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Experimental investigation of the properties of dust suppressants after magnetic-field treatment and mechanism exploration

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ABSTRACT

To understand the properties of dust suppressants after magnetic-field (MF) treatment and to explore the MF mechanism, dust suppressants (nonionic and anionic surfactants) with different solute volume fractions and MF exposure time were investigated. The effect of the MF on the dust suppressants was characterized by two property changes, namely, the wetting ability and the permeability. During the experiments, parameters such as exposure time to the MF, the surface tension, the contact angle, and the penetrating speed were measured. Nonionic and anionic surfactant solutions responded to MF treatment. The most responsive surfactant was 0.05 vol% Tween-80, which showed a maximal improvement of 11.8 mN/m surface tension and 16.3° in contact angle. Its penetrating speed was also higher than that previously. MF had an obvious influence on nonionic surfactant solutions, especially at concentrations below the critical micelle concentration, and a relatively weak effect on anionic surfactant solutions. This may be because the two surfactant types ionized differently in solution. A relationship existed between concentration and property improvement. A higher surfactant solution surface tension resulted in a greater surface tension improvement during MF treatment, and similar results were observed for the contact angle. The regularity of the effect was difficult to describe precisely and quantitatively. To explain the effect of an external MF on dust suppressant solutions and for practical applications, a mechanism was proposed from a molecular and hydrogen-bond perspective. The critical point was the dynamic process of the formation and fracture of hydrogen bonds in solutions, which was affected by the MF and by surfactant ionization. This research is of important guiding significance for the development of magnetized dust suppressants.

1. Introduction

Dust that is generated from industrial production processes is termed productive dust. The sources of productive dust are wide-ranging, as almost all mines and factories produce dust during operation, including mining and tunnel drilling, blasting, handling, ore crushing, grinding, and packaging. Productive dust is harmful and can cause pneumoconiosis and explosions [1]. Pneumoconiosis is a disease that is dominated by diffuse interstitial fibrosis of the lungs due to long-term inhalation of productive dust in the work environment. It is one of the most serious occupational diseases worldwide [2,3], is currently incurable, and causes severe pain to the patient. Dust explosions often cause numerous casualties and economic losses. Thus, the control of productive dust is of great significance to promote cleaner production and to ensure the occupational health and safety of workers.

Researchers have completed extensive theoretical and practical research into productive dust control. As a result, a variety of technologies have been developed, of which the most commonly used are hydraulic dust-reduction methods [4–8], such as water spray, water injection, wet dust collection, and chemical dust suppression [9–14]. The advantage of chemical dust suppression by surfactant addition is that it can reduce the surface tension of water, improve its wetting ability, and increase the efficiency of dust reduction. This allows it to be used in combination with water spray and coal seam water injection [15]. However, the dust reduction ability tends to be related to the surfactant concentration; only when the surfactant concentration is relatively high can good dust suppression be achieved. Consequently, the application of dust suppressants leads to high costs, which limit their range of use. In recent years, to improve the dust-reduction performance of water by physical means, "magnetized" water and "magnetized" surfactant solutions have attracted the attention of researchers, and studies have been conducted on water or surfactant solutions after magnetic-field (MF) treatment. Research has shown that MF can change the physical properties of water, mainly to decrease the surface tension and contact angle [16]. However, the decrease in surface tension is low and it cannot suppress dust efficiently. Thus, some researchers have studied the synergism between surfactants and MF [17–20]. The results show that the surface

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tension of surfactant solutions decreased within a certain concentration range after magnetic treatment [18]. A compound surfactant was developed and exhibited a good synergetic effect with MF treatment at a low dosage, with a reduced surface tension that was 7.2% lower than that of the non-magnetized solution [19]. Most current research has only analyzed the mechanism of "magnetized" water [21,22]. There is still a lack of research on the properties of "magnetized" surfactant solutions and the mechanism of the MF effect, which has restricted the development and application of magnetized dust suppressants.

In the present study, we investigated typical surfactant solutions under MF treatment to study property changes and understand the underlying mechanism. The property changes are summarized according to the wetting ability and permeability. Assessment parameters involve the surface tension coefficient, contact angle, and penetrating speed, with the former two characterizing the wetting ability and the latter characterizing the permeability. The relative change ratio and numerical fluctuations in surface tension and contact angle, and a comparison of the penetrating speed were also determined. Through theoretical deduction, the phenomenon of permeability enhancement in the permeation experiments was verified. Then, the experimental phenomena were explained from a molecular and a hydrogen-bond standpoint.

