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# Study on the Effect of Coal Bed Water Injection Wetting Enhancer on the Wettability of Hongliulin Bituminous Coal

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**Abstract:** A coal seam water injection wettability enhancer was developed through surfactant compounding to enhance water injection and dust suppression in underground coal seams of coal mines. The enhancer, comprising an anionic surfactant (SAS-60) and a nonionic surfactant (APG), was evaluated for its impact on the wettability of Hongliulin bituminous coal using surface tension, contact angle, and Fourier transform infrared spectroscopy tests. The results revealed that the surface tension of the coal seam water injection wetting agent (AS) was 26.51 mN/m with a contact angle of 26.66°. Furthermore, AS demonstrated superior wetting properties by exhibiting optimal peak area and percentage of hydroxyl structures, thereby significantly enhancing the wetting properties of coal dust. These findings offer valuable insights for mitigating coal mine dust and developing effective coal seam water injection wettability enhancers.

**Keywords:** Coal dust; Wettability; Coal mine dust control

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## 1. Introduction

In recent years, coal production has gradually shifted to fully mechanized mining, and with the expansion of fully mechanized mining equipment, the amount of dust generated in the coal mining stage has increased significantly, and the concentration of dust has also increased [1–2]. It poses a serious safety hazard to the safe operation of mines and the physical and mental health of operators and is highly susceptible to the development of occupational pneumoconiosis. Pneumoconiosis remains the most serious occupational disease among coal miners. In the process of coal mining, water injection into coal seams is a sustainable dust control measure that can play a role in wetting the coal seams, thus reducing the amount of coal dust generated during the mining process [3–4]. Therefore, it is of great significance to adopt effective dust prevention and control technology to improve the safety of coal production and maintain the health of workers.

Chemical dust suppression represents a critical facet of coal mine dust prevention and control technology, attracting considerable scholarly attention owing to its promising efficacy and broad developmental potential. The capacity of surfactants to modify the interfacial characteristics of coal dust stands as a pivotal factor in dust mitigation, with extensive research focusing on the impacts of anionic, nonionic, and cationic surfactants on microstructure and water injection efficacy. Scholars have delved into theoretical and experimental avenues to elucidate the dynamics of water migration in coal seams to achieve optimal wetting effects. Initial endeavors incorporating surfactants into coal seam water injection processes revealed enhanced injection efficiency. Subsequent investigations explored the influence of surfactants on water injection in coal seams. Wang et al. studied the effects of cationic and anionic surfactants on water injection in long-flame coal seams and found that the adsorption of cations was stronger than that of anions, and the water solubility of cations was better than that of anions [5]. Wang et al. independently developed a cationic surfactant using an alkane mixture as a lubricant and verified the fracturing effect of surfactant by contact angle experiment. The addition of surfactants is beneficial to water injection and dust suppression in coal seams, but no scholars have studied the effect of compound surfactants as water injection wetting agents in coal seams on the wettability of Hongliulin bituminous coal.

Given this, immersion modification experiments employing anionic and nonionic surfactant solutions were conducted on highly metamorphosed Hongliulin coal specimens. Surface tension tests via the platinum plate method, contact angle assessments using the seated drop method, and infrared spectroscopy analyses were carried out to evaluate alterations in the surface groups of the coal samples. These experiments lay the groundwork for leveraging coal seam water injection wetting enhancers to enhance bituminous coal water injection effectiveness and curtail respiratory dust emissions in coal mining operations.

## 2. Experiments

### 2.1. Materials and methods

#### 2.1.1. Collection and preparation of coal samples

The experimental coal samples were taken from the Hongliulin coal mine, and the sampled coal samples were cut and crushed into coal sample particles with a particle size of 200 mesh (0.074 mm) by hand and ball mill. The coal sample particles were placed in a drying oven at 40°C for 24 hours and sealed in a vacuum bag to prepare for the next test. The entire experimental process is presented in **Figure 1**.

