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Novel technology for synergetic dust suppression using surfactant-magnetized water in underground coal mines

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ABSTRACT

Coal dust is an increasingly serious problem in underground coal mines. This research developed and tested a novel dust prevention technology of surfactant-magnetized water that utilizes the synergy between magnetization and surfactants to markedly improve the wettability of water, resulting in better dust suppression than water sprays alone. The technology was systematically studied in laboratory and field conditions. A compound surfactant was developed as part of the new technology and was effective at low dosage (0.03 wt%, approximately one-sixth that of conventional alternatives). The new surfactant exhibited excellent synergetic effects with magnetization, with reduced surface tension (28.07 $mN\,m^{-1}$, 7.2% lower than that of the original solution). A new type of magnetic apparatus was designed and formed the core of the novel dust suppression technology. The magnetic device produces a powerful and consistent magnetic field (300–350 mT) to achieve effective magnetization of water flow. In field tests, the new technology increased respirable dust and total dust suppression efficiencies by 44.94% and 31.79%, respectively, compared to that of water spray. And the new technology effectively improves the atmosphere in mechanized underground coal mines, contributing to a safer and healthier working environment.

1. Introduction

Coal dust is an urgent and constantly perplexing problem for the coal industry. With the continuous improvement of mechanized mining techniques in underground coal mines, dust production has increased markedly, causing adverse working conditions and endangering workers' health, specifically from coal workers' pneumoconiosis (Mo et al., 2014; Wang et al., 2015a,b). Statistical data from the China National Institute of Occupational Health and Poison Control indicates that approximately 23,000 pneumoconiosis cases were diagnosed throughout the country in 2013, of which almost 14,000 (approximately 60%) came from the coal mining industry (Han et al., 2015). Furthermore, when mixtures of floating dust and oxygen reach a certain concentration, accidental coal dust explosions are likely to occur, leading to heavy casualties and huge economic losses (Zheng et al., 2009). An example occurred on 15 July 2006 in the Lin Jiazhuang coal mine in Shanxi province, China, where a serious coal dust explosion accident killed 54 workers.

At present, water spray is widely used as an economical method of dust control in underground coal mines, but the dust-prevention efficiency of water spray is usually poor owing to the hydrophobic characteristics of coal dust and the high surface tension of water (Lu et al., 2015; Zheng et al., 2012). Surfactants have been developed to solve these problems and improve dust control (Dixon-Hardy et al., 2008; Summers and Parmigiani, 2015; Wang et al., 2015a,b). These additives form a dense hydrophilic layer on the water surface to prevent contact of the water with air, allowing the surface tension of the water to

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Table 1 – Relevant parameters of Nd–Fe–B permanent magnet.

Type	Br (T)	Hc ($KA\,m^{-1}$)	(BH)max ($KJ\,m^{-3}$)
N35	1.39	1000	335–395

decrease significantly, thus improving the wettability of the solution. However, the required dosage of surfactants is generally high (usually more than 0.2 wt%), rendering them a high-cost solution for dust prevention (Tessum et al., 2014; Wu et al., 2007). Thus, to safely achieve the production goals of the coal mining industry, effective and economic measures are urgently needed to reduce dust concentrations in the working environment, especially the concentration of respirable dust.

In recent years, research on magnetized water has attracted increasing attention, such as for scale inhibition in pipe networks and boilers and for crop breeding (Ambashta and Sillanpaa, 2010; Moon and Chung, 2000; Silva et al., 2015). In terms of dust prevention, relevant studies on magnetized water are also continually emerging. In comparative dust prevention experiments between untreated water and magnetized water, the dust control efficiency of magnetized water was 12%–30% greater than that of untreated water (Chen et al., 2014; Zeng et al., 2014). Magnetization can change the physical–chemical properties of water, such as enhancing its wettability (Lee et al., 2013). Dust suppression using magnetized water is both environmentally and economically advantageous. Nevertheless, in its present form, this technique cannot effectively solve the dust problems of coal mines because the improvement in wettability from magnetization is limited (Pang and Deng, 2008).

