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ORIGINAL PAPER

The influence of surfactant on the wettability of coal dust and dust reduction efficiency

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Abstract

In order to deal with the great surface tension and difficulty on wetting the micro dust, this paper designs wetting experiment of surfactant and studied the influence of its concentration on the contact angle and reduction efficiency of coal dust. Based on the collision coupling mechanism between surfactant and coal dust, the contact angle between surfactant and coal powder is measured by drop angle method. An experimental platform for spray dust suppression is designed, and dust removal efficiency is calculated by adding surfactant in the water. The experimental results show that the wettability of surfactant to coal dust increases with the increase of its concentration. When the surfactant concentration reaches the critical micelle concentration, the solution has the best wettability to coal dust. The wettability of anionic surfactant solution to coal dust is stronger than that of nonionic surfactant solution and cationic surfactant solution; with the increasing surfactant concentration, the efficiency of air water spray and dust removal is the optimal when the surfactant concentration reaches critical micelle concentration.

Keywords Surfactant · Contact angle · Critical micelle concentration · Dust reduction efficiency · Dust

Introduction

As the main energy for production and life in China and in the world's energy development, coal plays an important role. However, with the development of coal resources, the coal dust is becoming a more and more serious problem. When the dust concentration reaches a certain extent, it is prone to explode. Also, high concentration dust can reduce the visibility of the workplace, accelerate machine wear, and increase the probability of pneumoconiosis. Therefore, it is of great significance to reduce the dust concentration in the working environment (Fan et al. 2011; Hernandez-Carrillo and Beltran 2019; Zhang et al. 2005).

At present, the spray is the most commonly used measures for dust control in underground coal mines. However, the surface tension of spray water is greater than the critical surface tension of coal dust. As the coal dust is not easy to be wetted and trapped by water, the effect of spray dust suppression is poor, especially on respirable dust (Cheng et al. 2009; Huang et al. 2010; Li et al. 2013). Under this circumstance, many scholars chose to reduce the surface tension of water, enhance the wettability and trapping ability of coal dust, and improve the dust reduction efficiency by adding surfactants (Ge et al. 2016; Gui et al. 2016; Li et al. 2017; Jin et al. 2007; Wei et al. 2007). Crawford et al. (1994) studied the relationship between the content of different inorganic minerals in different rank coals and the wettability of coal through experiments. It was found that the ratio of hydrogen and oxygen content in coal was the main factor underlying the wettability of coal surface (Crawford et al. 1994). Dong et al. (2004) measured the contact angle of coal samples with different ranks after superfine treatment and found that the contact angle of superfine coal was close to or equal to 90 degrees, which indicated that the surface of superfine coal has strong hydrophobicity (Dong et al. 2004).

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The wettability of coal dust is affected by the surface tension of water. The surface tension can be measured by measuring the contact angle between water and coal dust. The greater the contact angle is, the worse the wettability of coal dust becomes. After different concentrations of surfactants are added into water, the dust reduction effect is also different. On this basis, the contact angles of various surfactants on the surface of coal samples are measured, and then the influence of different concentrations of surfactants on the wettability of coal dust is deduced. In this way, the influence of surfactant types and concentrations on the dust reduction effect can be better obtained (Carletti Negri and Lima Segantine 2020).

Test

Test reagents and samples

Surfactants, sodium dodecylbenzene sulfonate (SDBS), octylphenol polyoxyethylene ether (OP-10), and dodecyl trimethyl ammonium chloride (DTAC), were selected as the research objects according to critical micelle concentration (CMC, the lowest concentration of surfactant molecules for forming micelles in solvent is the best wetting concentration of water to coal sample). Six kinds of surfactant reagents with different concentrations were prepared, and the change rule of contact angle between surfactant and briquette was studied. The concentration and CMC of surfactant are shown in Table 1, and the industrial analysis and determination of coal preparation samples are shown in Table 2.