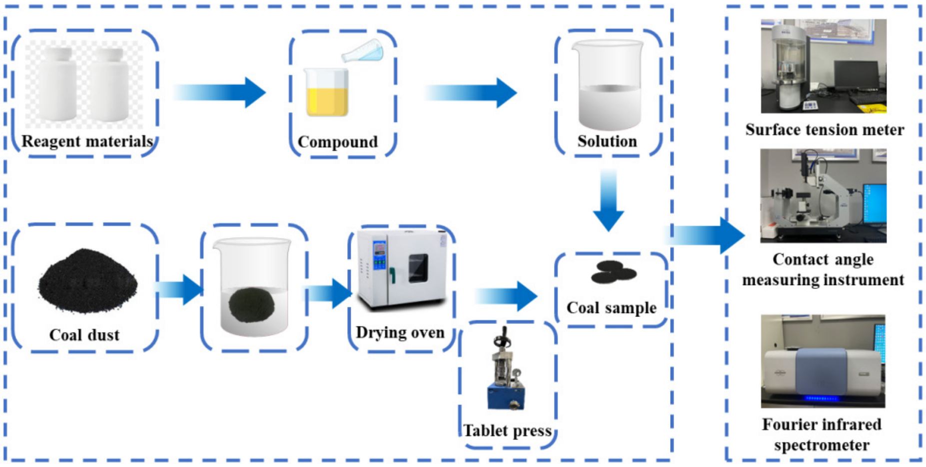


**Figure 1**. Flow chart of the experiments

### 2.1.2. Selection of wetting agents for coal seam injection

Previous studies demonstrated that the anionic surfactant SAS-60 and the nonionic surfactant APG exhibit synergistic effects on coal dust wetting and downhole dust control. SAS-60 is an effective anionic surfactant with a penetration force comparable to JFC, offering excellent wetting properties and biodegradability, making it an environmentally friendly option [7]. APG, a novel nonionic surfactant, combines the benefits of both nonionic and anionic surfactants, possessing superior compatibility, stability, and surface activity while being fully biodegradable without causing environmental harm. Consequently, SAS-60 and APG were chosen for the coal bed water injection wetting agent due to their economic and ecological advantages.

## 2.2. Experimental setup

### 2.2.1. Surface tension

The surface tension of SAS-60, APG, and SAS-60 compounded with APG at different mass concentrations was determined using the platinum plate method on a K100 smart surface tensiometer from KRÜSS, Germany. For the surface tension experiments, the solutions were placed in the sample stage of the smart surface tension meter. Before starting the test, the platinum plates were cleaned and cauterized, and waited for them to cool down before starting the surface tension values. In the surface tension test, three replicate measurements were taken for each solution and the average value was taken as the result.

### 2.2.2. Contact angle

Before performing the contact angle experiments, 0.20 g of 200 mesh dry coal powder needed to be weighed and pressed into coal flakes under 20 MPa pressure. The contact angle of SAS-60, APG, and SAS-60 composite with APG was measured by using the seated drop method on a DSA30 contact angle measuring instrument from KRÜSS, Germany. Three repetitions were made and the average value was taken to ensure the accuracy of the experiment.

### 2.2.3. Fourier transform infrared (FTIR)

In this study, an infrared FTIR spectrometer was used with the wave number range set to 4000-400 $cm^{-1}$, the scanning resolution to 4 $cm^{-1}$, and the number of scans to 32. Coal samples and KBr were ground in agate mortar at a mass ratio of 1:99, and the resulting transparent sheets were placed in the infrared spectrometer. Each experiment was repeated more than three times to ensure the accuracy of the experiment.

# 3. Results and analysis

## 3.1. Surface tension analysis

Surface tension significantly influences the effectiveness of dust suppression measures, with lower values indicating better wettability of coal dust. This study utilized six concentrations (0.01% to 0.2%) to measure the surface tension of 18 groups. Results show that the surface tension decreased notably with increasing APG concentrations, from 55.78 mN/m at 0.01% to 27.73 mN/m at 0.2%, a reduction of 50.29%. In contrast, SAS-60 exhibited a gradual decrease followed by stabilization, dropping from 31.28 mN/m at 0.01% to 27.52 mN/m at 0.2%, a total decrease of 12.02%. When compounded with APG, the surface tension of the coalbed water injection wetting agent AS remained lower than that of SAS-60 above 0.03% concentration, reaching a minimum of 26.61 mN/m at 0.2%. This effect can be attributed to electrostatic repulsion among anionic SAS-60 molecules at the gas-liquid interface, leading to larger intermolecular spacing. APG molecules, possessing numerous oxygen functional groups, enhance hydrogen bonding with water and diffusivity, effectively filling gaps between SAS-60 molecules and further reducing the surface tension of the resulting wetting agent AS.

