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Research on Low Concentration Polymer Dust Removal Foam in Coal Mine Boring Face

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Abstract In order to solve the problems of high dust concentration, unsatisfactory dust removal efficiency and inefficient foam dust removal in underground coal mines, we have carried out experiments related to the preparation of excellent aqueous foam solution, and developed a kind of aqueous foam solution with a low concentration of polymers added, whose foaming performance is higher than that without polymers added and the stability is greatly improved. The foaming performance is higher than that of the foam solution without adding polymer and the stability is greatly improved. According to the dust removal mechanism of the foam, the foaming performance and wettability of the dust removal foam with the addition of a low concentration of polymers were investigated. Foaming experiments were carried out on four different foaming agents, which were then compounded two by two, and finally, different types of wetting agents, stabilizers, and polymers with different concentrations were added in order to carry out the preference experiments. The test results show that amphoteric ionic foaming performance is the worst, anionic foaming agent is the best, cationic, non-ionic type is the next best, adding polymer foam aqueous solution of foaming capacity increased by 30%, attenuation rate decreased by 10%. After experimental demonstration, it was determined that the formulation of dust removal foam was: 0.3% SDS + 0.3% AEC-9Na + 0.5% STPP + 0.3% OA-12 + 0.01% XG.

Keywords Low-concentration polymer; Foam dusting; Foaming agent; Foaming performance; Compounding

1. Introduction

China's energy data report shows that the total primary energy production of 4.33 billion tonnes of standard coal in 2021, a year-on-year increase of 6.2%, the annual raw coal production of 4.07 billion tonnes, an increase of 4.7% year-on-year growth, an increase of 5.6% over 2019, the import of 320 million tonnes of coal, year-on-year growth, the continued development of China's clean energy, but in the fairly long period of time, the status of the main source of energy for the short term will not be changed in the short term of the main source of energy of coal [1].

In the process of coal mining, mine dust is one of the mine disasters, with the improvement of the degree of underground mechanisation, the dust pollution problem of the excavation working face is also gradually serious, which not only worsens the underground working environment and affects the health of the workers, but also greatly reduces the safe production efficiency of the underground, and at the same time a large amount of explosive dust floating in the air in the underground also brings a potential threat to the excavation work [2], so it is necessary to do a good job of dust removal in the underground. Currently, the existing technical means for dust removal in coal mines include ventilation and dust removal, water curtain dust removal, and fan dust removal [3-5].

In 2019, Wang and Tang et al [6] proposed a method of exposing the foaming agent solution to a magnetic field of specific intensity before foaming, and the results showed that the foaming ability and foaming stability of the magnetised foaming agent solution were higher than that of the original solution. In 2017, Tianjin Xi et al [7] investigated the mechanism of coal dust inhibition of the solution of a mixture of poly(ethylene oxide) (g-PEO) and SDS, and the results showed that the solution containing g-PEO and SDS was more effective than the original solution. PEO and SDS had better wetting ability and adhesion. In 2017, Wang et al [8] from China University of Mining and Technology (CUMT) used the foamscan technique to explore the effects of xanthan gum (XG) and partially hydrolysed polyacrylamide (HPAM) on the performance of sodium dodecylbenzene sulfonate (SDBS)-related foams with respect to dust, and found that XG foams had a larger contact area with the dust and can better achieve the dust removal effect. In 2020, Wei et al [9], China University of Mining and Technology, China, in order to study the effect of carboxymethyl cellulose (CMC) on the morphological characteristics of foams, explored the effect on the size, distribution and uniformity of foams when CMC was added to different concentrations of AOS, and the results showed that, with the increasing concentration of AOS, the average bubble size decreased, and the uniformity of foams increased. In 2017, O. Arjmandi-Tash et al [10], UK, developed a mathematical model for the free drainage of foams accumulated by power-law non-Newtonian liquids, and the results of numerical simulation analyses showed that the height of the foam decreases faster in the phase when the foam first starts to drain, but it can reach a stable state in a longer period of time.

Foam dust removal technology is a new type of dust removal means, is the use of non-void foam body covered in the dust source, the dust will be adhered to the wetting, so that it loses the ability to fly, and then achieve the purpose of dust removal. Foam dust removal technology first appeared in the 1950s, the United Kingdom was the first to develop this technology, China's foam dust removal technology started late, the current domestic mine foam dust removal technology is still in the primary stage, the existing foam dust removal agent foaming rate is low, the dust reduction capacity is weak, the cost is high, and has not been widely used [11]. How to develop a low-cost, dust removal effect of high foaming rate of foam has become the focus of the current research of scholars, at present, for the addition of polymers in the foam aqueous solution, to improve the dust adhesion agglomeration of the research carried out less. Preparation of a foam aqueous solution can not only enhance the foaming ability of the foam, but also increase the stability of the foam, so that it can capture more dust, is the dust has a certain degree of adhesion, is not easy to secondary dust.