Test plan

Measurement of contact angle

The test coal sample and pure alcohol were mixed evenly, the wet coal dust was put into the slide groove, and the thin glass slide was fully compacted. After alcohol volatilization, the sample was fixed on the slide. The prepared coal sample is shown in Fig. 1. The contact angles of surfactant solution with different concentrations on the surface of pulverized coal were measured. First of all, zero the electric water injection system, adjust the sample platform to the horizontal position, lift the sample platform to focus the camera and set the frame number, then place the prepared coal sample slide horizontally in the center of the sample platform, and adjust the LED cold light source to make the coal sample surface flat and clear. Secondly, add 1 μL of liquid to be tested each time, and drop it onto the surface of coal sample through micro syringe. Before the liquid to be measured contacts with the coal sample, press the shooting key to capture the moment when the drop contacts the coal sample. The average value of five groups of experimental results was taken as the test result, which was photographed with industrial camera and set to 30 frames. For each group of contact angle test, the glass slide of coal sample was replaced to avoid the influence of repeated use of coal

Table 1 Surfactants used for testing

Reagent name	Type of active agent	Concentration ($mol \cdot L^{-1}$)	CMC ($mol \cdot L^{-1}$)
Sodium dodecylbenzene sulfonate (SDBS)	Anion	0.6×10^{-3}	1.2×10^{-3}
		0.8×10^{-3}	
		1.0×10^{-3}	
		1.2×10^{-3}	
		1.4×10^{-3}	
		1.6×10^{-3}	
Octylphenol polyoxyethylene ether (OP-10)	Nonionic	1.80×10^{-4}	6.18×10^{-4}
		3.26×10^{-4}	
		4.72×10^{-4}	
		6.18×10^{-4}	
		7.64×10^{-4}	
		9.10×10^{-4}	
Dodecyl trimethyl ammonium chloride (DTAC)	Cation	0.7×10^{-2}	1.6×10^{-2}
		1.0×10^{-2}	
		1.3×10^{-2}	
		1.6×10^{-2}	
		1.9×10^{-2}	
		2.2×10^{-2}	

Table 2 Composition distribution of coal samples

Coal quality	Mad (%)	Aad (%)	Vad (%)	Fcad (%)
Coking coal	3.12	11.38	16.89	68.61

sample on the determination results. The contact angle tester is shown in Fig. 2.

Dust reduction efficiency test

In order to determine the influence of surfactant on dust removal efficiency, the study established an experimental system of gas water spray. The system consists of 1 monitoring window, 2 pneumatic nozzle, 3 gas pressure relief valve, 4 gas flow meter, 5 barometer, 6 air compressor, 7 liquid pressure relief valve, 8 liquid flow meter, 9 water pressure gauge, 10 pressure regulating valve, 11 water pump, 12 water storage tank, 13 dust concentration detector, 14 vector frequency converter, and 15 dust sampler and self-made dust generator. The high-pressure pump and the air compressor pressurize the water and air, respectively, and then transfer them to the inlet and intake ports of the nozzle at a certain proportion, and then spray out from the nozzle to form a spray field. The CCZ-1000 type direct reading dust detector installed in the monitoring area and the AKFC-92A mine dust sampler was used to obtain the changes of dust mass concentration before and after spraying based on testing and data analysis. The experimental system of gas water spray is shown in Fig. 3.

In this experiment, under the condition of 0.3MPa air pressure and 0.1MPa water pressure, the dust reduction efficiency of three kinds of surfactants with different concentrations was measured. The dust selected in the experiment was the pulverized coal with particle size d < 125 μm screened by 120 mesh screen. The CCZ-1000 direct reading dust detector and the AKFC-92A mine dust sampler were arranged in the spray monitoring area of the experimental platform. The total dust concentration and respirable dust concentration in the dusty airflow before and after spraying were measured, respectively, and the efficiency of spray dustfall was calculated.

