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Influence on coal pore structure during liquid CO_2-ECBM process for CO_2 utilization

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ABSTRACT

As an effective technology for carbon utilization, enhanced coalbed methane (ECBM) with CO_2 injection has great potential for reduction of CO_2 emission. To better comprehend the effects of ECBM using liquid CO_2, a combination of low-pressure nitrogen adsorption-desorption (LP-N_2-Ad), mercury intrusion porosimetry (MIP), and scanning electron microscopy (SEM) was used to investigate the varying characteristics in coal before and after infiltration by liquid CO_2. The specific surface area and volume were 5.08% and 9.82% higher on average in the treated specimens than in the untreated ones. The average pore diameter and permeability of the treated samples were higher than those of the untreated samples. The features of the pore structure after liquid CO_2 immersion were found to be characterized by new pore generation and the transformation of original pores into larger ones. D_1 and D_2 can be used to quantitatively represent the adsorbed pore surface roughness and volumetric complexity. They were both found to be higher after liquid CO_2 treatment, which indicated the treated coal samples have more rough and complex pore structure than that of the raw specimens. D_4 can be used to describe characteristics of seepage pores. A positive relationship was obtained between D_4 and seepage capability. The SEM images indicated a higher number of microfractures and fewer minerals filled in the coal pores with the treated specimens, representing an improvement of seepage capability with the coal samples through liquid CO_2 infiltration. This study provides a theoretical basis for the understanding of its influence on liquid CO_2-ECBM process.

1. Introduction

Coalbed methane (CBM), an unconventional gas resource, is clean, efficient, and safe. Enhanced coalbed methane (ECBM) has great value for the economy and environment. Coal is an intricate porous media with a complicated structure that has a strong effect on CBM exploitation. The pore structure of coal is the main storage space of adsorbed methane and the most crucial factor affecting methane extraction from coal. Low permeability, high gas content, and high geostress are common characteristics of the coal in Chinese coal seams, and these qualities make gas drainage difficult. In 2016, 17 billion m^3 of methane was extracted in China, which accounted for approximately 6%–9% of the worldwide natural gas production [1]. During coal seam mining, a massive amount of adsorbed methane dissociates and mixes with underground air. This not only threatens the safety of occupational workers, but also intensifies the greenhouse effect, which is partially caused by methane emissions. Liquid CO_2, regarded as one of the dominating mediums of ECBM, has been applied internationally [2–4].

Thermal stress, created by a temperature gradient, develops during the process of liquid CO_2 injection and causes the formation of pores and fractures in coal seams. The methane extraction efficiency can be accurately determined by evaluating the pore characteristics in the process of liquid CO_2-ECBM. Zou et al. [5] calculated the total porosity, comprising both movable and unmovable porosity, and indicated that movable cleats and the meso-macro-pore porosity of each pore system had a strong impact on coal permeability. Cai et al. [6] examined the pore structure of a rock cooled by liquid nitrogen through nuclear magnetic resonance (NMR) and scanning electron microscopy (SEM) as well as indicated the occurrence of three main changes in the pore structure: A reduction in pore volume, an increase in pore size, and micropore expansion. Vishal [7] examined the permeability of bituminous coal during liquid CO_2 injection and analyzed its evolution

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Table 1
Properties of coal specimens.

Sample no.	Proximate analysis [mass%]				Coal macerals [%]			$R_{0,max}$ [%]	Metamorphic grade
	M_{ad}	A_{ad}	V_{daf}	FC_{ad}	V	I	E		
LHG	4.57	18.88	39.74	36.81	79.4	15.3	5.3	0.502	Long-flame coal
HN	1.67	25.71	38.87	33.75	52.6	31.6	15.8	0.991	1/3 coking coal
YC	1.31	2.52	7.03	89.14	69.3	28.3	2.4	3.77	Anthracite

Notes: M_{ad}, moisture on air-dried basis; A_{ad}, ash content on air-dried basis; V_{daf}, volatile component on dry-ash-free basis; FC_{ad}, fixed carbon on air-dried basis; V, vitrinite; I, inertinite; E, exinite; $R_{0,max}$, vitrinite reflectance.

