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Dynamic Change Laws of the Porosity and Permeability of Low- to Medium-Rank Coals under Heating and Pressurization Treatments in the Eastern Junggar Basin, China

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ABSTRACT: Deep coalbed methane exists in high-temperature and high-pressure reservoirs. To elucidate the dynamic-change laws of the deep coal reservoir porosity and permeability characteristics in the process of coalbed methane production, based on three pieces of low- to medium-rank coal samples in the eastern Junggar Basin, Xinjiang, we analyse their mercury-injection pore structures. We measured the porosity and permeability of the coal samples at various temperatures and confining pressures by high-temperature and confining pressure testing. The results show that the porosity of a coal sample decreases exponentially with increasing effective stress. With increasing temperature, the initial porosity increases for two pieces of relatively low-rank coal samples. The increased rate of porosity decreases with increasing confining pressure. With increasing temperature, the initial porosity of a relatively high-rank coal sample decreases, and the rate of change of the porosity become faster. An exponential relationship exists between the porosity and permeability. With increasing coal rank, the initial porosity and permeability decrease. The change rate of the permeability decreases with increasing porosity.
KEY WORDS: high-temperature and confining pressure, coalbed methane reservoir, porosity, permeability, dynamic change.

0 INTRODUCTION

China is rich in deep coalbed methane resources. The geological resource of coalbed methane is 11.93×10^{12} m^3 between 1 500–2 000 m in depth, accounting for 32.4% of the total resources above 2 000 m, which are mainly distributed in the northwestern Junggar Basin and the northern regions of the Ordos Basin and Qinshui Basin (Liu et al., 2009). In the Junggar Basin, there is a 3.87×10^{12} m^3 coalbed methane resource that is shallower than 2 000 m and a 1.57×10^{12} m^3 coalbed methane resource at a reservoir depth between 1 500 and 2 000 m. The favourable area is mainly distributed in the Fukang and Wucaiwan areas (Li et al., 2012). It is known that with increasing buried depth, the permeability of a coal seam is reduced. This is disadvantageous for mining deep coalbed methane resources (Qin et al., 2012; Cui and Bustin, 2005). However, successful examp- les exist. For example, at the start of this century, the United States performed a co-mining experiment of deep coalbed gas and low-permeability sandstone gas in the White River uplift of the Piceance Basin. The buried depth of the target coal seam was 1 560–2 561 m, and single-well gas production of 65 wells is stable at approximately 10 890 m^3/d, 60% of which is derived from the coal seam (Olson et al., 2002; Nelson et al., 2000). There are 30 coalbed gas wells in three Rocky Mountain basins that produce from reservoir depths greater than 1 370 m. The cumulative gas production through year-end 2001 from these 30 deep coalbed gas wells totals 1.12×10^{15} m^3 (Nelson, 2003). In the Chinese eastern Junggar Basin, we have tested coal seam gas at the Jurassic formation in 1993. We obtain 2 000–4 000 m^3/d airflow (Cui et al., 2007). From 2005 to 2007, using an abandoned conventional oil and gas well, we performed fracturing and drainage in a deep coal seam, the depth of which is 2 567–2 583 m. The maximum production capacity is 6 500 m^3/d (Qin et al., 2012). The engineering practice proves that there is still a large recoverable potential for deep coalbed methane under the conditions of high temperature and high pressure.

It is difficult to measure the dynamic-change law of coal seam permeability in the coalbed methane mining process directly. Studying the relationship between the coal porosity, permeability and formation temperature and pressure is an

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indirect way to predict the variation of deep coal seam permeability.

The relationship between the porosity and permeability of coal reservoirs has been investigated. Many of them are the empirical equation (Moosavi et al., 2014; McKee et al., 1988; Reiss, 1980; Carman, 1956). Palmer and Mansoori (1998, 1996) deduced a simplified formula for the porosity and permeability of coal rock. Permeability is proportional to the third power of porosity, which is widely used in coal reservoir numerical simulations. However, the relationship between the porosity and permeability of coal reservoirs under high-temperature and high-pressure conditions has not been reported.

Many studied have been performed, both in China and globally, on the relationship between the coal rock porosity, permeability and temperature and pressure. McKee et al. (1988), Palmer (2010, 2009) discussed the deep coal rock porosity and pore compressibility with dynamically changing effective stress. However, the deep coal rock pore compressibility under high-temperature and high-pressure conditions has been only infrequently reported. Niu et al. (2014), Yin et al. (2013), Perera et al. (2012), Qin et al. (2012), Jasinge et al. (2011), Harpalani and Mopherson (1984), and Somerton et al. (1975) investigated the relationship between the coal permeability and effective stress, pore pressure and temperature. A comprehensive formula relating the effective stress, permeability and temperature was deduced (Pan and Connell, 2012; Li et al., 2009; Shi and Durucan, 2004; Cheng et al., 1998; Seidle et al., 1992). Shen (2011) observed the temperature effect on the seepage ability of coal rock which is controlled by the coal rank. Heat can improve the pore structure of the low and medium rank coals with a large amount of micropores generated during the heating process (Cai et al., 2014). The dynamic-change laws of porosity and permeability of low- to medium-rank coals under heating and pressurization treatments are less reported.

