Experiment and research of chemical de-dusting agent with spraying dust-settling

WANG Naiguoa,b,c, NIE Wen*a,b,*, CHENG Weimin*a,b, LIU Yanghaob, ZHU Liang*a,b, ZHANG Lei*a,b

Abstract

In order to improve binding capacity between water and dust and the efficiency of dust removal in spray, in this paper, the surface tensions and contact angles of four surfactant solutions, such as SDS, CAB-35, JFCS and BS-12, in different concentrations were tested by using automatic surface tensiometer and video optical contact angle measuring instrument, determining their CMC, which was also the concentration ratio of the four surfactant solutions; By the principle of each two single surfactant’s combination, coal dust settling and up-ward seepage experiments of the six combination solutions were conducted, combined with simulation experiment, determining that the optimum surfactant agent used for de-dusting was the combination of these two surfactants: CAB-35 and JFCS, in the mass fraction of 0.05%. Meanwhile, it was also applied in fully mechanized heading face of 2th mining area of Xin Zhi coal mine, Huozhou Coal Electricity Group, Shanxi Coking Coal Group.

Keywords: surfactants; CMC; composite stabilizer; experiment; spraying simulation

1. Introduction

Coal mine often produce significant amount of dust in the production process, especially the extracting coal face...
where powder dust is more serious, which can threaten enterprise safety production and operating personnel’s physical and mental health. Based on the measured data, the original concentration of dust reaches to 1200–1500 mg/m³ in fully mechanized coal face while it is up to 2500–3000 mg/m³[1-3]. Traditional spraying dust-settling use clear water as the liquid medium. Although such measure is simple and economy, water droplet’s capability of capture dust is limited because of big water-vapor interface and the surface of coal contain amounts of hydrophobic nonpolar gene which lead to coal have hydrophobicity. Meanwhile, the evaporation rate of exiguous water particle is fast, therefore, many dust can fall effectively for a long time because it is difficult to captured and absorbed by free water fastly and totally. For this reason, it is necessary to develop a new chemical dedusting-agent with high quality and efficiency in order to further improve the ability of spraying dust-settling especially the respirable dust.

2. Selection of surfactant with spraying dust-settling

According to the principles of surfactant that poison less and harmless, good wettability and low cost, four kinds of reagents are selected to experiment from the surfactant, such as anionic surfactant aliphatic alcohol sodium sulfate salt (SDS), zwitterionic surfactant amide propyl betaine (CAB-35), nonionic surfactant alcohol polyoxyethylene ether JFCS and amphoteric surfactant amide propyl betaine BS-12.

3. Research of chemical de-dusting agent with spraying dust-settling

In low concentration region, water-vapor interface declined sharply with the increase of concentration of wetting agent and levels off gradually. Wetting agent molecules will form micelle gather with hydrophobic group, and the minimum concentration of micelle called Critical Micelle Concentration (CMC). It is firstly necessary to measure the best compounding concentration of CMC that is the surfactant through experiment.

3.1. Determine of surface tension

From Table 1 and Fig. 1, we may see that the surface tension will decrease obviously before these solutions’ mass concentration reach 0.05% and the descending trends to ease after it reaches 0.05%. All of the results indicate that the average CMC of the four kinds f surfactant solutions is 0.05%.

| S | M | M | M | M | M | M |
|---|---|---|---|---|---|---|
| SDS | 73.028 | 68.972 | 62.778 | 50.653 | 30.097 | 33.431 | 32.569 |
| CAB-35 | 71.875 | 72.403 | 67.944 | 52.806 | 40.847 | 25.139 | 27.500 |
| JFCS | 72.681 | 67.000 | 53.167 | 43.153 | 32.625 | 31.000 | 32.764 |
| BS-12 | 69.777 | 69.655 | 70.236 | 57.917 | 30.500 | 32.139 | 31.889 |

Fig. 1. Surface tension of SDS when the mass concentration was 0.05%.
The average surface tension under 35 N/m when mass concentration of the four kinds of solutions reaches 0.05%, which meet the requirement of spraying dust-settling in coal mine. Therefore, the mixing concentration of the four kinds of surfactant is determined as 0.05%.

