

## Research Article

# Wetting Process and Adsorption Mechanism of Surfactant Solutions on Coal Dust Surface

Xiaonan Wang,<sup>1,2</sup> Shujie Yuan ,<sup>1,2</sup> and Bingyou Jiang<sup>1,2</sup>

<sup>1</sup>Key Laboratory of Safe and Effective Coal Mining, Ministry of Education, Anhui University of Science and Technology, Huainan 232001, China

<sup>2</sup>School of Energy and Safety, Anhui University of Science and Technology, Huainan 232001, China

Correspondence should be addressed to Shujie Yuan; [yuansj@aust.edu.cn](mailto:yuansj@aust.edu.cn)

Received 17 May 2019; Accepted 10 September 2019; Published 9 October 2019

Academic Editor: Hassan Arida

Copyright © 2019 Xiaonan Wang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

To determine the wetting process and wetting mechanism of different surfactant solutions on coal dust surface, four types of surfactants (anionic surfactant 1227, anionic surfactant AOS, amphoteric surfactant CAB-35, and nonionic surfactant CDEA) are selected to measure their surface tension and contact angle. Based on the data, the adhesion work, spreading coefficient, and immersion work of the surfactant solutions on a coal dust surface are calculated and their adsorption mechanism is discussed. The results show that the surface tension and contact angle of AOS and CDEA are lower and smaller, respectively, their calculated spreading coefficients are higher, and their adhesion work and immersion work are less than those of 1227 and CAB-35. This shows that the wettability of the AOS and CDEA solutions for a coal dust surface is more than that of 1227 and CAB-35, whereas their adhesion is lower than that of the latter. The spreading coefficient can be used as an index to determine the wettability. The wetting ability of the AOS and CDEA aqueous solutions for coal dust is stronger than that of 1227 and CAB-35 because of the different adsorption forms of the surfactant molecules on the surface of the coal dust. The tail hydrophobic group of the AOS and CDEA surfactant molecules orient to the surface of the coal dust, whereas the head hydrophilic group directs to the solution, being easier to wet. The results show that anionic and nonionic surfactant solutions can significantly improve the wettability of a coal dust surface, providing a theoretical basis for selecting suitable surfactants as water-spray additives to improve the dust suppression efficiency.

## 1. Introduction

In the process of coal production, a large amount of dust is frequently produced [1–3], particularly in the mining phase, which not only directly threatens the safety of coal mine production but also causes pneumoconiosis when workers inhale dust for a long time [4–6]. Therefore, dust control has typically been a prominent topic of research [7–9]. Presently, the most common dustproof measure adopted by our coal mines is water-spray dust suppression, which produces small water mist particles through a spray nozzle, which collide and bond with the dust particles and increase the size of the dust particles, thus achieving settlement [10–12]. The liquid medium mostly used for spray dustfall is clean water.

Although this measure is simple and economical, because the surface of coal contains numerous hydrophobic non-polar groups, it has a certain hydrophobicity and the water surface tension is high, so that the dust is not easily and rapidly wetted and captured by water [13, 14]. Adding a surfactant in water as a dust control method can effectively improve the dust suppression efficiency and has become an important approach to control coal dust in Europe and the United States. This is because a surfactant can significantly reduce the surface tension of a solution and effectively wet the dust surface [15, 16], leading to dust agglomeration and settling, thereby achieving the effect of dust suppression. Therefore, selecting a suitable surfactant is the key factor to improve the effect of the spray dustfall [13]. Although

Chinese scholars have developed various dust suppressant products and achieved some results in field applications, a study of the mechanism of a surfactant wetting coal dust is relatively rare.

In recent years, the main research results have been as follows: Yang et al. [3] studied the surface chemical structure, surface electrical properties, and surface wettability of coal dust via infrared spectroscopy, electrophoresis, and forward penetration experiments. The results showed that the wettability of a surfactant solution for coal dust depended not only on the gas-liquid surface tension of the solution but also on the solid-liquid interfacial tension between the solution and coal dust. The interfacial tension between the solution and coal dust was closely related to the hydrophobicity, electricity of the dust, and structural properties of the surfactant. Zhang [17] studied the surface dynamic adsorption and spreading properties of nonionic surfactants and preliminarily discussed the inhibition mechanism of coal dust. Ma and Zhu [18] theoretically analysed the micromechanism of water and coal dust by applying the knowledge of molecular thermodynamics and surface physicochemistry and revealed that the basis of wetting coal dust by water was a result of the interaction of the short-range and long-range forces between the molecules. A surfactant increases the interaction between water and coal dust, reduces the surface tension of water and interfacial tension between the coal dust and water, and reduces the free energy of the system, thereby improving the ability of water to wet coal dust.

In this study, four types of surfactants were selected, and by measuring the surface tension and contact angle,  $\gamma_{LV} - \cos \theta e$  the curve was correspondingly drawn, and the law between  $\gamma_{LV}$  and  $\cos \theta e$  was explored. The wettability and adhesion of the surfactant solutions for a coal dust surface should be evaluated by calculating the adhesion, spreading, and immersion works of the different surfactant systems, and the process of wetting coal dust by a surfactant may be explored. The surface modification principle of the surfactants for water and coal dust could be expounded, and the adsorption mechanism of the different surfactants for wetting coal dust will be discussed.

## 2. Materials and Methods

**2.1. Experimental Material.** The coal sample used in the experiments was acquired from a coal mine in Erdos, China, which is characteristically composed of bituminous coal. In the experiments, tap water was used to more closely replicate the actual conditions of the coal mine. The coal sample was crushed and sieved into powders finer than a 200 mesh (0.074 mm).