To overcome the individual limitations of magnetization and surfactants in dust prevention, this study developed and tested a novel dust prevention technology consisting of surfactants combined with magnetized water. This technique integrates the functions of magnetization and surfactants to significantly reduce dust control costs and improve wettability, reducing surfactant usage to only 0.03 wt%. Because most of the available magnetic systems are used in the medical and water purification fields (Dobersek and Goricanec, 2014; Mahmoud et al., 2016), the research involved first designing a surfactant-magnetized water generation system with a new type of magnetic apparatus for coal dust prevention. Field-scale experiments indicated that the new surfactant-magnetized water method had a better dust suppression efficiency than traditional water spray systems, especially in terms of controlling respirable dust.

2. Experimental preparation

2.1. Materials and facilities

Two surfactants were used to obtain a new low-cost surfactant mixture that would effectively improve the wettability of water under the effect of a magnetic field. These were nonionic surfactant D, which was a fatty acid methyl ester ethoxylate (FMEE), and anionic surfactant A, which was sodium dodecyl benzene sulfonate (SDBS). Both chemicals were procured from the Lin Yi Green Chemical Co. Ltd., Shandong, China. Both surfactants readily dissolve in water at room temperature and quickly decrease the surface tension of water.

Permanent magnets ($60 \times 40 \times 4$ mm) made of an Nd–Fe–B alloy were used to conduct laboratory tests and were acquired from Zheng Guo Magnetic Co. Ltd., Shanghai, China. Detailed parameters of the magnets are shown in Table 1.

Coal samples were acquired from the Lu Wa coal mine (Jining, Shandong, China), one-third of which were characteristically composed of coking coal. Each coal sample was crushed and sieved to produce particles finer than 325 mesh (less than 45 μm). The diameter of respirable dust is less than 7 μm, and the size of respirable dust throughout the experiments was checked using a LS609-type laser particle size analyzer (Omec Instruments Co. Ltd., Zhuhai, China). In addition, the main experimental equipment included a surface tensiometer (JYW-200B, Chengde Experimental Products Co. Ltd., Hebei, China), gauss meter (TM-701, Kanetec, Nagano-ken, Japan), contact angle instrument (JGW-360B, Cheng Hui Experimental Instrument Co. Ltd., Hebei, China), high-pressure water pump (HM280, Black Cat Trade Co. Ltd., Hongkong, China), and tablet press machine (FY-24, Strong Lean Technology Development Co. Ltd., Tianjin, China).

2.2. Experimental design

(1) Various mixtures of anionic surfactant A and nonionic surfactant D were used in synergetic combination experiments. The total mass fraction of the mixtures was 0.03 wt%, and the mixed mass ratios of A:D were 6:0, 5:1, 4:2, 3:3, 2:4, 1:5, 0:6. In addition, for the total A:D mass ratio of 5:1, the mixed mass fraction of their mixtures was 0.01 wt%, 0.02 wt%, 0.03 wt%, 0.04 wt%, 0.05 wt%, 0.06 wt%, 0.07 wt%, respectively. The effect of various compound methods on the solution surface tension was systematically measured. All samples were studied at 25 °C in the laboratory.

(2) To confirm the synergy between the surfactant solution and the magnetized field and to determine the optimal magnetization parameters of surfactant-magnetized water, the surface tension and contact angle of the surfactant solution were measured under various magnetic intensities and water flow velocities through the magnetic field.

(3) To carry out atomization and dust suppression experiments, a laboratory scale system was constructed to simulate a spray for dust prevention in an actual coal mine (Fig. 1). The system included a dust feeder, a fan, an air diffuser device, a simulated roadway, surfactant-magnetized water generation equipment, a dust sampler device, and atomization equipment. The simulated roadway of the experimental system was an enclosed chamber ($6 \times 1.2 \times 1.2$ m) constructed of glass and steel, with an air diffuser 1.7 m long. The water flow rate for the spray system was 8 $L\,min^{-1}$. The air sampling method followed the China National Standard method for determination of dust in the air of workplaces (Standard, 2008), using the AKFC92A-type dust sampler (Huaqiang Mining Equipment Co. Ltd., Shandong, China) to collect dust. Generally, the dust control efficiency cannot be directly measured but must be calculated using Eq. (1) and dust concentrations measured before and after applying dust control technologies.

$$\eta = \frac{C - c}{C} \times 100\% \quad (1)$$

In Eq. (1), η(%) is the dust suppression efficiency, C ($mg\,m^{-3}$) is the dust concentration before applying dust control technology, and c ($mg\,m^{-3}$) is the concentration after applying dust control technology.