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Micromechanism of coal dust wettability and its effect on the selection and development of dust suppressants

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ABSTRACT

This article investigated quantitative data of carbon- and oxygen-containing groups of lignites, gas coals and anthracites through nuclear magnetic resonance (NMR) and X-ray photoelectron spectroscopy (XPS) experiments. In this study, these three different coal samples were denoted as HM, QM and WY, respectively. For HM, the aromatic structures are scarce and simple, the side chains are abundant and long, and many hydrophilic oxygen-containing functional groups are present on the surface. Thus, HM has strong hydrophilicity. For QM, the aromatic rings have compact structure, but the content of oxygen-containing functional groups approximates 50%, which means that QM can be easily wetted. For WY, the polycyclic aromatic structures are compact and the oxygen-containing functional groups on the surface are nearly detached. Therefore, WY is characterized by poor wettability. Then, two commonly-used suppressants (AEO-9 and rapid penetrant T) were used and coal dust wettability was measured. However, these two suppressants, especially the rapid penetrant T, show poor wetting performance on WY but work well with HM and QM. From the perspective of structure, the hydrophobic groups in AEO-9 are similar to carbon structures in WY, and thus AEO-9 is superior to rapid penetrant in the wetting performance of WY, according to the principle of like dissolves like. In other words, for the coal dusts with good wettability, the application of appropriate dust suppressants guarantees satisfactory dust removal performance. However, for the dusts with poor wettability, macromolecular surfactant with similar structures should be developed in order to achieve better dust removal performance.

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1. Introduction

As one of the major hazards produced in the coal mining process, dust is considered a severe threat to the safety production and health of miners. Dust accumulation is not only a common cause of explosions, but also results in pneumoconiosis in miners. At present, water spray technology is widely applied in China to dust settling, which can reduce

the dust concentration in the coal face to a certain extent. However, the performance of current dust-settling technology is still far from being ideal (Ma and Kou, 2005; Wang et al., 2012; Zhou et al., 2012). Higher dust removal efficiency would require not only the enhancement of spraying effects, but also the improvement of dust wettability. In the 1920s, inspired by coal seam infusion method, some foreign scholars added surfactant (as a kind of dust suppressant) to water to reduce its surface

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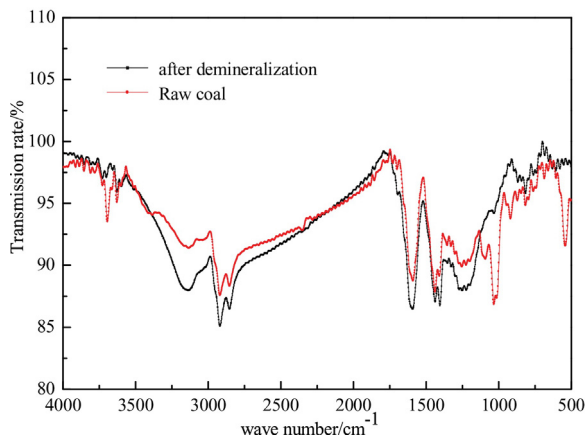


Fig. 1 – FTIR spectra comparisons of lignite before and after de-ashing.

tension and improve the wettability of coal dust particles (Zimon, 1982; Simons et al., 2005; Szymczyk, 2011). Since the 1960s, many patented products appeared, with a couple achieving remarkable performance, including DCL-1803 dust suppressant (USA) (Roe, 1997), ANT-1 wetting dust suppressant (South Africa) (Pullen et al., 1996), MONTAN dust adhesive (Germany) (Aitta et al., 1997) and CHJ-1 wetting agent (China) (Kuang, 1994).

In addition to the development of wetting dust suppressants, there have been studies on the measurements of coal dust wettability in order to uncover the wetting mechanism. Walker et al. (1952) first proposed test method for evaluating the dust wetting ability of solution in 1952, which was also known as Walker sedimentation test. James and Leighton (1982) used the same method to investigate the factors that could affect the wetting rate of dust coals. The experimental results showed that the wetting rate was mainly subjected to temperature, coal dust size and the type and characteristics of the surfactant used. Keller (1988) pointed out that, with the variation of coal rank, there were mainly four factors affecting coal wettability. Additionally, they deduced the related mathematical formula and stated that the mineral content and the oxidation state on the surface could be predicted based on the contact angle. Gosiewska et al. (2002) found that the contact angle of coal dust surface decreased gradually with the increase of its mineral content, and thus concluded that the wettability of coal dusts is dependent on the mineral content (since the wettability was usually characterized by measuring the contact angle).