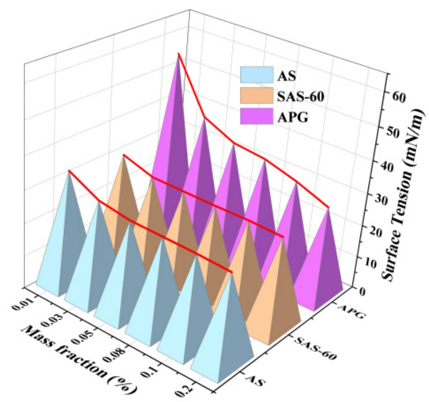


**Figure 2**. Surface tension of solutions at different concentrations

## 3.2. Contact angle test analysis

The contact angle is an important index to describe the wettability of coal dust solution [8]. The experimental results for the contact angles of APG, SAS-60, and the AS coal bed water injection wetting agent are presented in **Figure 3(a)**, with trends shown in **Figure 3(b)**. In the APG solution, the contact angle of coal dust gradually decreased as the concentration increased from 0.01% to 0.2%. Minor reductions in contact angle were observed for incremental concentrations of 0.01% to 0.03%, 0.05%, and 0.08%, with decreases of approximately 2.89°, 0.87°, and 3.78°, respectively. However, at higher concentrations of 0.1% and 0.2%, the contact angle sharply declined to 36.39° and 34°. Conversely, the SAS-60 solution showed a gradual decrease in contact angle as the concentration increased from 0.01% to 0.2%, although the reductions were modest. For concentrations from 0.01% to 0.08%, the contact angle decreased by approximately 15.27°, 1.34°, and 1.52%, while reductions at 0.1% and 0.2% were minor, at 4.13° and 0.75°, respectively. The AS wetting agent also exhibited a gradual decrease in contact angle, dropping by about 7.27° from 0.01% to 0.2%. Notably, the AS solution showed a more significant reduction in contact angle at lower concentrations compared to APG and SAS-60. Overall, the contact angle for AS ranged from 33.93° to 26.66°, consistently lower than that of APG and SAS-60. The AS solution demonstrated superior wetting performance at equivalent concentrations, with a gradual reduction in contact angle indicating enhanced wettability with increasing concentration. In contrast, the contact angle trends for APG and SAS-60 were more complex, exhibiting larger variations across different concentrations.

Combining the results of surface tension and contact angle assessments, and considering the cost-effectiveness of utilizing different surfactant concentrations, a 0.2% concentration of APG and SAS-60 in a 1:1 ratio for compounding the AS coal bed water injection wetting agent was chosen for conducting Fourier transform infrared (FTIR) experiments.

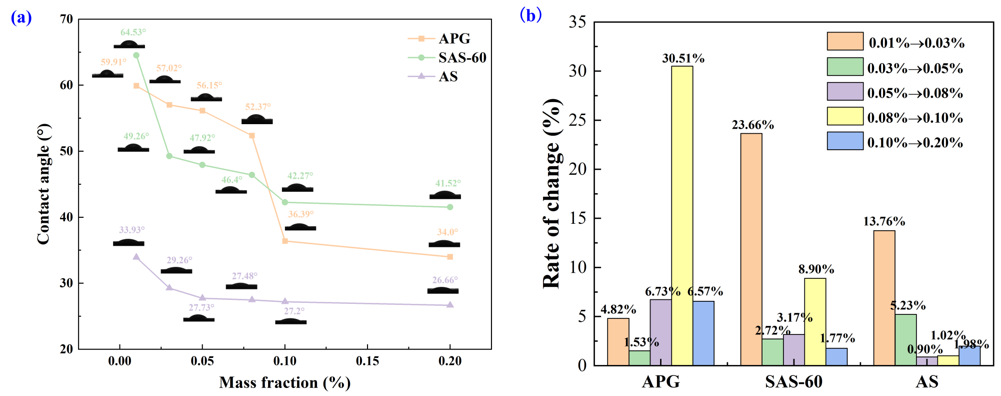


**Figure 3**. Contact angle of solutions at different concentrations and the trend of contact angle of solutions at different concentrations

