Experimental research on optimization and coal dust suppression performance of magnetized surfactant solution

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Abstract

Safety of coal mine and workers is seriously threatened by coal dust, which tends to inhale and explode. Based on several kinds of commonly used surfactants, the physical and chemical properties and the performance of wetting coal of magnetized surfactant solution were experimentally researched. The relationship between surfactant concentration and surface tension was analyzed, the best surfactant for dust suppression effects was defined according to the wettability, the influence of different concentrations of surfactant solution under the condition magnetization on contact angle of coal and PH value of solution were further researched and analyzed. The researches drew the following conclusions: the surface tension of solution decreases as surfactant concentration increases within a certain range; Triton was the best surfactant in the experiment; contact angle of coal decreases greatly after surfactant solution is magnetized, contact angle of coal is the minimum and wetting effect is the best when concentration increases from 0.02\% to 0.03\%; magnetization surfactant solution has great prospect in mine coal dust suppression.

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1. Introduction

In each process of coal mining underground, a great amount of dust is produced. The dust not only degrades the quality of surrounding environments such as atmosphere and water, but also leads to serious...
physiological damage to the workers in the workplace, results in pneumoconiosis to different extent, and endangers the lives and health of coal miners. In addition, coal dust in mine shafts tend to explode. Coal dust explosions occurred in a lot of mine shafts, posing a serious threat to the safe production of coal mines and the lives of the staff. Therefore, domestic and overseas scholars have conducted extensive research, theoretically and experimentally, on dust control techniques for a long time. However, their research mainly concentrated on how to enhance coal body permeability and wetting effects, for example, using dust suppressent \cite{1-3} to increase the wettability of dust, add dust-adhering bar in coal seam water infusion\cite{4} to improve water infusion effects. Besides, some researches focused on magnetized water to suppress the dust in mine shafts\cite{5-10}. Fruitful outcomes were acquired. According to literatures, it was found that few research was conducted on use of magnetized surfactant solution to control the dust in mine shafts. Therefore, this paper experimentally measured the change of contact angle before and after the magnetization of surfactants, and researched the effects of magnetized surfactant solution on the wetting of coal body. The research results are of important theoretical and practical significance to develop dust control techniques in coal mines.

2. Selection of surfactants used in coal mines

Surfactant means the substance that has inherent hydrophilic and oleophilic radicals, can align in fixed direction on the solution surface, and can make surface tension significantly decrease\cite{11}. Because surfactants can greatly decrease the surface tension of water, and have a wide range of physio-chemical properties such as wetting, emulsification, bubbling and solubilization and actual applications, they are used as chemical suppressants and extensively applied in hydraulic dust removal in coal mines. And satisfactory dust removal results were obtained. There are a variety of surfactants. In selecting surfactants, this research takes mainly into account the following aspects:

1) Surfactants should be non-toxic and easily dissolved in water;

2) No cationic surfactants are selected. Because most of the cationic surfactants are the derivatives of organic amines, when their solutions interact with coal, the solution appears acidic, the organic amines easily separate out, their role as surfactants is lost;

3) The surfactants selected can significantly decrease the surface tension of water. Surface tension is the important parameter of surfactants. The lower surface tension, the better the wettability of dust;

4) They are easily accessible, cheap and economical.