Considering the particular working environment of a coal mine, the surfactant should be nontoxic, nonirritating, nonflammable, low cost, and easy to dissolve in water [19]. In this study, four types of surfactants (Table 1) were selected to study the wetting law and were purchased from Usoft Chemical Technology Co. Ltd.

**2.2. Basic Theory.** Wetting originates from the adsorption of liquid molecules on the surface of particles. A wetting process is actually a process in which a liquid and gas compete for the surface of particles. It can be regarded as the disappearance of the solid-vapor interface and formation of a solid-liquid interface [20].

A wetting process is related to the surface tension of the system. When a drop of liquid falls on a horizontal solid surface and reaches equilibrium (Figure 1), the relationship between the contact angle and surface tension conforms to the following equation (Young's equation) [20]:

$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \times \cos \theta e, \quad (1)$$

where  $\gamma_{SV}$  is the solid-vapor surface tension (mN/m),  $\gamma_{SL}$  is the solid-liquid interfacial tension (mN/m),  $\gamma_{LV}$  is the liquid-vapor surface tension (mN/m), and  $\theta e$  is the contact angle at the solution interface ( $^{\circ}$ ).

**2.3. Experimental Methods and Facilities.** Based on Young's equation, the wetting law of a coal dust surface was studied by measuring the surface tension of the surfactant solutions and contact angle of the surfactant solutions on the coal dust.

The solutions of 1227, AOS, CAB-35, and CDEA of different concentrations (0.01 wt%, 0.03 wt%, 0.05 wt%, 0.07 wt%, 0.1 wt%, 0.3 wt%, and 0.5 wt%) were prepared, respectively. The surface tension of the different concentration solutions was measured using the maximum bubble method and a DMPY-2C surface tension meter manufactured by the Institute of Applied Physics in Nanjing. Every experimental sample was measured thrice. All the experiments were conducted at ambient temperature of 25°C.

The coal powder was pressed into a tablet form for the contact angle tests using a YP-2 type tablet press machine manufactured by Shanyue Science Instrument Co. Ltd., Shanghai, which maintained the compressing pressure at 20 MPa for 2 min [21]. The contact angles of the different concentration solutions (0.01 wt%, 0.03 wt%, 0.05 wt%, 0.07 wt%, 0.1 wt%, 0.3 wt%, and 0.5 wt%) on the coal surface were detected using the sessile drop method and a SL200C contact angle instrument manufactured by Kino Co. Ltd., USA. The photos from the testing of the contact angle of all the solutions were captured in the first second of the solution dripping for comparing the results of the experiment. Each experimental sample was measured thrice.

## 3. Results and Discussion

**3.1. Surface Modification of Surfactant on Water and Coal Dust.** Surfactants are polar hydrophilic and nonpolar hydrophobic groups, which can significantly reduce the surface tension of a solution at low concentrations [20]. The surface tension of the four different surfactants at the different concentrations (wt%) was measured by the maximum bubble method, and the experimental results are shown in Figure 2. The results show that the surface tension of the four surfactants decreases with the increase in the concentration at low concentrations. When the concentration reaches a certain value, the surface tension tends to be stable, and this

TABLE 1: The surfactants used in the experiment.

Reagent name	Abbreviation	Category	Molecular formula
Dodecyl dimethyl benzyl ammonium chloride	1227	Cationic	$C_{21}H_{38}NCl$
Sodium alpha-olefin sulfonate	AOS	Anionic	$RCH = CH(CH_2)_nSO_3Na$ , $R = C_{14-16}$
Cocoamido propyl betaine	CAB-35	Amphoteric	$C_{19}H_{38}N_2O_3$
Coconut diethanolamide	CDEA	Nonionic	$C_{11}H_{23}CON(CH_2CH_2OH)_2$

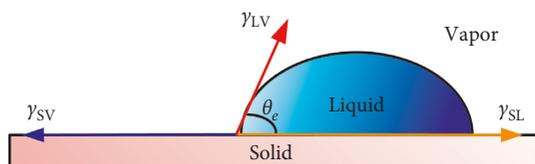


FIGURE 1: The relationship between the contact angle and solid-liquid, solid-vapor, and liquid-vapor surface tension.

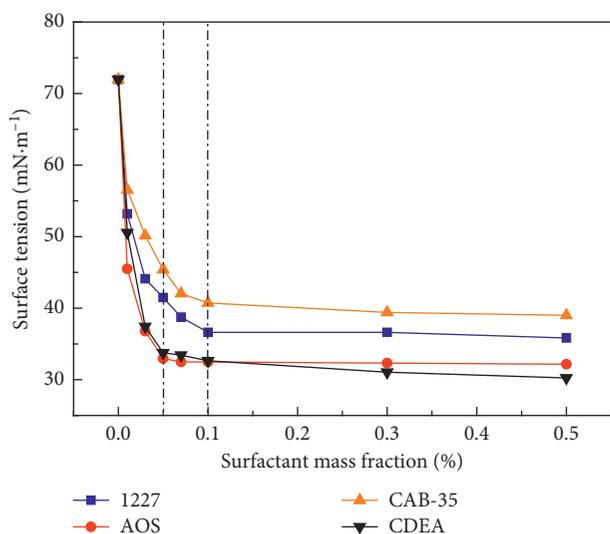


FIGURE 2: Surface tension of the surfactants at the different concentrations.

concentration is the critical micelle concentration (cmc). The cmc of the four surfactants is mainly concentrated at 0.05% and 0.1%. When a surfactant dissolves in water, because of the hydrophobic effect, the hydrophilic group is inserted in water, the hydrophobic group extends into air, and the surfactant molecule forms a directional interface adsorption layer on the surface of the water solution. This changes the contact state between the surface molecules of water and air, resulting in the decrease in the surface tension of the water solution [22]. In addition, by comparing the surface tension of the different surfactants, it can be concluded that when the concentration of the four surfactants reaches 0.1%, the surface tension decreases to less than 40 mN/m, which significantly reduces the surface tension of water.