Fig. 2 Contact angle tester

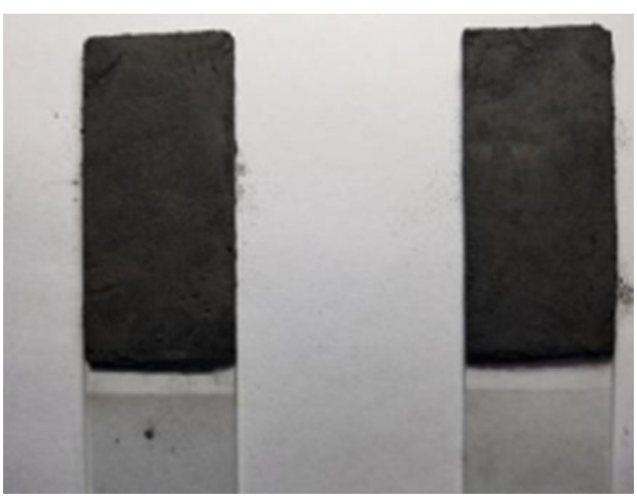

Fig. 1 Coal sample compression sheet

Analysis on experimental results

Effects of surfactant on contact angle

It can be seen from Figs. 4, 5, and 6 that when the solution concentration does not reach CMC, the contact angle decreases rapidly and the wettability increases rapidly with the increase of solution concentration (Jian and Chen 2019). When the solution concentration reaches CMC, the contact angle decreases slowly with the increase of solution concentration, and the change effect tends to be stable. The contact angles of three surfactants on coal surface decrease with the increase of concentration. When the concentration of surfactant reaches CMC, the measured value of contact angle of anionic surfactant is the smallest, followed by nonionic surfactant and cationic surfactant. The results show that the surface tension of anionic surfactant solution is the smallest, and the wettability to coal sample is the best, while the surface tension of cationic surfactant solution is the highest, and the wettability to coal sample is the worst. It is proved that the wettability of surfactant is closely related to its concentration and properties.

Effect of surfactant on dust reduction efficiency

In this experiment, under the condition of 0.3MPa air pressure and 0.1MPa water pressure, the dust reduction experiment is carried out with different concentrations and different kinds of surfactants to investigate the

