%.

2.4.2. Fracture fluid damage characteristics to core

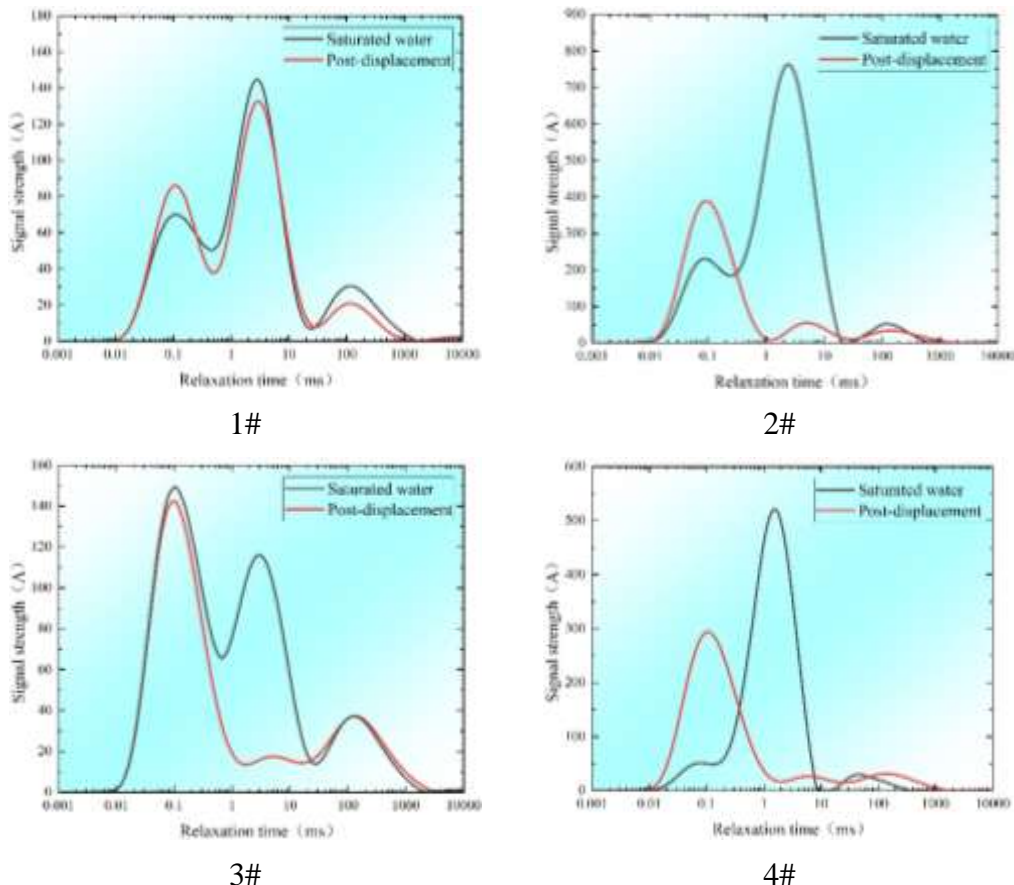
Based on the change of core permeability parameters before and after fracturing fluid damage test, the quantitative characterization of core damage degree can be realized. The experimental results are shown in Table 2.

Table 2 Results of gas permeability measurement

Sample	K1/mD	K2/mD	Matrix damage rate/%
1#	0.0937	0.0325	65.31
2#	0.1978	0.1237	37.46
3#	0.5421	0.2075	61.73
4#	0.0153	0.0073	52.38

The experimental results show that the core original permeability ranges from 0.0153mD to 0.5421mD, and the original gas permeability of rock samples is generally low. After fracturing fluid break fluid displacement, the core permeability generally decreased, and the matrix damage rate ranged from 37.46% to 65.31%, with an average of 54.22%. There was some damage after fracturing fluid entered the core.

In order to characterize the dynamic effects of fracturing fluid intrusion on reservoir pore throat structure, nuclear magnetic resonance (NMR) technology was used to conduct T2 spectrum tests on core samples before and after fracturing fluid treatment. Based on the nuclear magnetic resonance theory, T2 relaxation time represents the transverse relaxation characteristics of hydrogen nuclei in pore fluid, and its spectral distribution has a quantitative correspondence with the pore radius distribution. According to the pore classification standard of T2 spectrum, the reservoir pore system can be divided into four categories: micropore ($T_2 < 1\text{ms}$), small hole ($1\text{ms} < T_2 < 10\text{ms}$), medium hole ($10\text{ms} < T_2 < 100\text{ms}$) and large hole ($T_2 > 100\text{ms}$), which can effectively reflect the pore size distribution characteristics of porous media.

**Figure 2.** T2 spectral distribution curve before and after fracturing fluid injection into the core

As shown in Figure 2, tight sandstone mainly develops micro-pores and small throats. After the displacement by fracturing fluid, the amplitude of the nuclear magnetic resonance T2 spectrum is significantly lower than the original distribution. The displacement by fracturing fluid reduces the

pore-throat volume of tight sandstone gas reservoirs, indicating that the fracturing fluid has a certain degree of damage to the micro-pore-throats of the reservoir.

As can be seen from Table 1, after fracturing fluid displacement, the permeability generally decreased, and the matrix damage rate reached 65.31%. As can be seen from Figure 2, the signals of large and middle holes in the core are weakened, while those of small and micro holes are enhanced, indicating that after fracturing fluid displacement, large and medium holes are blocked into small and micro holes, resulting in an increase in the number of small holes and micro holes, but the overall pore throat content is relatively reduced. The analysis shows that after fracturing fluid displacement, the polymer components in fracturing fluid mainly enter and adhere to the middle and large pores of the core, resulting in an increase in the number of micropores and small holes in the core and a decrease in the number of middle and large pores. At the same time, it can be reflected in Figure 1 that the tight sandstone contains a certain amount of clay minerals, indicating that during the process of fracturing fluid entering the core, the middle and large pores are blocked due to the sensitivity of flow rate. Moreover, the water in fracturing fluid enters the core, resulting in clay expansion, which increases the number of small holes and microholes in the core, and decreases the number of large and medium pores, affecting the seepage channel. Resulting in a decrease in permeability. This shows that fracturing fluid damages the reservoir mainly to the medium and large pores in the tight sandstone.

3. SUMMARY

(1) The original gas permeability of rock samples from tight sandstone gas reservoirs is generally low, ranging from 0.0153mD to 0.5421mD. After being displaced by fracturing fluid, the permeability basically shows a decreasing trend.

(2) In the process of fracturing fluid displacement, the polymer in fracturing fluid mainly invades the medium and large pores of tight sandstone reservoirs and sticks to them. Moreover, the water in the fracturing fluid will cause clay expansion of clay minerals in the reservoir, which will reduce the pore throat volume and permeability.

(3) It can be seen from the nuclear magnetic curve that the number of holes and large holes in the rock samples decreases, while the number of microholes and small holes increases. Fracturing fluid mainly causes damage to medium and large pores in tight sandstone reservoirs.

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