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Study on pore characteristics and microstructure of sandstones with different grain sizes

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ABSTRACT

The grain sizes have a pronounced influence on the pore characteristics and microstructure of sandstone. This work examined the pore structure and characteristics of three kinds of sandstones with different grain sizes using the scanning electron microscopy (SEM) and nuclear magnetic resonance (NMR) methods and analyzed their grain size distributions, pore size distributions, T_2-distributions, and porosity variations. The experimental results showed that sandstones with different grain sizes have significant differences in the microstructures grain size distribution, pore size distribution, T_2-distribution, and porosity variation. The results show that coarse, medium and fine sandstones have two peaks in T_2-distributions, mean grain size of 398.5, 145.1 and 25.1 μm, respectively, mean pore size of 46.3, 25.9, and 8.4 μm, respectively, porosity of 7.52%, 5.88% and 1.55%, respectively, indicating that both coarse and medium sandstones contain big pores, while fine sandstone contains small pores. This study is of significance for understanding of water migration characteristics in aquifers and gas in coal seams after the working face exploitation.

1. Introduction

Sandstone is a representative sedimentary rock formed by the consolidation and compaction of sand grains of 0.05–2 mm in diameter. The size and homogeneity of these grains have significant effects not only on the mechanical characteristics of sandstone itself but also on the structure and characteristics of pores inside it. Therefore, exploring the pore and microstructure characteristics of sandstone will benefit not only our understanding of water migration characteristics in aquifers and gas in coal seams after the working face exploitation, but also our understanding of the internal causes of rock movement and mine pressure phenomena.

The study on rock microstructure started in the beginning of the 1930s only with the naked eyes and magnifying glassed. With the advent of the electron microscope, the study on the rock microstructure and their pore characteristics begin to step in the quantitatively research from the qualitative analysis. Some researchers independently used the mercury injection test and scanning electron microscope to study the pore structure of shale (Wang et al., 2014; Yang et al., 2013; Jiao et al., 2012; He et al., 2014) and found that the pore-size distribution of shales is very broad covering from the predominant mesopores (2–50 nm) to a certain amount of micropores (<2 nm) and to some macropores (>50 nm). Some researchers explored the effect of temperature on rock microstructure (Rong et al., 2015; Chen et al., 2005) and believed that both micro-fractures and fractures in rock grains occur under the influence of high temperature. He et al. (2005), Zhou et al. (2012a, b) and Liu et al. (2003) studied on the pore characteristics and size distribution in rocks by using nuclear magnetic resonance (NMR). Zhou et al. (2015) employed the T_2-distribution measured by NMR relaxometry to examine the porosity and pore size distributions in rocks. Some researchers investigated the rock's pore structure during freezing and thawing cycles using NMR (Zhou et al., 2012a, b; Li et al., 2012) and found that after rock underwent the freezing and thawing cycles, its porosity increased, but there was no significant relationship between the number of cycles and the increase in porosity.

The grain size of sandstone has a direct influence on its microstructures, pore characteristics, mechanical characteristics, rupture form and initial flaw length. Li et al. (2015) observed the microstructures of three kinds of sandstones using SEM and established a discrete element model to compute the mechanical behaviors of these rocks based on their microstructures. Many researchers (Kang, 2013; Cheung et al., 2012; Jiao et al., 2004; Fredrich et al., 1990; Wong et al., 1996) studied the effect of grain size on the mechanical properties of rocks and found that the grain size of these rocks significantly affects their mechanical properties and their strength decreases with the grain size increasing. Hatzort and Palchik (1997), Eberhardt et al. (1999), and

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Brace (1961) examined the effect of grain size on the crack initiation stress and critical flaw length in dolomites and found that the fracture initiation stress is shown to be inversely related to the mean grain size, while the initial flaw length is found to be directly proportional to the mean grain size. Wasantha et al. (2015) observed the microstructure and pore size distributions of sandstones with different grain sizes using the thin section identification technique and scanning electron microscopy (SEM) and obtained the microstructure and pore size distributions of the three kinds of sandstones with different grain sizes. However, they focused on the influence of strain rate on the mechanical behaviors.

Although many researchers have studied the microstructure and pore characteristics of different kinds of rocks, the variation characteristics of micro structure and pore characteristics of rocks under different conditions, the effect of grain size on peak strength, crack initiation stress and critical flaw length of rock in recent years, the pore structure and microstructure characterization of sandstones with different grain sizes are not well known. Because changes in microstructure and pore structure of rocks are the internal cause for the effects of grain size on peak strength, crack initiation stress and critical flaw length. Therefore, in this study, we focused on exploration of the pore structure and microstructure of sandstones with different grain sizes using SEM and NMR.

