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Investigation of the effect of low-temperature oxidation on extraction efficiency and capacity of coalbed methane

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ABSTRACT

To improve the extraction efficiency and capacity of coalbed methane (CBM) to the greatest extent possible, this study explores the effects of the internal mechanism of low-temperature oxidation of CBM reservoirs during CBM extraction. The evolution of the porosity and the methane adsorption and desorption characteristics of the coal matrix during low-temperature oxidation were separately explored using a nuclear magnetic resonance (NMR) spectrometer and a high-pressure gas adsorption analyzer. Moreover, the internal evolution mechanism was determined using gas chromatography and the experimental data of the proximate analysis parameters. This study shows that with an increase in the degree and temperature of low-temperature oxidation of CBM reservoirs, the moisture and volatile matter inside the coal matrix continuously decrease. This causes the number of pores with different diameters, porosity, and permeability in the coal matrix to be greatly improved, while the width and quantity of the flow channels for CBM increase synchronously. As a result, the resistance to CBM extraction declines and its efficiency improves. With constant CBM extraction, the maximum methane adsorption capacity of the coal matrix decreases, whereas the methane desorption capacity increases, under low pressures (lower than 1.74 MPa) owing to changes in the structures and quantities of pores inside the coal matrix. As a result, the maximum extraction capacity for CBM is improved. Finally, to guarantee CBM extraction safety and maximize its extraction capacity, it is necessary to control the temperature of the borehole used for extracting CBM to approximately 80 °C.

1. Introduction

Coalbed methane (CBM) refers to the hydrocarbon gases, dominated by methane, which are stored in coal reservoirs (Sun et al., 2017; Teng et al., 2017; Xu et al., 2017). These hydrocarbon gases are largely adsorbed on the surfaces of coal substrate particles and partially flow in the coal pores or are dissolved in the water in coal seams. On the one hand, as an associated product of coal and an unconventional gas, CBM is a clean and high-quality energy and chemical material, whose importance has increased in the last 10–20 y. On the other hand, CBM is a greenhouse gas that induces a greenhouse effect whose intensity is more than 20 times that of CO_2. CBM is also the most important cause of disastrous accidents in underground coalmines. Therefore, it is necessary to improve the extraction efficiency and capacity of CBM to enhance energy utilization, disaster prevention, and environmental protection (Ko, 2016; Salmachi and Karacan, 2017; Upadhyay and Laik, 2017). However, as a result of buried conditions and geological structures, CBM reservoirs in China have mostly demonstrated low or extremely low permeability. The permeability of most CBM reservoirs in China is within the range of 0.987×10^{-7} to 0.987×10^{-6} μm^2 (10^{-3} to 10^{-4} mD), which is 3- to 4-times lower than in other main areas producing CBM, such as the United States (Babaei Khorzoughi and Hall, 2016; Xiao et al., 2016; Zhai et al., 2016). Thus, for CBM extraction in the primary producing areas in China, including the Qinshui Basin and Ordos Basin, the gas permeability of CBM reservoirs is improved using various measures for fracturing and increasing the permeability of CBM, including hydraulic fracturing, hydraulic cut-

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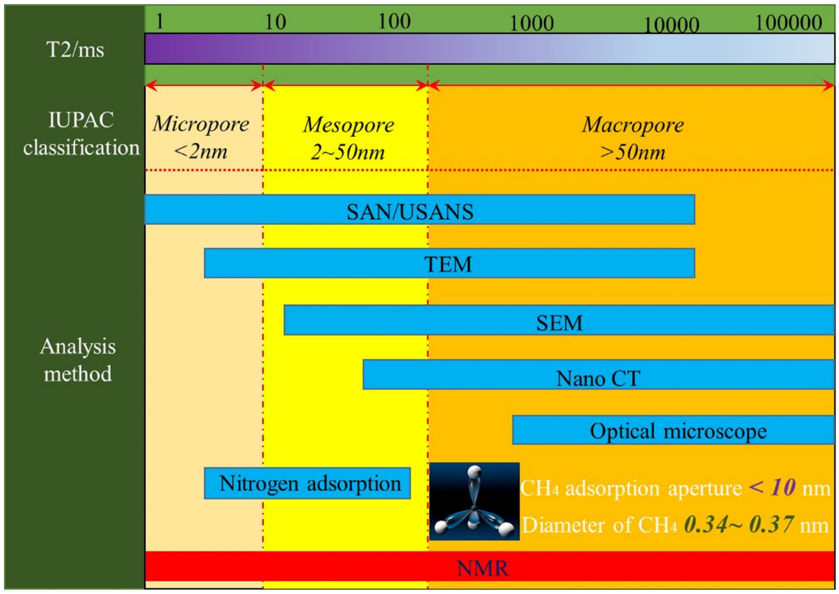