3.2. Contact angle measurement

In order to verify the wetting effective of coal tablets from surfactant solutions in different mass concentrations, disposing the coal sample which collected from underground coal face of Gao Zhuang coal mine in Shandong province through the ball mill for 30 seconds, and it will be pressed into circular specimens whose diameter is 13mm and thickness is about 2mm. The dosage of each specimen is 200mg.

Determine the contact angle between the surfactant solution and specimen through a DSA100-type optical contact angle measuring device. The concrete results as Table 2 implies, of which, the contact angle of distilled water used in the experiment is 89.75 ±0.36°. With purpose of making the experiment results more comparative, all of the test images of contact angles of the reference solution are selected as the time of 1 minutes. After the measure of contact angles, the experiment got the contact angles which in different mass concentrations, in different solutions and in different types. Shown in the following table, the wetting process of anionic surfactant type-BS-12 above the briquette is showed in the Fig. 2.

Table 2. Contact angles of four kind of surfactant in different mass concentrations (°).

| S     | M   | M   | M   | M   | M   | M   | M   |
|-------|-----|-----|-----|-----|-----|-----|-----|
|       | 0.000005 | 0.000005 | 0.0005 | 0.005 | 0.05 | 0.5 | 5   |
| SDS   | 44.43 | 48.81 | 47.75 | 47.75 | 28.04 | 0   | 0   |
| CAB-35| 55.27 | 57.65 | 57.03 | 54.23 | 29.06 | 0   | 0   |
| JFCS  | 59.88 | 58.36 | 58.42 | 24.94 | 0     | 0   | 0   |
| BS-12 | 49.65 | 53.73 | 57.34 | 58.19 | 16.47 | 0   | 0   |

Fig. 2. Wetting process diagram of BS-12 (mass concentration is 0.05%).

As time goes by, the droplet gradually spread out and the contact angle smaller and smaller, after then, it will become balance. Three minutes later, when the mass concentration of solution reach to 0.05%, all contact angle will decreasing significantly. After the mass concentration reach to 0.5%, the contact angle will levels off, certainly, there is a clear decline of the contact angle when the mass concentration of JFCS reach to 0.005%, and it will levels off after the concentration of solution reach to 0.05%, which can be regarded as the best surfactant. All of the contact angles are under 30° when the mass concentration of the four kind of solutions was 0.05%, thus, after determining the CMC of the four kind of monomer about the change of contact angle and all the concentration are 0.05%.

3.3. Formulation experiment of surfactant and optimization de-dusting agent formulation

Considering the values of CMC of surfactant which were involved in compound were near, that was to say, the change of mass fraction between monomer solutions was small, thus, in this paper, we got six kind of different
compound solutions through the principle of monomer compound instead of orthogonal test, in addition, coal dust settling and reverse permeating experiments were conducted by the simulation system, as shown in Fig. 3. All of the values of mass fractions of monomer solution which involved in compound were 0.025% and the same coal powder used in the contact angle experiment were still adopted.

The amount of powders used in the settling and permeating experiment is 300mg and 150mg, and the test results are shown as Table 3 and Table 4.

The complex compatibility of nonionic surfactant is better, and after remixed with anionic surfactant, the wettability of the mixed solution is better compared with the other solutions. Comparing and analyzing by the test data of Table 3 and Table 4, we can see that the sedimentation time increasing as the mass concentration of mixed solution decreasing.

The wettability size order of different mixed solution to coal dust is CAB-35+JFCS>SDS+JFCS>JFCS+BS-12>SDS+CAB-35>CAB-35+BS-12>SDS+BS-12.