Based on the above points, experiments for selecting the best surfactants were firstly conducted. Four types of surfactant specimen were chosen: sodium dodecanesulfonate (SDS), sodium dodecylbenzenesulfonate, sodium dodecyl sulfate and Triton. The experimental procedures include: at normal temperature and pressure, the four kinds of surfactants were firstly made by ordinary tap water into solutions of 10 different concentrations ranging from 0 to 0.3%, as shown in Fig.1. Then, JZYW-200B interfacial tension meter (Fig.2) was used to measure their surface tension. Measurement was made by Du Nouy Ring method. That is, suspend the ring for measurement (normally platinum ring) on the hang arm, making it submerge about 1cm below the solution surface. Slowly apply force to make the ring separate from the surface. The moment it separates, record the value of the force, which is the real time tension of the liquid. Repeat this six times. The average value is taken as the eventual surface tension of the solution. The measurement results are shown in Fig.3.
It can be seen from Fig. 3 that, for the four kinds of surfactants, with their solution concentration increasing, the surface tension abruptly decreases, indicating that the surfactants can substantially decrease the surface tension of water. However, when the solution concentration further increases to a certain value, its surface tension tends to stabilize. Through quantitative analysis it is known that, when the concentration of sodium dodecanesulfonate increases to 0.01%, the surface tension rapidly decreases; when its concentration is more than 0.01%, the surface tension firstly decreases and then slightly increases with the concentration increasing, and the minimal value is reached at the concentration of 0.1%. For the solution of sodium dodecylbenzenesulfonate and sodium dodecyl sulfate, when their concentration is below 0.05%, with the concentration increasing, the surface tension of the solution quickly decreases, and then tends to stabilize. For the Triton solution, when its concentration is less than 0.01%, with the concentration increasing, the surface tension speedily decreases, and subsequently tends to stabilize basically. It is evident from the above analysis that, the surface tension of the above four solutions decreases accordingly in the following orders:

sodium dodecanesulfonate < sodium dodecyl sulfate < sodium dodecylbenzenesulfonate < Triton.
The surface tension of Triton solution decreases quickest with the concentration increasing, and the value is the smallest after stabilization. It is the best surfactant. Therefore, this experiment chose Triton as magnetized dust suppressant. At the same time, in taking into account dust suppression effects and economy, concentration of 0.02%~0.03% is the best. Subsequently, the influence on the contact angle of coal, i.e., wettability, by Triton solution before and after magnetization was investigated so as to further evaluate its wettability of coal dust and dust suppression effects.

3. Measurement of the contact angle of magnetized surfactant solution

The wettability of solid surface, i.e., the attractive force of surface towards water molecules or hydrophilic or hydrophobic extent, is often measured by contact angle\(^{[12]}\). It is an important parameter liquid’s wettability of dust. The smaller the contact angle, the better the solution’s wettability of dust and the permeability of coal body. By measuring the contact angle \(\theta\) of the system, it is convenient to judge various kinds of wetting process:

\[
\begin{align*}
\text{Adhesion} & \quad \sigma_w (1 + \cos \theta) \geq 0 \quad \theta \leq 180^\circ \\
\text{Wetting} & \quad \sigma_w \cos \theta \geq 0 \quad \theta \leq 90^\circ \\
\text{Spreading out} & \quad \sigma_w (\cos \theta - 1) \geq 0 \quad \theta \leq 0
\end{align*}
\]

The available researches suggested that, magnetization can reduce the surface tension of water\(^{[13]}\). Hence, based on the researches mentioned above, another experiment research was conducted for the influence of pre and post-magnetized Triton solution on the contact angle of coal in order to assess the effects of magnetized surfactant solution on the wetting of coal. The magnetization parameters chosen for this experiment: magnetization intensity is 800mT, magnetization time is 5min\(^{[14]}\). The experiment instruments include TYU-2000H magnetization instrument (adjustable magnetic field scope: 0-1.6T) and JY-PHb contact angle measurer, as shown in Fig.4 and 5. Coal samples were taken from Chengzhuang Coal Mine in Jincheng, Shanxi. The procedures of making the samples: the coal samples were cut and made into block slices, polished with abrasive paper to make its surface smooth, as shown in Fig.6.

![Fig. 4 TYU-2000H magnetic instrument](image_url)
The experiment process: 1) with ordinary tap water, dilute Triton into solution with concentration of 0.01%, 0.02% and 0.03%, respectively; 2) the magnetic field intensity of TYU-2000H magnetic instrument is set at 800mT, and place the solution into the both poles of the electromagnetic iron of the instrument for 5min magnetization; 3) place the coal samples on the test platform for contact angle. JY-PHB contact angle measurer and angular measurement are used to measure the contact angle of coal before and after magnetization of the solution, as shown in Fig.7; 4) repeat three times for the contact angle of each kind of water sample, and seek the average value. The experiment measurement results are listed in Table 2.