Fig. 1. Comparison of the measurement ranges of pores using different technologies.

ting, and deep hole blasting (Hu et al., 2014; Yan et al., 2015; Ni et al., 2016a; Salmi et al., 2017). While these methods for fracturing and increasing CBM permeability have improved the permeability of CBM reservoirs, they also increase air leaks and trigger and accelerate low-temperature oxidation of CBM reservoirs.

Qi et al. (2010) found that it is difficult to avoid the low-temperature oxidation process in CBM reservoir prone to spontaneous combustion after employing measures to fracture and increase the permeability of CBM reservoirs. However, the physical and chemical characteristics of CBM reservoirs change during low-temperature oxidation, which affects the CBM extraction process. The factors influencing CBM extraction fall mainly into two categories: fracture development in CBM reservoirs, and CBM desorption and adsorption characteristics. Regarding fracture development in CBM reservoirs during low-temperature oxidation, Tang et al. (2016, 2017) used nuclear magnetic resonance (NMR) to study the development and evolution laws for fractures during low-temperature oxidation of a coal matrix at different temperatures. Moreover, they found that pores with different diameters develop in the order of micropores, mesopores, and macropores. To explore the evolution law for the adsorption and desorption characteristics of CBM during low-temperature oxidation, Krooss et al. (2002) investigated the adsorption and desorption processes of coal for multiple gases during low-temperature oxidation of coal matrices with different metamorphic grades. The results revealed the adsorption and desorption laws for CH_4 and CO_2 under different oxidation times and pressures. Using a self-made heating and oxidizing experimental table for the spontaneous combustion of coal, Qi et al. (2013) investigated dynamic changes in adsorption and desorption laws for various gases, including CO, CO_2, and CH_4, as well as the mechanism governing coal oxidation during low-temperature oxidation of a coal matrix.

Previous research has demonstrated that the low-temperature oxidation process in CBM reservoirs can influence fracture development in CBM reservoirs, as well as the adsorption and desorption characteristics of the CBM (Adamus et al., 2011; Sahu et al., 2012; Singh, 2013; Salmi et al., 2017). The coupling of these two factors influences the overall progress of CBM extraction. However, studies have tended to focus on only one of the two factors: either fracture development, or the adsorption and desorption of methane. There has been no significant research conducted on the coupling of these two different factors, particularly the fact that fracture development changes the adsorption and desorption characteristics of methane, thereby further influencing the CBM extraction mechanism. Thus, the mechanism by which the low-temperature oxidation of CBM reservoirs affects CBM extraction was investigated in this study using various instruments considering the fracture development, the adsorption and desorption of multiple gases, and the relationship between these two aspects during low-temperature oxidation of CBM reservoirs. The instruments used in this study include an NMR spectrometer, a high-pressure gas absorption apparatus, and a liquid nitrogen adsorption device. The results of this study can provide a theoretical basis for reducing the influence of low-temperature oxidation of CBM reservoirs on CBM extraction, and increasing the extraction efficiency and capacity of CBM.

2. Experimental theory and methods

2.1. NMR mechanism

2.1.1. Mechanism for measuring pores using NMR

The permeability of CBM reservoirs mainly depends on the quantity, size, and distribution characteristics of the internal pores and fractures (Yao et al., 2010; Zou et al., 2015; Ban et al., 2016; Jiang et al., 2016; LeDoux et al., 2016; Park et al., 2016; Wang et al., 2016). At present, the methods for measuring the distributions of pores inside rocks or a coal matrix include scanning electron microscopy (SEM), computed tomography (CT), mercury intrusion, and N_2/CO_2 adsorption. Although the distribution of pores inside coal and rocks can be measured to a certain extent using these methods, they have a few drawbacks, including long measurement times, limited measurement range of pores, and destructive effects on the samples. However, NMR is a technology characterized by advantages such as a short detection time, wide measurement range of pores (Fig. 1), and little damage to the samples. As a result, NMR has been widely used in various fields including industry, medicine, and the measurement of pore size distributions in coal and rocks.

NMR uses a magnetic field to create a dipole moment, the amplitude of which is proportional to the number of hydrogen atoms within the fluid, and it is thus a measure of the pore volume. The