The solutions of the four surfactants were prepared with different mass fractions to determine the contact angle formed between them and the coal tablets. The measured contact angle between the tap water and coal tablet is  $56.18^\circ$ . At low concentrations (0–0.1 wt%), the

contact angle of the surfactant solutions on the coal tablet decreases rapidly ( $25.21^\circ$ – $20^\circ$ ), whereas when the concentration exceeds 0.1 wt%, the change in the surface tension tends to be gradual (Figure 3). Because the hydrophobic group of each surfactant solution has a strong interaction with the coal dust particles, the interaction between water and coal dust is increased, the interfacial tension between water and coal dust,  $\gamma_{SL}$ , is reduced, the contact angle,  $\theta_e$ , is reduced, and the wetting process becomes easier than when without the surfactant [22]. Simultaneously, the contact angle of the anionic and nonionic surfactant solutions on the coal tablets is smaller than that of the cationic and amphoteric surfactants, which indicates that the wettability of the former for the coal tablets is better than that of the latter.

As can be seen from Figures 2 and 3, the changes in the surface tension and contact angle with the concentration are basically the same. Figure 4 shows the relationship between the surface tension of the surfactant aqueous solutions,  $\gamma_{LV}$ , and cosine of the contact angles of the surfactant aqueous solutions on the coal tablet,  $\cos \theta_e$ . It can be seen that there are two linear relationships between  $\gamma_{LV}$  and  $\cos \theta_e$ : before the cmc,  $\cos \theta_e$  increases linearly with the decrease in  $\gamma_{LV}$  and changes gradually. Following this, a turning point appears near the cmc, and after reaching the cmc,  $\cos \theta_e$  increases linearly with the decrease in  $\gamma_{LV}$ , but changes rapidly [22]. The straight line after the cmc of the different surfactant solutions extends to  $\cos \theta_e = 1$ , i.e.,  $\theta_e = 0^\circ$ , corresponding to  $\gamma_{LV}$ , which implies that the liquid with that surface tension can wet the surface of the coal dust completely and can spread on it. This shows that the spreading of a surfactant solution on a coal dust surface is the result of the decrease in the surface tension of the surfactant solution [22].

### 3.2. Process of Wetting Coal Dust with Surfactant Solution.

In fact, the wetting process can be divided into three parts: adhesion, spreading, and immersion [20]. In the process of dust suppression by spraying with the addition of a surfactant, when the surfactant contacts the surface of coal dust, adhesion, spreading, and immersion occur successively, as shown in Figure 5.

**3.2.1. Adhesion of Surfactant to Coal Dust.** In the instant when a surfactant and coal dust contact, the surfactant–air interface and coal-dust–air interface become a coal-dust–surfactant interface, and this process is adhesion. The adhesion work is used to characterize the binding ability of a surfactant to coal dust and the interaction force between the molecules of the two phases.

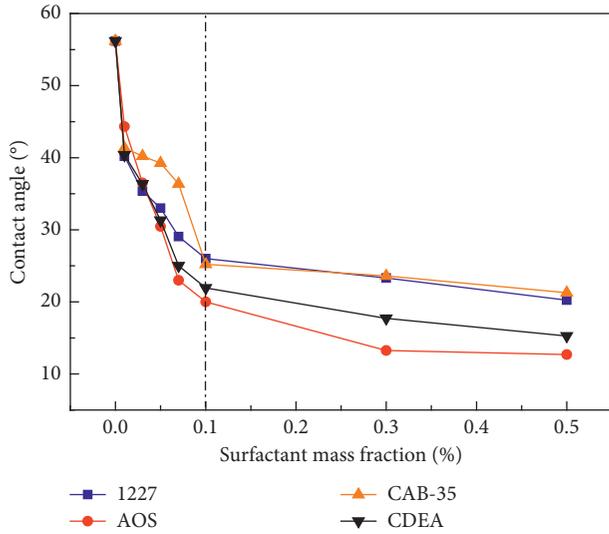


FIGURE 3: Contact angle of the surfactants at the different concentrations.

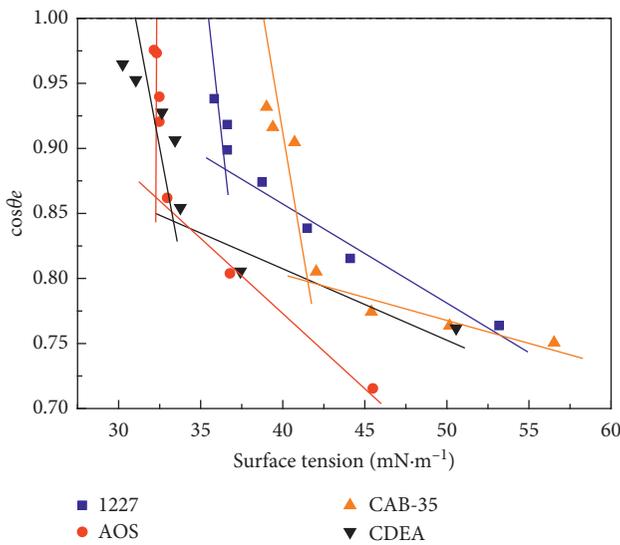


FIGURE 4: The relationship between  $\gamma_{LV}$  and  $\cos \theta_e$ .