## 3.3. Fourier transform infrared experiment

The infrared data obtained were divided into four regions according to the class of functional groups. 900–700 $cm^{-1}$ denotes aromatic functional groups, 1800–1000 $cm^{-1}$ denotes oxygenated functional groups, 3000–2800 $cm^{-1}$ for aliphatic functional groups, and 3600–3000 $cm^{-1}$ for hydroxyl structures [9]. For absorption peaks in the same wavelength range and under the same test conditions, the change in the number of functional groups can be expressed in terms of peak area and percentage of peak area. Different surfactant solutions did not affect the absorption bands and characteristic absorption peaks, and the functional group structure of the coal samples did not change, but the peak area changed, indicating that the solutions changed the relative content of functional groups. In this paper, the infrared spectra of water and conventional surfactant w=0.2% SDBS as a control group were compared with those of w=0.2% APG and SAS-60 coal bed water injection wetting agent AS treated coal samples as shown in **Figure 4**.

Usually, the hydroxyl structural group is more reflective of the wetting property in terms of wettability [10]. Among the hydroxyl structural groups, the OH...π bond has an important influence on the wetting properties. **Figure 5** demonstrates the peak area (a) and the percentage of functional groups (b) in the absorption region of the hydroxyl structure (3600–3000 $cm^{-1}$).

According to the fitting results in the figure, the peak areas of OH...π bonds are 9.2478 (water), 10.8218 (SDBS), and 13.8057 (AS), and the percentages of peak areas are 22% (water), 22% (SDBS) and 25% (AS), respectively. Based on the experimental results, it can be concluded that the AS samples showed better results in terms of coal dust wetting properties, followed by the SDBS samples, while the water samples showed relatively low wetting properties.

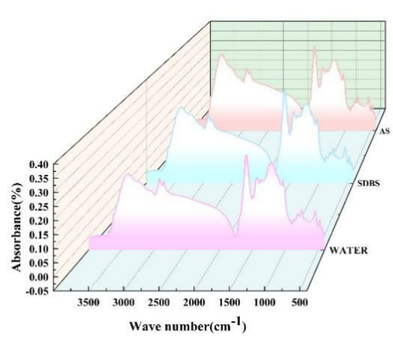


**Figure 4**. Infrared spectra of different surfactants adsorbed on the coal dust surface

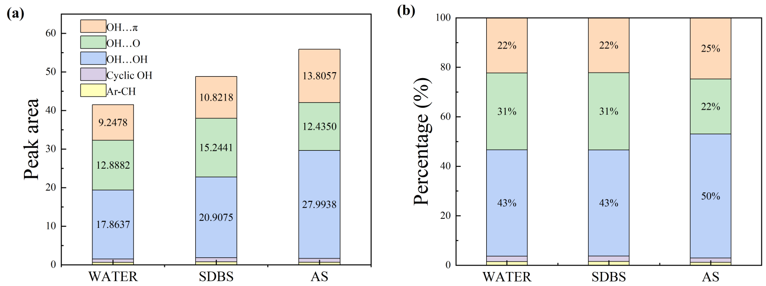


**Figure 5**. Peak area (a) and percentage of functional groups (b) in the absorption region of the hydroxyl structure (3600–3000 $cm^{-1}$)

## 4. Conclusion

This study explored the impact of a coal seam water injection wetting enhancer on the wetting characteristics of Hongliulin bituminous coal, leading to the following conclusions.

The coal bed water injection wetting enhancer AS solution exhibited exceptional wetting properties across various concentrations, characterized by low surface tension values and minimal contact angles.

The coal bed water injection wetting enhancer AS demonstrated superior peak area and percentage concerning hydroxyl structure related to wetting efficacy, thereby markedly enhancing the wetting performance of coal dust. This enhancement can effectively mitigate the adverse effects of coal dust on workers and the environment.

## Disclosure statement

The author declares no conflict of interest.

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