| Type of solution | Water | Triton |
|------------------|-------|--------|
| Concentration % | 0     | 0.01   | 0.02   | 0.03 | 0.01 | 0.02 | 0.03 |
| Contact angle ° | 68.1  | 24.8   | 10.8   | 5.1  | 17.9 | 6.1  | 0    |
|                  | 69.6  | 24.3   | 10.1   | 5.9  | 18.1 | 6.0  | 0    |
|                  | 68.2  | 25.3   | 9.8    | 4.8  | 16.6 | 5.8  | 0    |
| Average value °  | 68.6  | 24.8   | 10.2   | 5.3  | 17.5 | 6.0  | 0    |
It can be seen from Table 2 that, the contact angle between coal body and Triton solution is obviously lower than that of water. Moreover, as the concentration increasing, the contact angle significantly decreases. By comparing the contact angle of pre and post-magnetized solution at different concentrations, it is easy to find that, the contact angle after magnetization is smaller than that before magnetization, in particular, when the concentration is 0.03%, the contact angle after magnetization is 0°, which dramatically enhances the wettability of Triton solution on coal body. The reasons are as follows: first, absorption phenomenon happened in the surfactant solution, and the surfactant molecules are closely absorbed on the water interface in a fixed direction which caused the interface energy to decrease. therefore, the surface tension of surfactant solution is lower than that of water, and it will decrease with the increasing of surfactant concentration. On the other hand, after surfactant solution is magnetized, the surface tension of water itself will decrease due to the distortion and broken of hydrogen bond of water molecule chain (group), the enlarged balance distance and the decreased attractive force constant. Therefore, After being magnetized, the surface tension of surfactant solution can be further reduced. the contact angle between water and coal also decreases so as to the coal particle can be wet and removed much more easily.

4. Measurement of PH value of magnetized surfactant solution

It can be known from the above analysis that, Triton solution can greatly decrease the surface tension of water, enhance the wettability of coal body, and play better dust suppression effects. However, its solution flows into drainage ditch in the form of liquid. In order to evaluate whether it can cause secondary pollution, experimental research was conducted for the chemical properties of the solution.

Main instruments and devices used in the experiment are one PARA 211 Ph meter and four 200ml beakers. Main experiment procedures:

① Prepare Triton solution with concentration of 0.03%;
② Magnetize the prepared solution and ordinary water in the magnetic field with intensity of 800mT for 5min;
③ Place certain amount of pre and post-magnetized solution to be measured and ordinary water into four beakers;
④ Use Ph measurer to measure Ph value of Triton solution and ordinary water before and after magnetization.

| Magnetic field intensity (mT) | Nature of water sample | PH value | Value of variation |
|------------------------------|------------------------|----------|-------------------|
|                              | Magnetized             | Not magnetized |                  |
| 800mT                        | Ordinary water         | 7.548    | 7.362             | +0.186           |
|                              | Triton solution (0.03%)| 7.884    | 7.748             | +0.136           |

The experiment results are listed in Table 3. Analysis of the data in the table indicates that, PH value of the magnetized ordinary water and Triton solution all increases somewhat. At the same time, the solution of magnetized surfactant is used mainly to remove the dust in mine roadway and infuse water into coal
seam, in order to prevent harm of human body and flowing of the solution into drainage ditch causing secondary pollution, so the solution of magnetized surfactant should be closely neutral. It is known from the data in the table that, PH value of the magnetized Triton solution is 7.884, nearly neutral. It is completely suitable for suppressing the dust in mine shafts.

5. Conclusions

Experimental research was conducted for the physio-chemical properties of magnetized surfactants and their wettability of coal body. By measurement and analysis of the surface tension of surfactant solution at different concentrations and the contact angle before and after magnetization of surfactant solution, the results suggest that, magnetized surfactant solution can effectively reduce the contact angle of coal samples, and greatly strengthen the wettability of coal body and coal dust. They have good prospect in water infusion in coal seam and dust suppression by misting. Main conclusions are drawn as follows:

(1) In the experiment conditions, the surface tension of Triton solution decreases the quickest with the concentration increasing, and its surface tension value is the smallest. Its most suitable concentration is 0.02%~0.03%;
(2) After Triton solution is magnetized, its contact angle greatly decreases. When its solution is 0.03%, its contact angle is zero. This further validates its best concentration being 0.02%~0.03%;
(3) PH value of magnetized Triton solution is nearly neutral. It is completely suitable for suppressing the dust in mine shafts.

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