If the contact area is taken as a unit value, the decrease in the free energy of the system in the process of adhesion,  $-\Delta G$ , should be as follows:

$$-\Delta G = \gamma_{SV} + \gamma_{LV} - \gamma_{SL} = W_a, \quad (2)$$

where  $\gamma_{SV}$  is the solid–vapor surface tension (mN/m),  $\gamma_{SL}$  is the solid–liquid interfacial tension (mN/m),  $\gamma_{LV}$  is the liquid–vapor surface tension (mN/m), and  $W_a$  is the adhesion work (mN/m) [20].

By introducing Young's equation (equation (1)), we can obtain

$$W_a = \gamma_{LV} (1 + \cos \theta_e). \quad (3)$$

The adhesion works of the surfactant solutions on the surface of coal dust calculated according to equation (3) are shown in Figure 6. It can be seen that the adhesion work

curves of the four surfactants with the increase of solution concentration are basically similar, and all first decrease and then stabilize. The adhesion works of 1227 and CAB-35 are significantly more than those of AOS and CDEA, and comparatively, the contact angles of AOS and CDEA on the coal dust are less than those of 1227 and CAB-35, which indicates that the adhesion work cannot be used as a discriminant index of wettability. It only exhibits that the adhesion of 1227 and CAB-35 on coal dust is better than that of AOS and CDEA, which is consistent with the research results of Zhang et al. [23].

**3.2.2. Surfactant Spreading on Coal Dust Surface.** While the coal-dust–surfactant interface replaces the coal-dust–air interface, the surfactant also extends on the coal dust surface, which is the spreading process.

When the spread area is a unit value, the system free energy is reduced to

$$-\Delta G = \gamma_{SV} - (\gamma_{SL} + \gamma_{LV}) = W_s, \quad (4)$$

where  $W_s$  is the spreading work (spreading coefficient) (mN/m) [20].

By introducing Young's equation (equation (1)), we can obtain

$$W_s = \gamma_{LV} (\cos \theta_e - 1). \quad (5)$$

The spreading works of the surfactant solutions on the surface of coal dust calculated according to equation (5) are shown in Figure 7. The results exhibit that the spreading coefficients of the different surfactant solutions display similar trends with the concentration, i.e., first they rise rapidly and then stabilize. The spreading works of the AOS and CDEA solutions are obviously more than those of 1227 and CAB-35, indicating that the wettability of the former on the surface of coal dust is higher than that of the latter, which is similar to the measurement results of the contact angle. However, at a constant temperature and pressure, the condition under which a liquid can spread automatically on a solid surface is  $W_s \geq 0$  [20]. It can be seen from Figure 7 that the spreading works of the four surfactants on the surface of coal dust are less than zero, which indicates that they cannot spread themselves on the surface of coal dust under the experimental concentration. However, the AOS and CDEA solutions are closer to self-spreading.

**3.2.3. Surfactant Immersion of Coal Dust.** The basis of the immersion process of coal dust in a surfactant is that the coal-dust–air interface is replaced by the coal-dust–surfactant interface, with the surface of the surfactant not changing during this process. The immersion work reflects the ability of a surfactant to replace air on the surface of coal dust. When the wetting area is a unit value, the free energy of the process decreases to

$$-\Delta G = \gamma_{SV} - \gamma_{SL} = W_i, \quad (6)$$

where  $W_i$  is the immersion work (mN/m) [20].

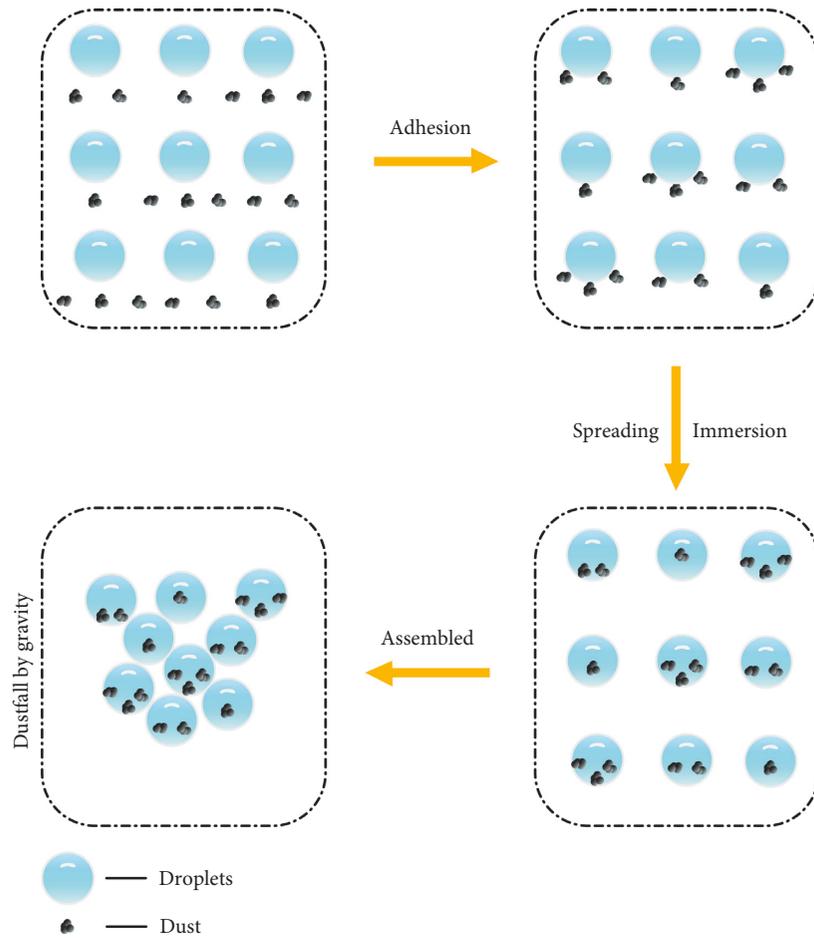


FIGURE 5: The process of the capture of dust particles capture by droplets.