Coal dust wettability is the theoretical basis for coal dust suppression using wetting approach, and is also a major reference factor in the design and development of chemical suppressants. Nevertheless, the current research on coal dust wettability is far from being perfect and the micromechanism of wetting process still remains unclear. Additionally, the dust suppression techniques were seldom investigated by considering the characteristics of coal dusts. The same suppressant could lead to great differences in dust removal performances in different coal mines. Therefore, these issues resulted in a period during which the development of wetting dust-control measures was stagnant. With the development of coal chemical industry, many scholars explored the microstructure and quantitative structural information of coal dusts by using Fourier transform infrared spectrum (FTIR), nuclear magnetic resonance (NMR), X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), computed tomography (CT) and other techniques (Michael and Anthony, 1985; Kozłowski, 2004; Okolo et al., 2015; Heriawan and Koike, 2015; Baysal et al., 2016; Hazra et al., 2016). These new techniques have different emphases and show different information about coal structure: FTIR and XRD can analyze the characteristics and content of inorganic mineral groups in coal dust and CT can analyze the pore structure characteristics of coal dust, while NMR can quantitatively obtain the contents of carbon groups and XPS can quantitatively analyze the existing forms of surface elements. The basic skeleton of coal is carbon and wetting behavior occurs on the surface of coal dust. Therefore, NMR and XPS are used to obtain quantitative infor-

mation of carbon groups and the existences of surface elements in this context. The present work adopted NMR technique to investigate the distribution pattern of carbons in the molecular structure of the dust particles of lignites, gas coals and anthracites. Meanwhile, the binding form of carbon and oxygen on the surface of coal dusts was explored by XPS, and the quantitative information of some hydrophilic groups such as carboxyls (–COOH) and hydroxys (–OH) was clarified. Thus, this study may serve as a reference to unravel the influence of microscopic molecular structure on the wettability of coal dusts. Finally, based on the skeleton structural characteristics of coal dusts, the coal dust suppression mechanism for different types of suppressants was elaborated, which provides theoretical guidance for the selection of appropriate suppressant and the development of new suppressants.

2. Materials and methods

2.1. Coal samples and pretreatment

3 representative coal samples (lignite, gas coal and anthracite) are selected in coal rank, which are HM, QM and WY. The experiment coals are specially prepared to meet required size (passing through 200-mesh) by crushing, mixing, filtering and drying (ISO 18283-2006), and are sealed in desiccators.

In order to better analyze the organic matters in coals (mainly including carbon skeleton and oxygen-containing function groups) and meet the sample requirements by the experimental equipment, the de-ashing processing was first conducted for coal samples by means of acid treatment (i.e., the addition of the mixture of hydrochloric acid and hydrofluoric acid) (Liang et al., 2014). According to the previous experimental results (Bao et al., 2000), the coal structure is generally unaffected if the acid treatment is strictly controlled within 4 h. However, the aromaticity of coal would increase if the acid treatment exceeds 7 h.

The de-ashed coal sample was primarily used to investigate the organic structure characteristics of coal. The Fourier transform infrared spectrometer (FTIR) spectra of the lignite sample before and after de-ashing are shown in Fig. 1 for direct comparison.

One can clearly observe that, the infrared spectra of raw and de-ashed coal samples show a roughly similar variation trend, i.e., many absorption peaks appear at 3853 cm^{-1} and 3727 cm^{-1} . However, the infrared spectra of the coals before and after de-ashing show great differences in the range of 900 cm^{-1} – 1100 cm^{-1} . The absorptivity of de-ashed coal sample increases significantly in this wave band and approaches 100%. The stretching vibration absorption of inorganic quartz mineral dominates the absorption in this range, which suggests that most of ashes in coal dusts were washed off. Therefore, after de-ashing treatment, the macromolecular structure of coal is not dramatically affected (the variation was within the range of allowable error), and only the in-organics in coals were washed off. This observation is consistent with the research results by Song et al. (2016).

2.2. NMR experiment

HD NMR (BRUKER AVANCE III 500M) with a 4 mm solid H–X–Y triple resonance probe was used to the samples. Desiccated samples were kept in ZrO_2 sample tubes. The measurement parameters included: 5 kHz magic angular speed, 100.38 MHz ^{13}C nucleus resonance frequency, 0.0026 s sampling time, 2 s delay between cycles, and 10,240–20,480 scanning cycles. Cross polarization (CP) and sideband suppression (TOSS) were

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