2. Foam Dust Removal Mechanism

Foam Generation Mechanism

Foam is a kind of dispersed-phase substance, the gas as the dispersed phase, the liquid as the dispersing medium, the foam can be generated by the method of inflation and stirring. The process of foam generation can be divided into two stages: (1) the gas is dispersed in the foaming liquid to form a large number of foam systems; (2) the aggregation of foam can make the surface free energy decrease, and the generated large number of foam systems reach a more stable equilibrium state through aggregation [12-14].

The surfactant in the foam has a hydrophilic group at one end and a hydrophobic group at the other end, and when the foaming agent is mixed with water, the hydrophilic group is oriented towards water and the hydrophobic group is oriented towards air [15]. With the increasing concentration of the foaming agent, the volume of the foaming agent molecules will automatically contract, and will eventually form a directional arrangement of the upright state, the density of the foam is less than the density of the water, the generated foam will continue to rise to the liquid surface, the foam will also generate a layer of molecular film in contact with the air, at this time, the foam is relatively stable, with the continuous accumulation of foam, it will form a foam cluster, the following figure shows the process of the formation of foam.

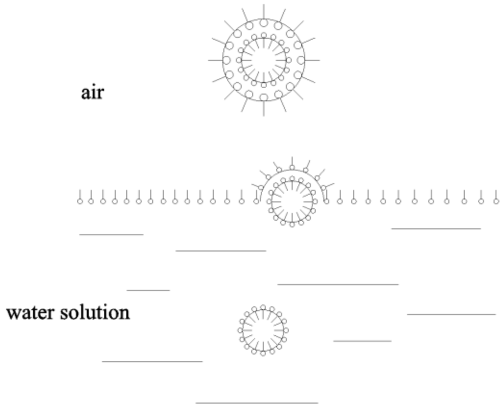

Figure 1: The process of foam formation

Foam-dust Interaction

The interaction process between foam and dust mainly includes interception, inertial collision, diffusion, adhesion and gravity settling [16]. Foam sprayed to the dust by the nozzle at a certain speed, a series of interactions will occur with the dust, through these actions will produce two results: one is gravity settlement, dust is adhered to the foam and wetted, under the action of gravity together with the landing; the second is the rupture of the settlement, the foam will be adhered to the dust after the dust is aggregated together, under the action of gravity settlement occurs, the dust that is not wetted to continue to interact with the foam, the following figure for the The following figure shows the dust trapping process of foam.

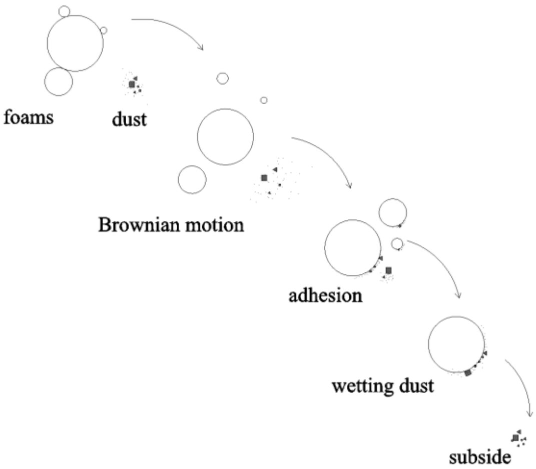

Figure 2: Foam dust capture process

Foam Solution Formulation Requirements

Foam for dusting is a mixture of multiple surfactants, generally containing a foaming agent, wetting agent, stabiliser and solubiliser. Experiments have proved that the performance of a single surfactant is not all-encompassing and has limitations. Therefore, a variety of surfactants need to be used synergistically, and the surface chemistry of the compounded system is obviously superior to that of a single system, and there is a synergistic synergistic effect of the compounded solution in lowering the surface tension of the solution and the ability to form micelles [16-19].

All surfactants are composed of polar hydrophilic and non-polar lipophilic groups, and surfactants can be classified into ionic and non-ionic according to the structure of hydrophilic groups, those that ionise in water to generate anionic lipophilic groups are known as anionic surfactants, those that ionise to generate cationic lipophilic groups are known as cationic surfactants, and those that don't ionise in water are known as non-ionic surfactants [20-22].