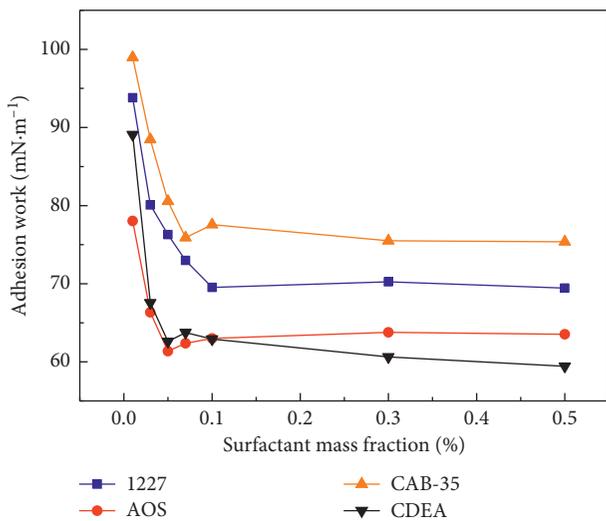


FIGURE 6: The adhesion works of the surfactant solutions on the coal dust surface at the different concentrations.

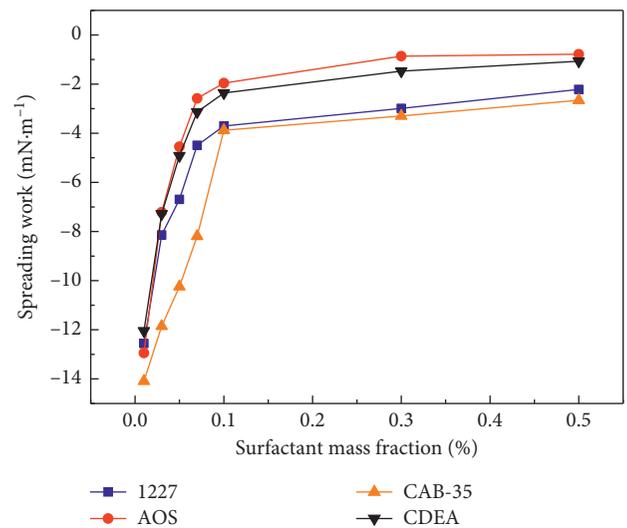


FIGURE 7: The spreading works of the surfactant solutions on the coal dust surface at the different concentrations.

By introducing Young's equation (equation (1)), we can obtain

$$W_i = \gamma_{LV} \times \cos \theta_e. \quad (7)$$

Based on equation (7), the immersion works of the surfactant solutions on the surface of coal dust are shown in Figure 8. The immersion works of the four surfactants on the

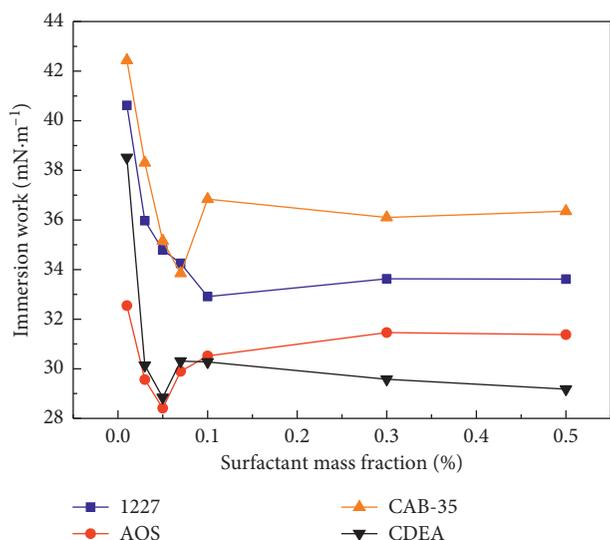


FIGURE 8: The immersion works of the surfactant solutions on the coal dust surface at the different concentrations.

surface of coal dust are basically similar with the change in concentration, and all of them first decrease and then stabilize. The immersion works of 1227 and CAB-35 are significantly more than those of AOS and CDEA, indicating that the former have a stronger ability to replace air on the surface of coal dust than the latter.

Equations (3), (5), and (7) show that the contributions of the solid–vapor and solid–liquid interface energy to the three wetting processes of the system are the same. They all act in the form of adhesion tension  $A = \gamma_{SV} - \gamma_{SL}$ , i.e., a large  $\gamma_{SV}$  implies a smaller  $\gamma_{SL}$  and a large  $(\gamma_{SV} - \gamma_{SL})$  value corresponds to high wetting [20]. The contribution of the liquid–vapor surface tension to the three processes is different. For adhesion,  $\gamma_{LV}$  is beneficial, and the liquid–vapor surface tension of 1227 and CAB-35 is higher than that of AOS and CDEA. Therefore, the adhesion works of 1227 and CAB-35 are more than those of AOS and CDEA, and they are more likely to adhere coal dust. For spreading,  $\gamma_{LV}$  is slightly advantageous. The liquid–vapor surface tension of AOS and CDEA is lower than that of 1227 and CAB-35, and so, the spreading works of the AOS and CDEA solutions are obviously more than those of 1227 and CAB-35. By contrast, for immersion,  $\gamma_{LV}$  does not play a role. From the above three phenomena, it can be deduced that the wettability of a surfactant on a coal dust surface is more closely related to the spreading process, which is mainly related to the surface tension of the surfactants, than the other processes. A low surface tension of a surfactant implies a good wettability. Therefore, the spreading coefficient can be used as an index to determine the wettability.