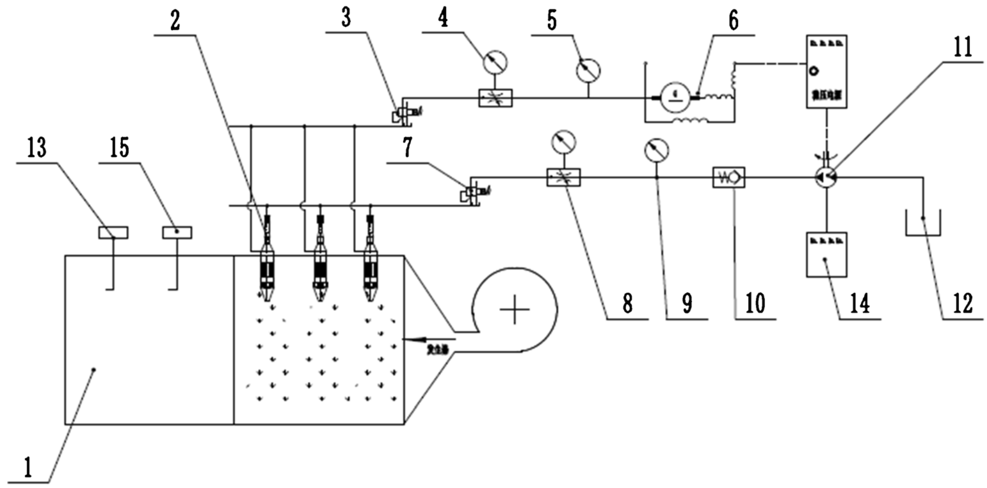

Fig. 3 The experimental system of gas water spray

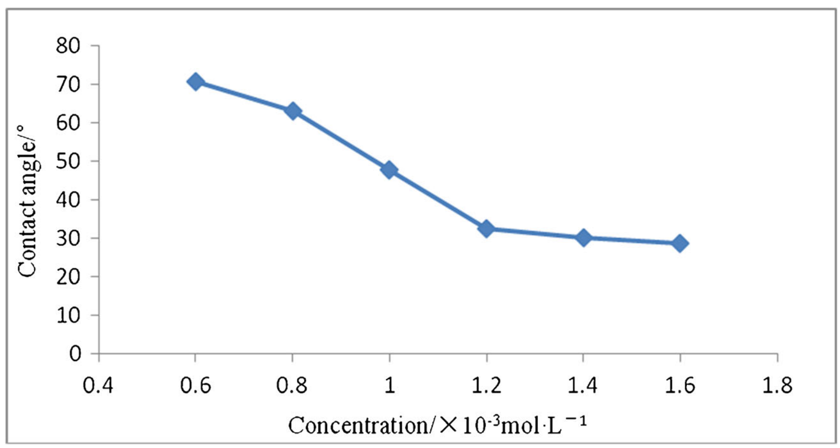

Fig. 4 Effect of SDBS solution on contact angle of coal sample

influence of the types and concentrations of surfactants on the dust reduction efficiency. The experimental results are shown in Tables 3, 4, and 5. According to the data in the table, the efficiency of spray dust removal by adding surfactants is obviously higher than that of clear water spray, and the efficiency of respirable dust removal is higher than that of the whole dust. The results show that adding surfactants in the clear water can improve the dust reduction of the fine dust particles. For different kinds of surfactants, the dust reduction efficiency of total dust and exhaled dust increases with the increase of surfactant concentration; when the concentration of the active agent reaches CMC, with the increase of the concentration, the dust reduction efficiency tends to increase in a slow manner. When the concentration of active agent reaches CMC, the dust

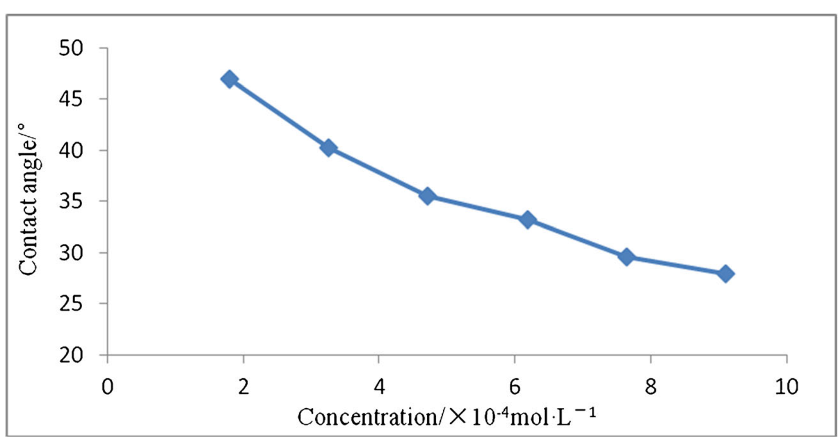

Fig. 5 Effect of OP-10 solution on contact angle of coal sample

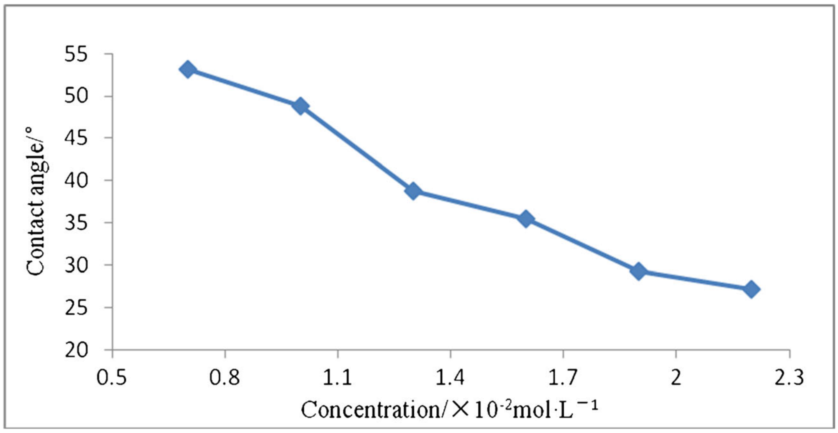

Fig. 6 Effect of DTAC solution on contact angle of coal sample

reduction efficiency of anion outperforms that of non-ionic and cationic active agent, and the dust reduction efficiency of cationic active agent reaches the lowest. By comparing the data in the table, it is found that the efficiency of dust suppression is closely correlated to the concentration and type of dust suppressants.