In the foam formulation, cationic and anionic surfactants cannot be mixed, the selection of surfactants, to follow the principle of wide source of raw materials, low price, etc., it is best to use anionic or non-ionic surfactants. When preparing dust removal foam, it is best to use a variety of surfactants mixed use, can be determined through the compounding experiment to determine the type of surfactant and its content.

3. Preferential Testing of Low Concentration Polymer Dusting Foams

Pilot Programme

Initial measurement of foaming rate, take a 50ml beaker, weigh a certain mass of foaming agent, add to the beaker and heat to dissolve, after dissolution, pour into a 500ml beaker, and add water to dilute to 100ml, and finally put into the magnet to stir for 10min and then turn off the power supply, after resting for 5min, use a syringe to extract and weigh 20ml of the foam mass, the foaming rate of the formula for the formula of R=V/M, where R is the foaming rate, ml/g; V is the volume of the foam, ml; M is the quality of the foam, g.

Model 2151 Roche Foam Meter includes jacketed graduated tube, 250ml dropper, constant temperature water bath, fixed bracket. During the test, the foaming agent is added into a 500ml beaker and placed in a constant temperature water bath at 40°C, stirred slowly with a stirrer until it is completely dissolved, so that the water at 40℃ passes through the casing in the jacketed graduated tube for the purpose of warming up, and then with a glass rod tightly pressed against the inner wall of the casing, the Foamer solution was slowly poured along the glass rod to the 50 ml mark of the cannula. Inject 200ml of the solution into the dropping tube, open the piston of the dropping tube, so that the solution flows down, all flow through and start timing, at this time read down the height of the foam solution, and then record the height of the foam surface after 5min. At the end of the test, open the piston of the casing, empty the solution and clean the experimental apparatus, repeat the test three times, if a large error needs to be repeated test, take the average of the three test results.

Reagent Selection

The foaming properties of the foams were determined using the Ross-Miles method [23], which evaluates the foaming properties of the reagents by the height of the foam produced and the foam decay rate.

The foaming properties of each surfactant were different and three foaming agents, two wetting and foam stabilising agents and two polymers were selected for the experiments. The three foaming agents were firstly used for the single foaming experiment, and then the three were compounded two by two to select the best combination of foaming agents, and the rest of the reagents were selected through the experiment, and the specific reagents selected are shown in Table 1.

Reagent Type	Reagent Name	Ion Type
Foaming Agent	SDS	Anionic
	AEC-9Na	Anionic
	APG0814	Nonionic
Wetting Agent	STPP	Anionic
	APG	Nonionic
Stabilising Agent	TEOA	Nonionic
	OA-12	Nonionic
Polymer	XG	Anionic
	HEC	Nonionic

Test results

Analysis of Foam Compounding Test Results

Adding surfactant to water can reduce the surface tension of water and make it easier to produce stable foam. The performance of the foaming agent will be different with different concentrations of surfactant, and each surfactant will have the optimal concentration, in which the foaming performance and stability of the surfactant are in a good state. The following figure shows the foaming effect of a single foaming agent and the foam decay within 5min.