**3.3. Adsorption Mechanism of Different Surfactants on Interface.** Under the experimental conditions, the surface tension of water is 71.97 mN/m, whereas the critical tension of most coal dust is about 45 mN/m [24]. Therefore, the effect of wetting coal dust with water alone is not extremely good. However, the surface tension and contact angle

experiments show that the wettability of coal dust can be improved by adding a certain amount of a surfactant in water; this is achieved owing to the adsorption of the surfactant on the liquid–vapor and solid–liquid interfaces.

**3.3.1. Adsorption of Surfactant Molecules in Aqueous Solution.** As shown in Figure 9, the surfactant molecules are amphiphilic molecules, which tend to escape from the aqueous solution; therefore, they easily get adsorbed on the surface of a solution in the form of a directional arrangement. The hydrophilic groups of the surfactants are attached to the water surface, whereas the hydrophobic groups are toward the air [20]. With the increase in the concentration, the adsorption increases gradually, the surfactant in the surface molecular layer increases gradually, and the water molecules decrease gradually [22]. When the concentration of a surfactant solution reaches the cmc, the surfactant molecules reach adsorption saturation on the surface of the solution, and stable micelles composed of several to hundreds of ions or molecules are synthesized from a dispersion state inside the solution. At this instant, the concentration of a single molecule or ion in the solution will not increase significantly and only more micelles can be formed; therefore, the surface tension of the solution does not change much [25, 26]. The turning point at the cmc is related to the structural change of the adsorption layer on the surfactant interface. Before the turning point, the adsorption layer is not completely formed; after the turning point, the adsorption layer is formed, and more stable micelles are produced with the increase in the concentration.

**3.3.2. Adsorption of Surfactant Molecules on Coal Dust Surface.** Infrared spectrum experiments show that numerous hydrophobic groups are present on the surface of coal dust, such as aromatic hydrocarbons and aliphatic hydrocarbons. Electrophoresis experiments reveal that a coal dust surface is negatively charged [3]. In the spray dustfall process, when the coal dust collides with the surfactant, owing to the effect of Van der Waals force [27], the hydrophobic groups of the surfactant adsorb on the aromatic hydrocarbons and aliphatic hydrocarbons present on the surface of coal dust, and the coal dust gets rapidly trapped in the surfactant aqueous solution. Therefore, an aqueous solution containing a surfactant has an obvious wetting effect.

Although different types of surfactants can improve the wettability of coal dust, the wettability itself is different. As shown in Figure 10(a), in the process of adsorption of cationic surfactant 1227 and coal dust, the negative charge on the hydrophobic surface of the coal dust attracts the cationic hydrophilic groups of the surfactants. Therefore, an outer hydrophobic adsorption layer is formed on the surface of coal dust and the surface property changes from hydrophilic to hydrophobic. Now, water can no longer spread on the surface, instead a water droplet with a certain contact angle with the surface is formed. If the concentration of the surfactant solution increases, the adsorption continues, so

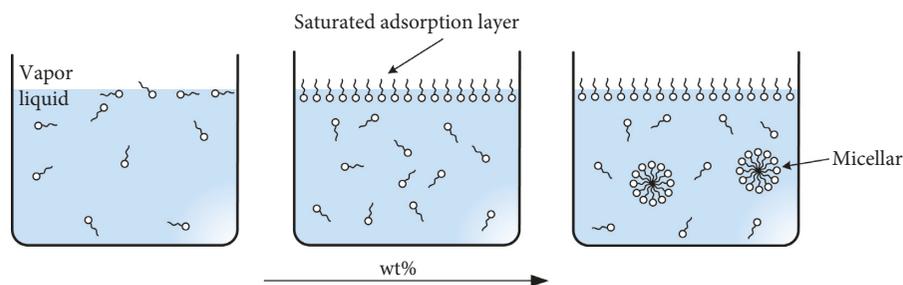


FIGURE 9: Adsorption state of a surfactant molecule in an aqueous solution with concentration change.

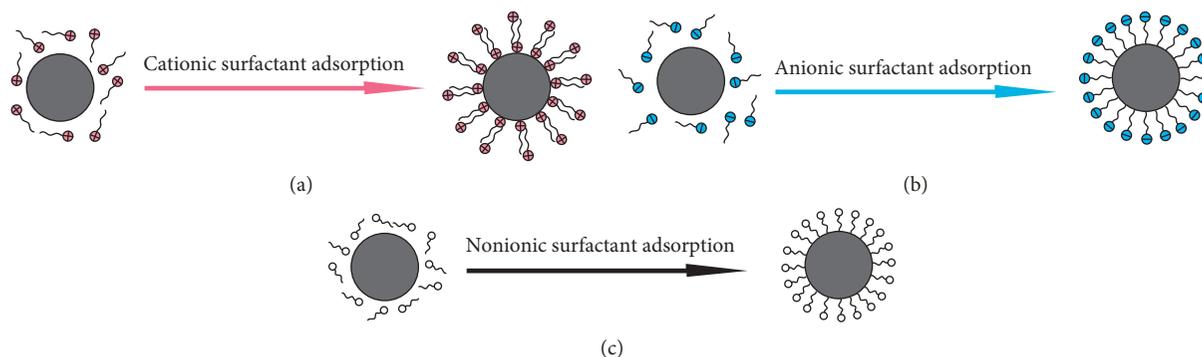


FIGURE 10: The adsorption process of coal dust by the different surfactants.