Conclusions

1) When the concentration of surfactant approaches CMC, the contact angle of coal sample is the smallest, and the wettability is good. The wettability of surfactant increases with the increasing concentration. When the

Table 3 Dust reduction efficiency of SDBS solution

Surfactant concentration ($mol{\cdot}L^{-1}$)	Total dust mass concentration (mg/m^3)		Total dust reduction efficiency (%)	Respiratory dust mass concentration (mg/m^3)		Respirable dust reduction efficiency (%)
	Before spraying	After spraying		Before spraying	After spraying	
0	323.58	146.81	54.63	69.24	34.47	50.29
0.6×10^{-3}	345.62	144.01	58.31	73.18	28.81	60.63
0.8×10^{-3}	351.48	105.97	63.85	78.69	25.54	67.54
1.0×10^{-3}	336.75	127.06	69.26	63.52	17.27	72.81
1.2×10^{-3}	329.76	77.72	76.43	81.27	16.88	79.23
1.4×10^{-3}	346.59	75.38	78.25	76.74	14.85	80.65
1.6×10^{-3}	360.18	75.03	79.17	65.82	13.98	78.76

Table 4 Dust reduction efficiency of OP-10 solution

Surfactant concentration ($mol{\cdot}L^{-1}$)	Total dust mass concentration (mg/m^3)		Total dust reduction efficiency (%)	Respiratory dust mass concentration (mg/m^3)		Respirable dust reduction efficiency (%)
	Before spraying	After spraying		Before spraying	After spraying	
0	332.16	159.11	52.28	62.58	31.49	49.68
1.80×10^{-4}	348.53	151.85	56.43	68.43	29.25	57.26
3.26×10^{-4}	362.17	136.97	62.18	72.16	24.67	65.81
4.72×10^{-4}	336.89	106.69	68.33	77.69	22.90	70.52
6.18×10^{-4}	357.41	92.39	74.15	62.14	13.93	77.58
7.64×10^{-4}	345.10	82.13	76.62	75.26	16.38	78.23
9.10×10^{-4}	352.22	76.78	77.54	73.50	15.14	79.40

Table 5 Dust reduction efficiency of DTAC solution

Surfactant concentration ($mol \cdot L^{-1}$)	Total dust mass concentration (mg/m^3)		Total dust reduction efficiency (%)	Respiratory dust mass concentration (mg/m^3)		Respirable dust reduction efficiency (%)
	Before spraying	After spraying		Before spraying	After spraying	
0	354.23	157.77	55.46	64.18	30.68	52.19
0.7×10^{-2}	346.18	147.16	57.49	78.25	31.08	60.28
1.0×10^{-2}	333.27	131.57	60.52	72.16	23.93	66.84
1.3×10^{-2}	364.19	120.29	66.97	62.55	18.43	70.53
1.6×10^{-2}	349.67	99.24	71.62	65.29	16.84	74.21
1.9×10^{-2}	335.69	91.54	72.73	69.28	16.05	76.83
2.2×10^{-2}	342.18	96.36	71.84	80.12	19.63	75.50

concentration reaches the critical micelle concentration, the wettability changes to a stable level.

2) Based on CMC, the wettability of anionic surfactant SDBS is the best, followed by nonionic surfactant OP-10 and DTAC.
3) The dust removal efficiency of the surfactants on the dust is obviously higher than that of the water. Adding surfactants spray can increase the dust removal efficiency.
4) With the increase of surfactant concentration, the dust removal efficiency of gas water spray is improved. When the surfactant concentration reaches CMC, the dust removal efficiency increases slowly.
5) Based on CMC, the dust reduction effect of SDBS is the best, followed by OP-10 and DTAC.
6) The wetting effect and dust reduction efficiency of different active agents are compared, which lay the foundation for further research in the future. However, these active agents have not applied in the actual workplace, so the next step is to apply the dust suppressant in the actual production environment.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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