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Temperature and deformation changes in anthracite coal after methane adsorption

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HIGHLIGHTS

- SEM, X-ray CT and infrared thermal imager were used to contrast tests of methane adsorption.
- Four categories of mesostructures were classified based on SEM micrographs.
- Heterogeneity of methane adsorption is related to four categories of mesostructures.
- Both swelling and extrusion deformation occurred in coal during methane adsorption.
- Deformations make the direct determination of regional uptake a challenge.

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ABSTRACT

Micropores are the primary sites of methane adsorption in coal, and the heterogeneous mesostructures of coal create the non-uniform distribution of the micropores in coal. Using a thermal infrared imager, the temperature distribution on the surface of an anthracite sample during methane adsorption/desorption was tested in this paper, and a new method is advanced to calculate methane adsorption capacity in coal based on its temperature increment. The results confirm the strongly non-uniform distribution of methane adsorption in coal. A X-ray CT scan test demonstrates that the volumetric zones of coal sample with a strong methane adsorption capacity have a lower average density. In these regions, the clay minerals with developed micropores also have a strong methane adsorption capacity. During the coal skeleton deformation of methane adsorption, the high density is hard to be squeezed, while low density areas are likely to be squeezed. Therefore, the complexity density distribution in coal leads to the incompatibility of deformation, which make the direct determination of regional uptake a challenge; From the SEM micrographs of the same coal sample with different densities determined by the X-ray CT scan, the mesostructures of cell cavity pores with non-compact packing of the clay minerals appear to be the primary sites of methane adsorption in coal, and the telocollinite with fewer pores has a lower methane adsorption capacity.

1. Introduction

Pores are the primary sites of methane adsorption in coal. From the distinction of the pore sizes in a porous adsorbent by Dubinin, the number and specific surface area of the micropores with a pore size less than 2 nm directly determine the adsorption capacity of coal. Past studies have evaluated the number and structure of the micropores by MIP (Mercury Intrusion Porosimetry) and N_2 adsorption experiments. However, these studies did not consider the changes in the pore structures during methane adsorption. Recently, X-ray CT (Computed Tomography) scans have been widely used in the research into the mesostructures of coal [1–4]. Compared with the methods of MIP and N_2 adsorption, the methodology of X-ray CT scan has the advantage of studying the mesostructure deformation in coal during methane adsorption to infer the nature of the methane distribution in coal. Karacan et al. have observed and evaluated the differences in gas migration and adsorption rate between different categories of mesostructures using X-ray CT imaging technology, proposed that clay minerals in coal have a high porosity and density, and pore structures in the coal matrix have higher gas storage capacity[5,6]. However, during the methane adsorption, the local deformation of coal not under confining stress could be swelling or extrusion deformation

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Nomenclature

$-q$	isosteric adsorption heat of methane in coal (kJ/mol)	μ_m	the ratio constant of the attenuation coefficient
n	the methane adsorption capacity of per unit mass of coal (mol)	ρ_0	the density of a certain position of the coal sample before methane adsorption
Q	the adsorption heat released per unit mass (kJ)	ρ_a	the density after methane adsorption
ΔT	the increase in the temperature of the coal (°C)	V_0	original volume of a certain area of coal sample
C	the specific heat of coal (J/kg·°C)	ΔV	volume change after methane adsorption
$\mu_{i,j}$	the attenuation coefficient of a measured point	ε	volumetric strain
$\rho_{i,j}$	the density of the measured point		

[7]. Therefore, the evaluation of the methane adsorption capacity by the variation in the attenuation coefficient of X-ray CT is not sure yet.