Table 3. Test data of coal dusting landing of compounded solution.

| Compounded solution | E              | Turbidity |
|---------------------|----------------|-----------|
| SDS+ CAB-35         | 0:02:00.27     | muddy     |
| SDS+JFCS            | 0:00:14.10     | muddy     |
| SDS+BS-12           | 0:09:36.48     | clear     |
| CAB-35+JFCS         | 0:00:11.43     | clear     |
| CAB-35+BS-12        | 0:07:05.77     | muddy     |
| JFCS+BS-12          | 0:01:00.27     | muddy     |

Table 4. Test data of reverse permeation.

| compounded solution | average creased weight of coal powder |
|---------------------|--------------------------------------|
| SDS+CAB-35          | 0.28                                 |
| SDS+JFCS            | 0.57                                 |
| SDS+BS-12           | 0.21                                 |
| CAB-35+JFCS         | 0.65                                 |
| CAB-35+BS-12        | 0.24                                 |
| JFCS+BS-12          | 0.51                                 |

3.4. Spraying dusting simulation experiment after adding chemical de-dusting agent

The spraying dust-settling simulation device is mainly made by the high-pressure spray pump, fan, the closed-end test case, nozzle, the dust generator, the Winner312 laser spraying particle size instrument and the AKFC-92A dust-detecting instrument., which shown as Fig. 3. Determine the spraying dust-settling rate after adding de-dusting agent.
and the mist-spraying particle diameter after adding different de-dusting agent spraying and adding the clean water. For more accurate to simulate the condition of the coal face, determining the test results of the mist-spray particle diameter of the fog fields where vertical distance between laser line and nozzle is 1250mm and the fan rolling speed is 300r/min, the water pressure is 8MPa. The Winner312 laser spraying particle size instrument used in the experiment can mainly provide the test results such as $D_{0.1}$ (the whole volume fractions which smaller to the particle size is 10 percent of the total volume), $D_{0.5}$ (mass media diameter), $D_{0.9}$ (the whole volume fractions which smaller to the particle size is 90 percent of the total volume), $D_{32}$ (surface average particle diameter), $D_{43}$ (volume average particle diameter) and so on. Test data is shown as Table 5.

| solution          | $D_{0.1}/\mu m$ | $D_{0.5}/\mu m$ | $D_{0.9}/\mu m$ | $D_{32}/\mu m$ | $D_{43}/\mu m$ |
|-------------------|-----------------|-----------------|-----------------|----------------|----------------|
| Clean water       | 17.987          | 35.164          | 61.121          | 29.112         | 38.848         |
| SDS+ CAB-35       | 23.541          | 40.672          | 67.814          | 36.925         | 43.250         |
| SDS+JFCS          | 26.941          | 46.231          | 75.196          | 41.214         | 51.634         |
| SDS+BS-12         | 19.879          | 37.598          | 64.426          | 30.947         | 40.157         |
| CAB-35+JFCS       | 28.371          | 50.295          | 81.641          | 45.756         | 55.197         |
| CAB-35+BS-12      | 21.413          | 38.175          | 65.663          | 33.289         | 41.715         |
| JFCS+BS-12        | 24.732          | 41.815          | 67.381          | 38.041         | 45.168         |

From the Table 5, we can see that, after adding the chemical de-dusting agent, the mist-spray particles’ diameter which in the droplet fields are increased in different degree comparing with that no adding chemical de-dusting agent. Even in combination solution SDS+BS-12 with poor performance in the experiment above, the droplet diameters $D_{10}$, $D_{50}$, $D_{90}$, $D_{32}$ and $D_{43}$ were increased 1.892 μm, 2.434 μm, 3.305 μm, 1.835 μm and 1.309 μm compared with clean water.

Determining the test data by the dust detector in the outlet of the device after generating dust and spraying dust stablized. From the results, we can draw that concentrations of dust generator before spraying were: 270mg/m³ of total coal dust, 120mg/m³ of respirable dust. Meanwhile, control the time of gas extraction flow of dust detector at 20L/min and the time of impact at 2 minutes. Determining data shown as Fig. 4.

