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RESEARCH PAPER

Experiments on shale reservoirs plugs hydration

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Abstract: By using nuclear magnetic resonance (NMR) and CT scanning technologies, hydration experiments have been conducted on shale samples from the Lower Silurian Longmaxi Formation in Zhaotong area in North Yunnan and Guizhou Provinces under the confining pressure of 10 MPa to study the effect of hydration on the propagation of pores and natural fractures in shale formation. The results show that the hydration not only offsets the permeability drop caused by confining pressure, but makes the fracture network more complicated, the connection between fractures and pores better with larger volume, and permeability higher by facilitating the dilation, propagation and cross-connection of primary pores, natural fractures, and newly created micro-fractures; hydration damage mainly occurs along the bedding plane or the direction of primary fractures; samples with better-developed primary pores and fractures are most affected by hydration, samples with best-developed primary pores and natural fractures are less affected by hydration, samples with only pores are least affected by hydration; and the hydration intensity of shale plugs is affected by the development of primary pores and fractures, clay content, brittleness index, confining pressure and the hydration duration jointly. Therefore, in shale reservoir stimulation, it is suggested that the pumping schedule, shut-in operation or clean-up with small choke during early flow-back process be considered according to the features of shale reservoir to enhance the complexity and connection of facture network and improve the stimulation effect.

Key words: shale reservoir; stimulation; flow-back process; hydration; NMR; CT scanning; pores and natural fractures

Introduction

The large scale slick-water fracturing is a key technology for stimulating shale reservoir, which is characterized by low flowback ratio of injected fluids[1–2], without full knowledge on the existence mode and effect on reservoir of residual slick-water. Most of previous theoretical and experimental studies put focus on the initiation and propagation of hydraulic fracture net-work, but there isn't a clear understanding on the effect of original pore-fracture structure on stimulation and gas production performance. Under capillary force and osmotic pressure, the massive pore-fracture system in shale has strong water-absorbing capacity, thus external liquids can be absorbed into shale reservoir to interact with clay minerals etc., which is the so-called hydration effect. Researchers in China and abroad have mainly looked into the strength parameters variation of shale outcrops after imbibition under atmospheric pressure[3–7], which has provided some guidance for drilling. But the previous experimental results cannot represent the impact of hydration on shale under reservoir stress condition, and has paid little attention to the effect of hydration on shale stimulation.

In this study, the impact of hydration on shale plugs at confining pressure of 10 MPa is investigated by the spontaneous hydration experiment to study the interaction between residual fracturing fluids and shale rock, which can provide theoretical support for choke management, hydraulic fracturing strategy and drilling-fluid system design of shale reservoir.

1. Experimental introduction

Shale has a complicated pore-fracture system, leading to high capillary force, which is one of the main drives of spontaneous imbibition. Based on identifying development degree of pore-fracture structure in shale plugs, the experiments tested the impact and sensitivity of hydration on the original pore-fracture structure.

1.1. Experimental apparatus

The experiments were carried out with a hydration instrument developed independently (Fig. 1), in which confining pressure could be applied on the shale plug in the core holder, and the core holder was immersed into fluid which can be absorbed into the plug from its two ends. The evolution of pore-fracture was evaluated by CT scanner with a highest

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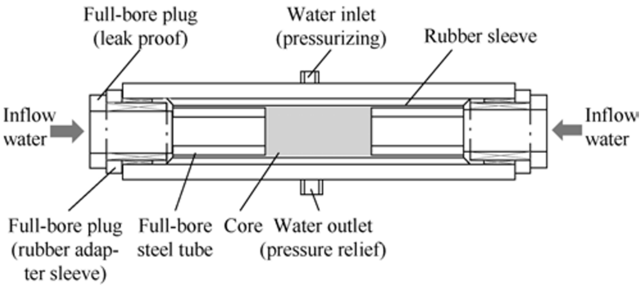

Fig. 1. Schematic of hydration experiment under confining pressure.

resolution of 0.5 μm, and NMR with a frequency of 12.798 MHz and magnetic strength of 3.0 T.

1.2. Experimental method

Different in principle, nuclear magnetic resonance (NMR) and CT technology detect damages of different scales in shale plugs. Therefore, the experimental plugs were divided into Group A and Group B in this study, which were measured by NMR and CT technologies respectively to analyze the impact of hydration on shale plugs.