2. Experimental procedures

2.1. Collection and preparation of sandstone samples

In order to study the pore characteristics and microstructure of sandstones with different grain sizes, three types of sandstones with coarse, medium, and fine grains were respectively collected from Buertai Coal Mine of Ordos, Inner Mongolia, China, as shown in Fig. 1. Further, for the NMR tests, 9 sandstones samples (three coarse grain sandstones, three medium grain sandstones and three fine grain sandstones) were drilled from each types of sandstone and processed into cylinders with 50 mm in diameter and 100 mm in length. At the same time, three sandstone samples (one coarse grain sandstone, one medium grain sandstone and one fine grain sandstone) of about 0.3 cm^2 were prepared for SEM detection.

2.2. Test instruments

2.2.1. Scanning electron microscope (SEM)

The pore characteristics and microstructure of sandstones with different grain sizes were analyzed using a JSM-6390LV scanning electron microscope (SEM) manufactured by Japan Electronic Co., Ltd. (Fig. 2).

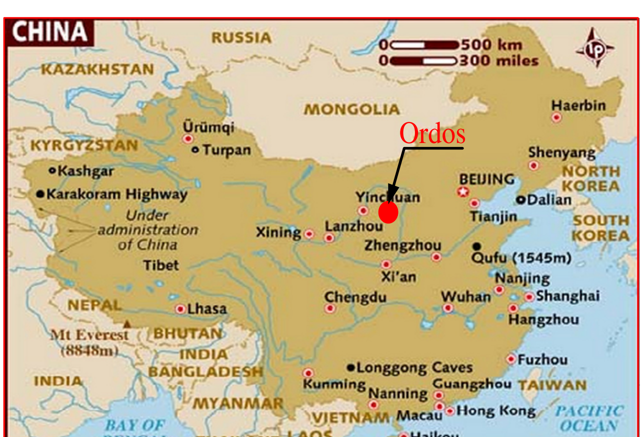

Fig. 1. Locations of collection samples.

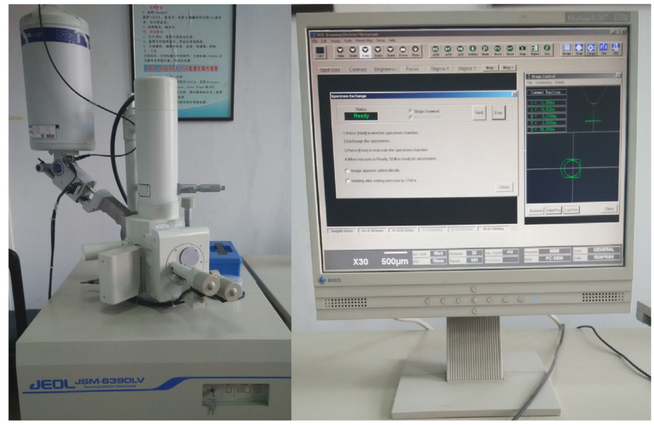

Fig. 2. Scanning electron microscope instrument.

The SEM has accelerating voltage of 0.5–30 kV, magnification of 30–300,000, and the aperture of 3.0 nm at the high vacuum mode (30 kV).

2.2.2. Nuclear magnetic resonance (NMR)

The pore sizes and their distribution in various samples were observed using a NMR relaxometry (Fig. 3). The device mainly includes: NMR magnets, electronic control system and NMR test software. In the test process, the temperature of the control box was 32 °C.

2.3. Experimental steps

2.3.1. Experimental procedure of SEM

Firstly, the samples were processed into 0.5 cm ∗ 0.5 cm ∗ 0.5 cm size. Then, fix the sample using a conductive adhesive tape on the microscope stage. Meanwhile, coat the sample with a thin gold layer using the ion-sputtering apparatus (SCD500). Finally, scan the sample and observe the pore characteristics and microstructures of the sample.

2.3.2. NMR experimental steps

Firstly, the sample was put into the vacuum saturation device for pumping. The vacuum pressure is 0.1 MPa, and the gas extraction time is 4 h. Secondly, injected distilled water into the sample to saturation for 24 h. Thirdly, wrap the sample with a plastic film and put it on

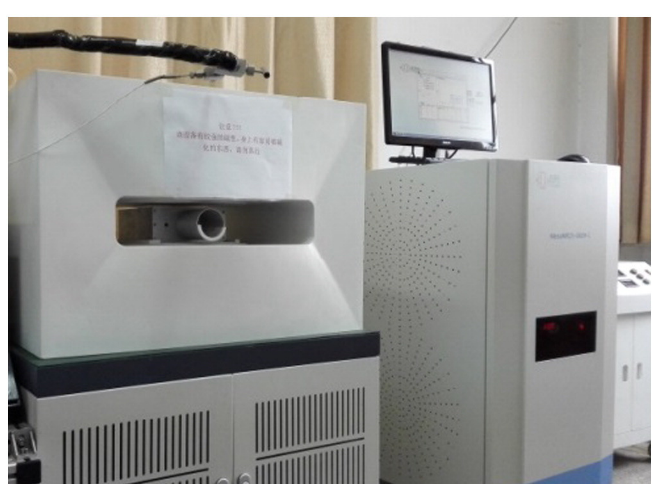

Fig. 3. Nuclear magnetic resonance (NMR) instrument.