2. Experimental

2.1. Experimental materials

To ensure the universality of the research sampling, two main categories of surfactants were selected, anionic and nonionic. The nine surfactants assessed in these experiments are widely used in chemical dust suppression, and their names and concentrations are detailed in Table 1. Dust suppressant I consisted of 92% anionic surfactants (30% Emulsifier OS, 62% Penetrating agent T), and 8% nonionic surfactant (Emulsifier OP-4SA). Dust suppressant II consisted of 97% anionic surfactants (40% Emulsifier OS, 57% Penetrating agent T), and 3% nonionic surfactant (Emulsifier OP-4SA).

The critical micelle concentration (CMC) is an important parameter in the application of surfactants. The lowest concentration for surfactant molecules to associate and form micelles in solution is defined as the CMC. When the solution reaches the CMC, the surface tension of the solution decreases to a minimum. The CMCs of the selected surfactants are detailed in Table 2. These values have been sourced from the literature and obtained experimentally.

The size of the permanent magnet selected was 50 mm × 20 mm × 20 mm, with a rectangular body. The magnetic flux density at its surface was ~4 kGs.

During the contact angle measurement, coal sample was obtained from a coal seam in the eighth mine of Pingdingshan (Henan Province, China). The coal sample was ground into powder and then sifted using an 80-mesh sieve before pressing 350-g powder samples into tablets at 10 MPa.

Table 1
The selected surfactants and their prepared solutions used in the experiments.

Types	Samples	Volume fraction/‰
Nonionic surfactant	Primary Alcobol Ethoxylate (AEO-9)	0.05
	Primary Alcobol Ethoxylate (Penetrating agent JFC)	1 2
	Polysorbate (Tween-80)	0.5 2
	Fatty Methyl Ester Ethoxylates (FMEE)	0.5
Anionic surfactant	alkyl phenol ether sulfosuccinate sodium (Emulsifier OS)	0.2 1.5
	Dioctyl sodium sulfosuccinate (Penetrating agent T)	0.2 0.5
	Sodium dodecylbenzenesulfonate (SDBS)	0.5
Mixed surfactant	Dust suppressant I	0.1–0.6
	Dust suppressant II	0.1–0.6

Table 2
CMC of two representation methods of the selected surfactants.

Types	Samples	Volume fraction/‰	Mass concentration/g/L
Nonionic surfactant	AEO-9	0.10	0.09
	Penetrating agent JFC	0.68	0.64
	Tween-80	0.02	0.02
	FMEE	0.99	0.98
Anionic surfactant	Emulsifier OS	2.30	–
	Penetrating agent T	0.47	0.51
	SDBS	0.38	1.45
Mixed surfactant	Dust suppressant I	0.38	–
	Dust suppressant II	0.52	–

2.2. Experimental setup and methods

A self-developed magnetizer was used for MF treatment of the surfactant solutions based on the principle of a magnetic induction line cutting fluid with a velocity of 110 times per minute. The device is shown in Fig. 1, and uses a solution barrel of appropriate size. The magnetic flux density was ~300 mT and was an invariant parameter. The MF effect was strengthened through turbulence generated by automatic mechanical stirring.

The solution concentration was displayed by the solvent volume fraction. At the first step, each quantity of surfactant solution was mixed for 1 h at 25 °C to ensure complete dissolution.

The surface tension and contact angle during the different solution exposure time to MF were measured using an Interfacial Shear Rheometer (TECLIS Mechanics, Lyon, France) and repeated to guarantee accuracy. The machine is shown in Fig. 2. Readings were taken at 10-s points during surface tension measurement and 0.5-s points during contact angle measurement. The relative surface tension changes of the different surfactant solutions are shown in Table 3. For reasons such as instrument accuracy, we set a maximum allowable deviation of ±0.4 mN/m for surface tension measurement and ± 0.5° for contact angle measurement.

The difference in surface tension value of solutions before and after MF treatment was divided by the surface tension value of the "non-magnetized" solutions, and this ratio was defined as the relative change ratio (%), as shown in Eq.(1).

$$\delta_{\alpha_i} = \frac{\alpha_0 - \alpha_i}{\alpha_0} \tag{1}$$

where δ_{α_i} is the relative change in surface tension, α_0 is the surface tension of "non-magnetized" solutions, and α_i is the surface tension of solutions after MF treatment.

During the penetrating speed measurements, we reproduced a permeation tube containing coal powder of the same mass and same

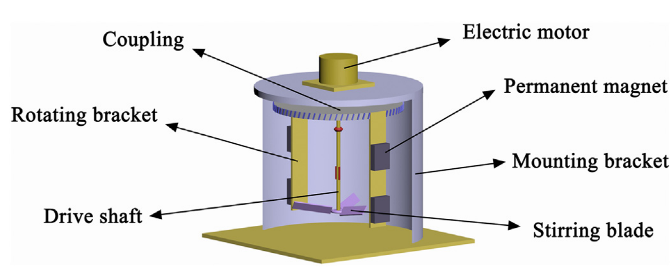

Fig. 1. Self-developed device to provide the magnetic-field.