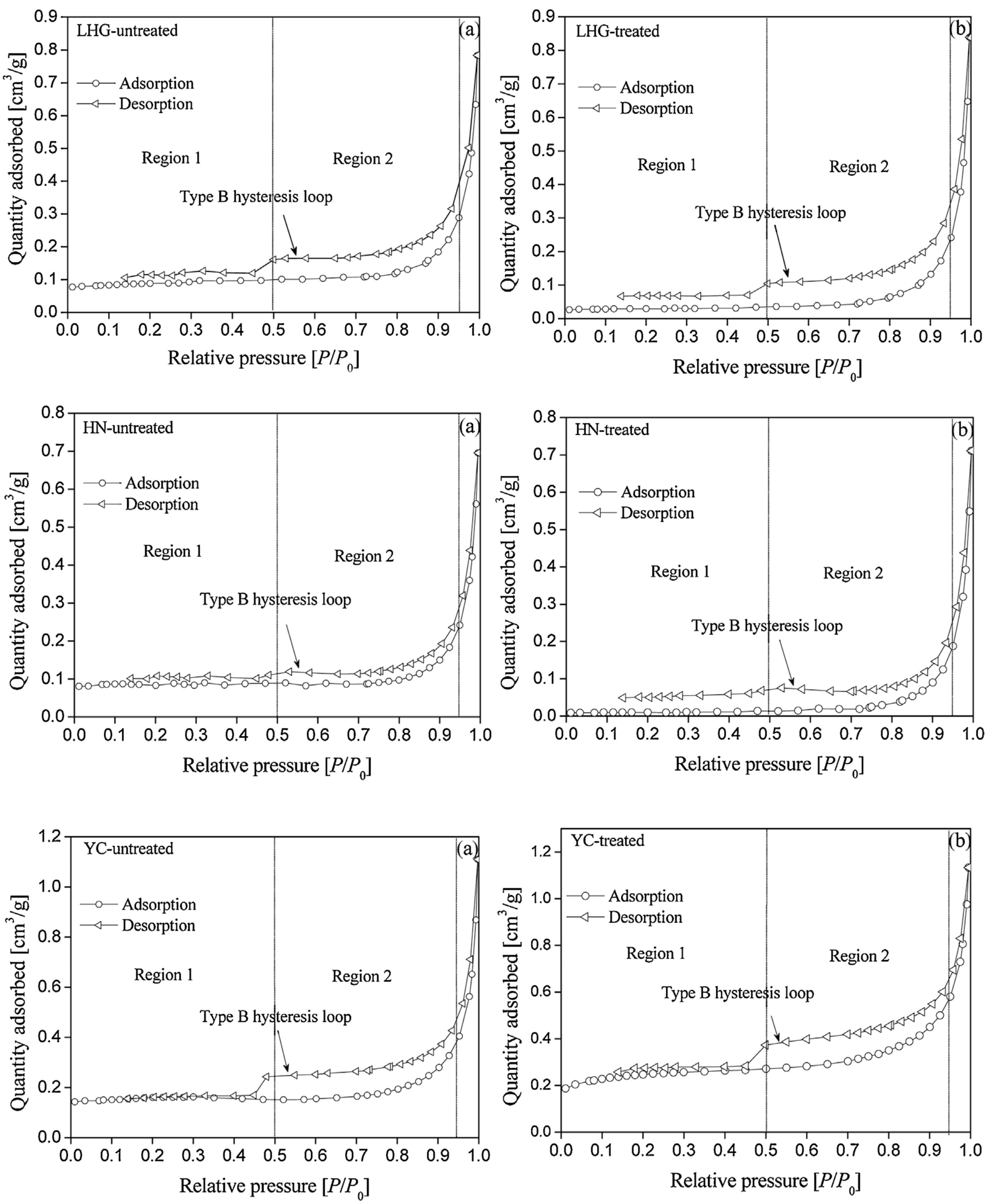

Fig. 1. Nitrogen adsorption–desorption curves for (a) initial coal samples and (b) coal samples infiltrated by liquid CO_2.