that the surface charge becomes positive. Now, the polar heads of the adsorbed surface-active ions are toward the aqueous solution, which increases the hydrophilicity of the coal dust surface and decreases the contact angle [20]. Because cationic surfactants frequently form such adsorbed layers on the surface of coal dust, they are not suitable as wetting agents for it [28].

As shown in Figure 10(b), in the adsorption process of anionic surfactant AOS and coal dust, the hydrophobic surface of the coal dust interacts strongly with the hydrophobic groups of the surfactant; therefore, they adsorb the coal dust surface as the tail hydrophobic group gets directed toward the surface of the coal dust and the head anionic hydrophilic group becomes directed toward the solution after adsorption, the hydrophilicity of the coal dust is enhanced and the wettability of the solution for the coal dust is significantly improved.

Amphoteric surfactants have an isoelectric point. A positive charge in a solution with a pH lower than the isoelectric point shows the performance of a cationic surfactant, and the adsorption mechanism is referred to in Figure 10(a). In a solution with a pH higher than the isoelectric point, a negative charge is shown, similar to the nature of an anionic surfactant, and the adsorption mechanism is shown in Figure 10(b) [25]. CAB-35 selected in the experiment is a betaine-type amphoteric surfactant, and its properties are distinct. Specifically, it is cationic below the isoelectric point, whereas it is an "internal salt" above the isoelectric point, and it does not show anionic properties [20]. Therefore, the wetting effect of the CAB-35 solution on coal dust is not strong.

As shown in Figure 10(c), the adsorption of nonionic surfactant CDEA and coal dust depends not on the ion exchange or ion pair but on the hydrogen bonds and intermolecular force. The hydrophilic group of the nonionic surfactant is oriented toward the water solution, which increases the hydrophilicity of the coal dust surface, making it easier to be wetted by water and dispersed in the aqueous phase [29].

It can be seen from the above that anionic surfactants and nonionic surfactants have a stronger ability to wet coal dust than cationic surfactants and amphoteric surfactants owing to the different adsorption mode.

## 4. Conclusions

- (1) The surface tension of AOS, CDEA, 1227, and CAB-35 decreases with increasing concentration. When the concentration is higher than cmc, the surface tension tends to be stable, and the change trend of the contact angle with the concentration is similar to that of the surface tension.
- (2) There are two linear relationships between  $\gamma_{LV}$  (the surface tension of a surfactant aqueous solution) and  $\cos \theta_e$  (the cosine of the contact angle of the surfactant aqueous solution on the coal tablet) of the four surfactants. Before the critical micelle concentration (cmc),  $\cos \theta_e$  increases linearly with the decrease in  $\gamma_{LV}$  and changes gradually. Next, a turning point appears near the cmc, and after reaching the cmc,  $\cos \theta_e$  increases linearly with the decrease in  $\gamma_{LV}$ , but changes rapidly.

- (3) The surface tension and contact angle of AOS and CDEA are less than, their calculated spreading coefficients are larger than, and their adhesion and immersion works are less than those of 1227 and CAB-35. This indicates that the wettability of the AOS and CDEA solutions on coal dust surface is stronger than that of 1227 and CAB-35, whereas their adhesion is lower than that of 1227 and CAB-35. The spreading coefficient can be used as an index to determine the wettability.
- (4) The wetting ability of the AOS and CDEA aqueous solutions for coal dust is stronger than that of 1227 and CAB-35 because of the different adsorption forms of the surfactant molecules on the surface of coal dust. The tail hydrophobic group of the AOS and CDEA surfactant molecules orient to the surface of the coal dust, whereas the head hydrophilic group directs to the solution, being easier to wet.
- (5) Anionic surfactants and nonionic surfactant aqueous solutions can significantly improve the wettability of coal dust surface.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Acknowledgments

The research was sponsored by the Fundamental Research Funds of the National Natural Science Foundation of China (No. 51874009).