From the Figs above, comparing with clean water, the settlement performance were improved to different degrees after adding chemical de-dusting agent, and diameters of fog droplets were increased obviously, however, they were within the droplet diameter scope of the best, the dust order of combination solution above mentioned was CAB-35+JFCS>SDS+JFCS>JFCS+BS-12>SDS+JFCS>CAB-35>CAB-35+BS-12>SDS+BS-12, which consistent with the settlement experiment, of which, the settlement rate of total coal dust and respirable dust of the best formulation CAB-35+JFCS can reached 63.7% and 56.3%. Finally, CAB-35+JFCS was selected as the chemical de-dusting agent.
formulation, concentrations of de-dusting agents were reached to 0.05% (concentrations of SDS and BS-12 were reached 0.025%).

4. Conclusions

(1) Measuring the surface tension of the four kind of surfactant solutions (SDS, CAB-35, JFCS and BS-12) in different concentrations by the automatic tension meter and contact angle analyzer, and the test result of CMC was 0.05% which as the compounding concentration of the four kind of solutions.

(2) Coal dust settlement and reverse permeation experiments of the six kind of compounding solutions with the principle of the two monomer distribution to confirm that the best formulation of de-dusting surfactant was the solution-CAB-35+JFCS, and the mass concentration of it was 0.05%.

(3) From the results of the experiment after adding chemical de-dusting agents, we can see that, the particle size of droplets which in the spray field was significantly increased, and the efficiency of dust-settling was improved compared with clean water, finally, the solution SDS+BS-12 as the chemical de-dusting agent was selected, the mass concentration of it was 0.05% (mass concentration of SDS and BS-12 were 0.025%).

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References

[1] Cheng Wei-min & Liu Xiangsheng & Ruan Guoqiang. The closed control theory and technology of coal roadway rapid concentration. [J]. Journal of China coal Society; 2009, 34(2): Pp 203-207.
[2] Zhang Yingxin & Wu qiang. The strengthening dust settling experiment of surfactant. [J]. Journal of Heilongjiang Institute of Science and Technology. 2008, 18(4): 269-271.
[3] Yang Jing & Tan Yunliang & Wang Zhenhua. The study of coal dust surface characteristic and the humid mechanism. [J]. Journal of China coal Society; 2007, 32(7): 737-740.
[4] Wu Chao. The chemical de-dusting. [M]. Changsha; Central south university press; 2003: 128-129.
[5] Zeng Kangsheng & Hu Nailian & Cheng Weimin & Zhou Gang & Yang Peng. The spraying settlement mechanism of the wetting agent in fully mechanized caving face and experiment of de-dusting wetting agent. [J]. Journal of China coal Society; 2009, 34(12): 1675-1680.
[6] Wei Guangping & Hou Fengcai & Wang Leping, and so on. The study and application of wetting de-dusting agent home and abroad. [J]. China Mining Magazine; 2007, 16(9): 90-92.
[7] Nie Wen & Cheng Weimin & Yu Yanbin. The study and application of the closed de-dusting system of the whole rock bore surface pressure air curtain. [J]. Journal of China coal Society; 2012, 37(7): 1165-1170.
[8] Zhou Gang & Cheng Weimin & Wang Gang & Nie Wen. The de-dusting technology of surfactant in fully mechanized caving face. [J]. Industrial Safety and Environmental Protection.; 2009, 35(11): 17-19.
[9] Wen Nie, Weimin Cheng, and Yujiing Yao. “Numerical simulation of vortex Air curtain suction dust control system and its applications”, Science & Technology Review, vol. 29, no. 3, pp. 48-52, 2011.
[10] Aichun Liang, Xiaohuan Jin, and Shengjun Guo, “Eddy dust control system and wet dedusting system flow effects compound factors affecting the test”, Mining safety and environmental protection, vol. 36, no. 3, pp. 4-6, 2009.