In this paper, we built on results from the literature by performing simulation experiments on the coal rock permeability under high temperature and confining pressure. We also analysed the evolution law of the low-medium rank coal rock porosity and permeability under various temperature and pressure conditions. The coal samples were obtained from the eastern Junggar Basin in Xinjiang, China. We propose a quantitative, characteristic equation that can be used for predicting the porosity and permeability characteristics of deep coal reservoirs.

1 COAL SAMPLES AND EXPERIMENTAL METHOD

The coal samples used for experiment were collected from the Laojunmiao, Tianlong and Xiaoxigou mines, which are distributed in the eastern Junggar Basin, Xinjiang, China. The Laojunmiao and Tianlong coal samples are from the Xishanyao Formation, Middle Jurassic series. The Xiaoxigou coal sample is from the Badaowan Formation, Lower Jurassic series. The raw coal blocks all consisted of a side length of more than 200 mm and collected from the new working faces of the coal mines. All coal blocks were immediately wrapped with black polyethylene bags once collected, and then carried to CBM laboratory for

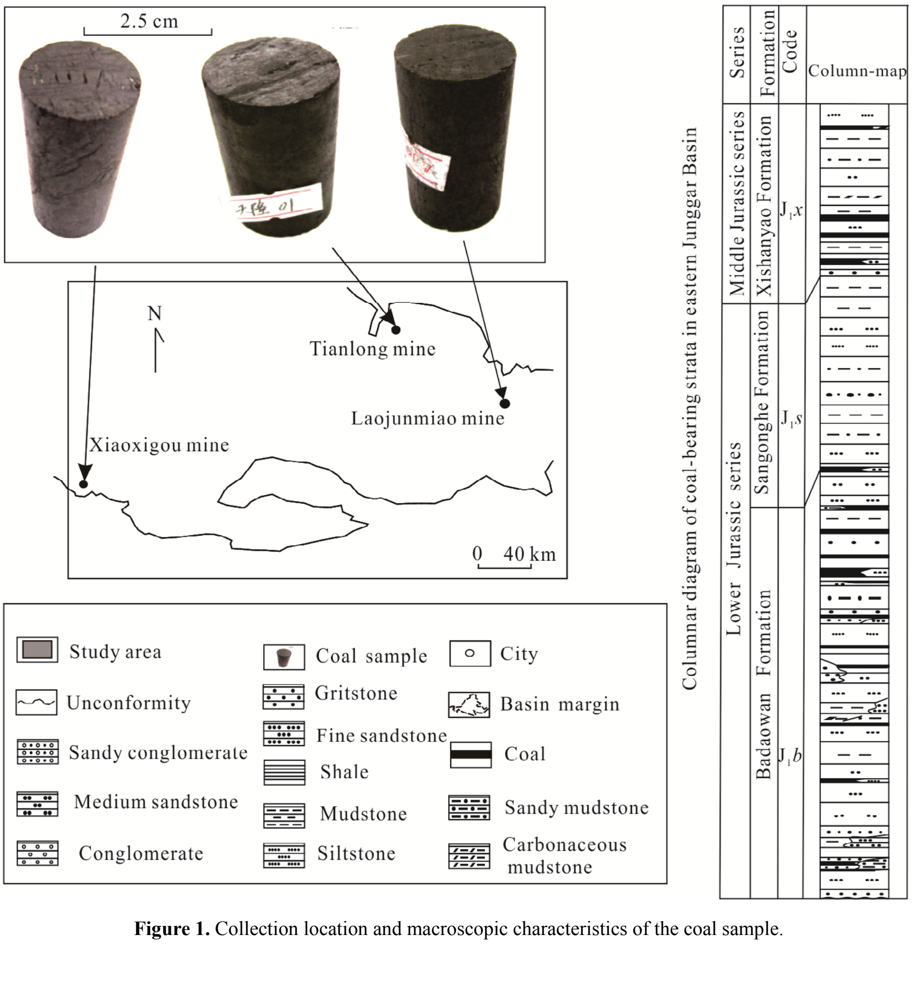

Figure 1. Collection location and macroscopic characteristics of the coal sample.