## References

- [1] W. M. Cheng, X. S. Liu, G. Q. Ruan et al., "The theory and technology of enclosure dust-laying model in speeded advance of coal road," *Journal of China Coal Society*, vol. 4, no. 2, pp. 203–207, 2009.
- [2] Y. X. Zhang and Q. Wu, "Enhanced spraying dust-settling experiment of surfactant," *Journal of Heilong Jiang Institute of Science and Technology*, vol. 18, no. 4, pp. 269–271, 2008.
- [3] J. Yang, Y. Z. Tan, Z. H. Wang et al., "Study on the coal dust surface characteristics and wetting mechanism," *Journal of China Coal Society*, vol. 32, no. 7, pp. 737–740, 2007.
- [4] X. Xi, S. Jiang, W. Zhang, K. Wang, H. Shao, and Z. Wu, "An experimental study on the effect of ionic liquids on the structure and wetting characteristics of coal," *Fuel*, vol. 244, pp. 176–183, 2019.
- [5] H. Wang, L. Zhang, D. Wang, and X. He, "Experimental investigation on the wettability of respirable coal dust based on infrared spectroscopy and contact angle analysis," *Advanced Powder Technology*, vol. 28, no. 12, pp. 3130–3139, 2017.
- [6] G. Ni, Z. Li, and H. Xie, "The mechanism and relief method of the coal seam water blocking effect (WBE) based on the surfactants," *Powder Technology*, vol. 323, pp. 60–68, 2018.
- [7] Q. Zhou, B. Qin, J. Wang, H. Wang, and F. Wang, "Experimental investigation on the changes of the wettability and surface characteristics of coal dust with different fractal dimensions," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 551, pp. 148–157, 2018.
- [8] Q. Yao, C. Xu, Y. Zhang, G. Zhou, S. Zhang, and D. Wang, "Micromechanism of coal dust wettability and its effect on the selection and development of dust suppressants," *Process Safety and Environmental Protection*, vol. 111, pp. 726–732, 2017.
- [9] C. Xu, D. Wang, H. Wang et al., "Experimental investigation of coal dust wetting ability of anionic surfactants with different structures," *Process Safety and Environmental Protection*, vol. 121, pp. 69–76, 2019.
- [10] L. Zhu, G. Zhou, M. D. Sun, and W. Nie, "Experiment study on chemical dedusting agent for spraying dust control," *Coal Engineering*, vol. 46, no. 9, pp. 96–98, 2014.
- [11] K. S. Zeng, N. L. Hu, W. M. Cheng et al., "Dedusting mechanism by water-cloud of wetting agents and the relevant tests for fully-mechanized and roof caving coal face," *Journal of the China Coal Society*, vol. 34, no. 12, pp. 1675–1680, 2009.
- [12] G. Zhou, H. Qiu, Q. Zhang et al., "Experimental investigation of coal dust wettability based on surface contact angle," *Journal of Chemistry*, vol. 2016, Article ID 9452303, 8 pages, 2016.
- [13] C. Wu, *Chemical Dust Suppression*, Central South University Press, Changsha, China, 2003.
- [14] X. Wang, S. Yuan, and B. Jiang, "Experimental investigation of the wetting ability of surfactants to coals dust based on physical chemistry characteristics of the different coal samples," *Advanced Powder Technology*, vol. 30, no. 8, pp. 1696–1708, 2019.
- [15] Q. Li, B. Lin, S. Zhao, and H. Dai, "Surface physical properties and its effects on the wetting behaviors of respirable coal mine dust," *Powder Technology*, vol. 233, no. 2, pp. 137–145, 2013.
- [16] J. Wang, G. Zhou, X. Wei, and S. Wang, "Experimental characterization of multi-nozzle atomization interference for dust reduction between hydraulic supports at a fully mechanized coal mining face," *Environmental Science and Pollution Research*, vol. 26, no. 10, pp. 10023–10036, 2019.
- [17] D. L. Zhang, "The dynamic adsorption spreading of typical nonionic surfactants and wetting mechanism of coal dust," Doctoral Dissertation, Taiyuan University of Technology, Taiyuan, China, 2016.
- [18] Y. L. Ma and X. W. Zhu, "Mechanism of surfactant improve water wetting coal dust," *Coal Technology*, vol. 34, no. 5, pp. 195–198, 2015.
- [19] B. Qin, Q. Zhou, X. Li et al., "Synergistic technology between surfactant and magnetized water for efficient dust control in underground coal mines," *Journal of the China Coal Society*, vol. 42, no. 11, pp. 2900–2907, 2017.
- [20] G. X. Zhao, *Surfactant Physical Chemistry*, Peking University Press, Peking, China, 2nd edition, 1991.
- [21] X. Wang, S. Yuan, X. Li, and B. Jiang, "Synergistic effect of surfactant compounding on improving dust suppression in a coal mine in Erdos, China," *Powder Technology*, vol. 344, pp. 561–569, 2019.
- [22] H. G. Liu, D. J. Sun, and J. C. Hao, *Colloid and Interface Chemistry*, Chemical Industry Press, Peking, China, 2016.
- [23] P. Zhang, W. L. Wei, X. Li et al., "Effects of four kinds of anionic surfactants on wetting of coal tar pitch surfaces,"

- Journal of the China Coal Society*, vol. 39, no. 5, pp. 966–970, 2014.
- [24] W. G. Huang, F. Hu, and N. Q. Liu, “Study on surfactant wettability for coal dust,” *Mining Safety & Environmental Protection*, vol. 37, no. 3, pp. 4–6, 2010.
- [25] S. R. Wang, X. G. Li, and D. Z. Liu, *Surfactant Chemistry*, Chemical Industry Press, Beijing, China, 2010.
- [26] S. Chowdhury, A. Rakshit, A. Acharjee, and B. Saha, “Novel amphiphiles and their applications for different purposes with special emphasis on polymeric surfactants,” *Chemistry Select*, vol. 4, no. 23, pp. 6978–6995, 2019.
- [27] B. Y. Zhu and Z. G. Zhao, *Interfacial Chemistry Basis*, Chemical Industry Press, Peking, China, 1996.
- [28] M. H. Mondal, A. Roy, S. Malik, A. Ghosh, and B. Saha, “Review on chemically bonded geminis with cationic heads: second-generation interfactants,” *Research on Chemical Intermediates*, vol. 42, no. 3, pp. 1913–1928, 2016.
- [29] M. E. Ginn, *Cationic Surfactants*, Marcel Dekker, New York, NY, USA, 1970.



Hindawi

Submit your manuscripts at  
[www.hindawi.com](http://www.hindawi.com)