The plug was jacketed in the core holder under confining pressure of 10 MPa, and then immersed into a container full of deionized water. Under capillary force, the water would be absorbed into the shale plug from two ends of the holder. The distribution of T_2 spectra (transversal relaxation time) of samples were obtained via NMR at different times. The greater value of T_2 represents larger pore structure. Although the T_2 spectra can reflect the pore structure of the plug, it can't distinguish pores from fractures. Therefore, in this paper, the inner structure of the plug was described as small-sized pore-fracture structure and large-sized pore-fracture structure.

3D images of the plug can be obtained by CT technology which is based on the electrical signals resulted from the interaction between x-ray and the material[8]. Because of the larger size of the samples, the actual scanning accuracy was 30 μm. All plugs were heated for 48 h at 105 °C to dry out the water, and scanned to get the original structure. After hydration for 21 h, the samples were dried and scanned again under the same condition, and the CT data of the two times were compared and analyzed.

1.3. Sample preparation

The shale samples were cored from high quality shale reservoir at the depth of 2 300 m in Lower Silurian Longmaxi Formation in Zhao Tong area located in North Yunnan and Guizhou Provinces. Table 1 shows the physical parameters of the plugs (25 mm in diameter and 50 mm in length).

In the diagenetic process of shale, higher content of brittle minerals such as quartz and calcite would result in more effective pores and micro-fractures, thus, the brittleness index, to some extent, can reflect the primary development degree of pores and fractures in shale and the potential of their further development[9–10]. Gas permeability of the plug measured by steady-state flow experiment reflects the ability of the plug to transmit the fluids under a certain differential pressure, and can be used to characterize the development degree of pore-fracture to some extent. However, the development degree of pore-fracture structure may be judged inaccurately simply based on gas permeability if there is a large natural fracture existing in the uncomplicated pore-fracture system. In order to avoid this, the gas permeability, porosity and brittleness index were considered jointly, and their product was used to represent the development degree of the primary pore–fracture structure and the potential ability of the plug to transmit the fluids. According to the magnitude order of the product, the experimental samples were divided into 3 levels of pore-fracture development degree, not-developed, better-developed and best-developed as shown in Table 1.

By using NMR and CT scanning, the development features of pore–fracture spaces in the plugs were described quantitatively further. As shown in Fig. 2, in Group A, 3# plug has the best developed pore–fractures structure, 2# plug is in the second place, and 3# plug is the last, which matches with the identifying results from the product of gas permeability, porosity and brittleness index. Fig. 3 shows that in Group B, 6# plug has the most pore-fracture structure, 5# plug has some pores and fractures, while 4# plug has no natural fracture, and they have a volumetric fraction of pore-fracture of 3.700 0%, 1.250 0%, and 0.0052% respectively.

2. Results and discussion

2.1. T_2 spectra of experimental plugs

2.1.1. Shape of T_2 spectra

The T_2 spectrum shape characterizes the distribution of pore–fracture structure in the plug. The longer the transversal relaxation time, the larger the size of pore- fracture structure will be.

Table 1. Physical parameters and development degree of pore-fracture structure of the cores

Group No.	Plug No.	N_2 permeability/ 10^{-3} μm^2	Porosity/ %	Wettability	Clay content/%	Brittleness index/%	Product of permeability, porosity and brittleness Index/μm^2	Development degree of pore-fracture structure
A	1#	0.002 1	0.67	Hydrophilic	29.0	29.1	4.09×10^{-9}	Not developed
	2#	0.960 0	2.20	Hydrophilic	16.1	44.7	9.44×10^{-6}	Better-developed
	3#	10.020 0	6.60	Hydrophilic	31.9	28.5	1.88×10^{-4}	Best-developed
B	4#	0.001 6	0.96	Hydrophilic	29.0	29.1	4.47×10^{-9}	Not developed
	5#	0.900 0	1.06	Hydrophilic	13.6	32.2	3.07×10^{-6}	Better-developed
	6#	12.180 0	6.43	Hydrophilic	31.9	28.5	2.23×10^{-4}	Best-developed