SEM (Scanning Electron Microscopy) makes use of secondary electron signal imaging to observe the surface morphology of the sample, to infer material components [8], and to reveal the microstructure on the nanometre scale. Many scholars have studied the pore characteristics of coal from different angles via the SEM test, which has multiple advantages in the study of coal pore fissures, mineral matter, and microstructures [9,10]. Past studies have shown that adsorption heat is released during methane Carbon dioxide and other gases adsorption in coal, resulting in a rise in the coal temperature [11,12]. The temperature variation during methane adsorption offers a new means to evaluate the methane adsorption/desorption capacity of coal and can also be used as the basis for the prediction of dynamic geological disasters, such as coal seam gas outbursts [1,13]. The research performed by Chaback et al. [14] shows that methane adsorption in coal is a physical process with heat release, and the temperature variation of the coal is caused by creation of adsorption heat in the process of adsorption. Nodzenski [15] found that under the same conditions, the isosteric adsorption heat of coal and methane increased with the increase of coal metamorphism. If the isosteric heat of adsorption is higher, the adsorption capacity of the coal sample is greater. The experimental study performed by Guo et al. with embedded temperature sensor [16] shows that heat release in coal during CO_2 adsorption is higher than methane, causing the temperature of coal to be increased by 10 °C followed by the heat release from methane adsorption, and the heat release from nitrogen adsorption is the lowest. Infrared thermal imager can be used to make multipoint temperature measurements on the surface of an object through the induction of infrared radiation in a colour image display. The infrared thermal imager measurement is a noncontact measurement with many advantages, including fast response, wide range of temperature measurement, high sensitivity, and high space resolution [17]. Liu et al. [18] has successfully observed the temperature change in the coal adsorption/desorption process by using an infrared thermal imager.

According to meso mechanics, the meso structures of a material refer to the subtle structures visible through optical or conventional electron microscopy with scales ranging from 10 nm to the millimetre range [19,20] which mainly refers to the coal matrix, clay minerals and meso pores and fissures in this paper. A suitable observation scale was selected based on the three evaluations (CT, SEM-EDS and infrared thermal imaging). From the SEM-EDS test on the coal sample surface, the original mesostructures of coal can be observed. From the synchronous real-time measurements of X-ray CT and infrared thermal imaging on the same position in the methane adsorption/desorption process, the non-uniformity of mesostructure deformation and methane distribution in coal can be tested under different adsorption pressures. From the combination of the three tests, the deformation characteristics and adsorption capacity of different mesostructures in coal can be analysed, and the diversity of the methane adsorption and the deformation of coal is revealed.

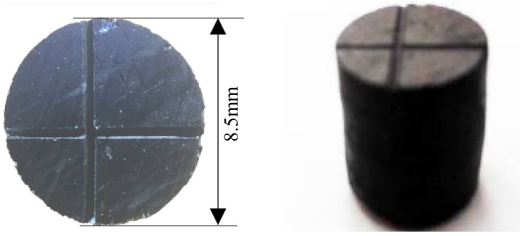

Fig. 1. Coal sample for test.

2. Infrared thermal imaging test for methane adsorption of coal

2.1. Preparation of coal sample

The coal sample for testing is a type of anthracite and was obtained from the Sijiazhuang Coal Mine, Yangquan Coal Industry Group, as shown in Fig. 1. The meso coal sample (12 mm height, 8.5 mm diameter) was cored into the bedding plane. A cross-cut groove was made in the radial direction on the surface of the coal sample. This groove was used as the mark line on the surface of coal sample in different positions. Next, the coal sample was cleaned and dried with oven no more than 60 °C for later use. The results from the measurement of proximate analysis and vitrinite reflectance of the anthracite coal are shown in Table 1.

2.2. SEM and micro X-ray CT scanning test

A JSM-7001F-type thermal field emission scanning electron microscope was used in this paper, with a scanning voltage of 5 kV and a breadth of 10 mm. The microscope could be used to observe the micro structure on the surface of coal on the micrometre scale. For X-ray CT scanning, a μCT225 kVFCB type high-

Table 1
Proximate analysis and vitrinite reflectance of the anthracite coal.

Rank	Weight (g)	Maximum reflectance of vitrinite (%)	Proximate analysis			
			Moisture (%)	Ash yield (%)	Volatile matter (%)	Fixed Carbon (%)
Anthracite	0.966	2.45	1.39	13.13	7.12	78.36