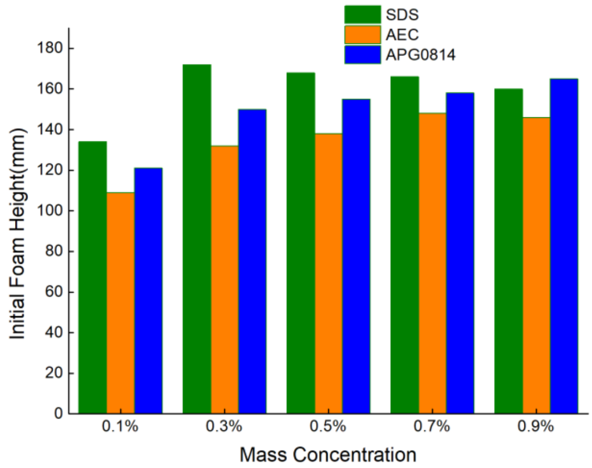

Figure 3: Foaming ability chart of foaming agent

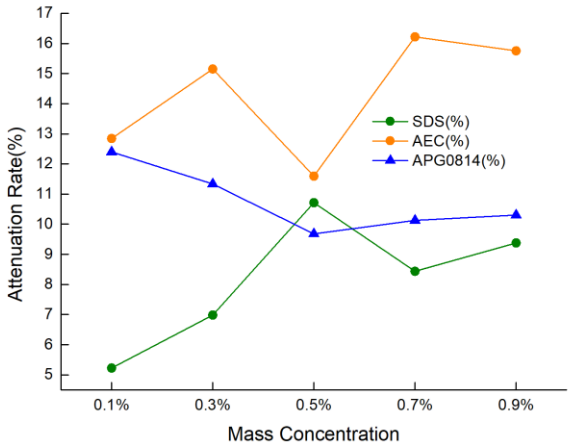

Figure 4: Foaming agent stability performance chart

Figure 3 shows that the foaming ability of the three foaming agents: SDS>APG0814>AEC-9Na, of which the ADS with a mass concentration of 0.3% has the best foaming ability, and with the increasing concentration of ADS, the foaming effect shows a trend of increasing and then decreasing. Combined with Figure 4, the stability of 0.3% ADS is better, so we chose 0.3% ADS and the other two foaming agents for two-two compounding, the following figure shows the effect of foaming agent compounding and foam attenuation diagram.

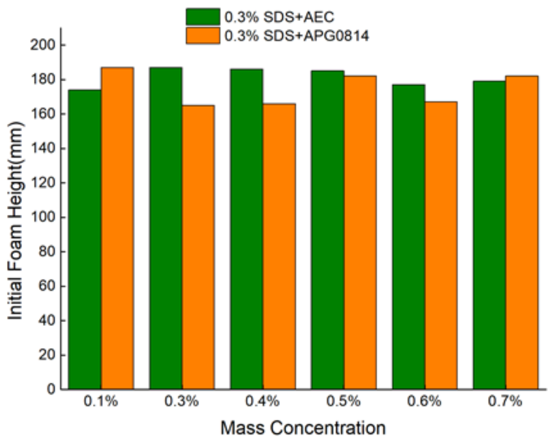

Figure 5: Foaming ability chart of foaming agent compounding test

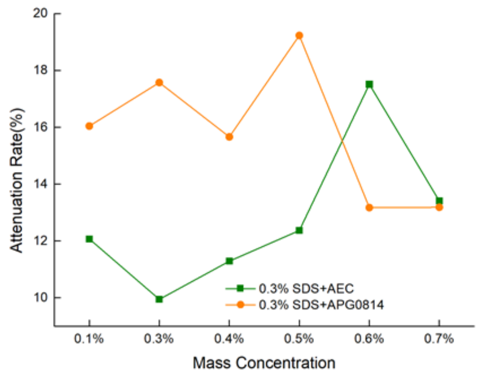

Figure 6: Stability chart of foaming agent compounding test

From Fig.5, when 0.3% SDS and AEC-9Na are compounded, the foaming effect is best when the concentration of AEC-9Na is 0.3%, and the foaming effect is best when 0.3% SDS and 0.1% APG0814 are compounded, and there is not much difference between these two cases when looking at the foaming effect alone. Combined with the stability performance graph in Figure 6, the stability of the foam solution is better when 0.3% SDS and 0.3% AEC-9Na are compounded than when 0.3% SDS and 0.1% APG0814 are compounded. Taken together, the combination of 0.3% SDS and 0.3% AEC-9Na was selected.

Preferred Wetting Agent Test

Dust removal foam for underground coal mine dust should not only have good foaming performance, but also have certain wettability. The wettability of foam is one of the criteria for evaluating the efficiency of foam dust removal, and on the other hand, the wettability of foam is also manifested as the adhesion, which is a key factor for capturing coal dust. After obtaining the optimal foam compounding combination, then add the wetting agent to explore the effect of wetting agent on the foam foaming performance, on the basis of the compounding solution, and then add different wetting agents to the compounding solution to explore the wetting time of the coal dust and then preferred to the optimal performance of the wetting agent。

During the test, a total volume of 200ml of solution was prepared in a 200ml beaker, keeping the addition concentration of foaming agent A and B both at 0.3%, and the addition concentration of wetting agent was taken as 0.1%, 0.3%, 0.5%, 0.7%, 0.9% in turn, and the test method selected in this paper was the aqueous film flotation method, and in order to reduce the test error, a group of tests was done four times, and the maximum value and the minimum value of the results of each test were removed. In order to reduce the test error, a group of tests are done four times, and the maximum and minimum values of each test result are removed, and the average value of the remaining two groups of test data is taken as the wetting time of coal dust completely immersed in the foam solution. The specific test results are shown in the table below:

Table 2: Wetting agent test results

Based on Formula	Wettability Type	Additive Concentration	Wetting Time/s		Average Value
			Numbers 1	Numbers 2	
Piped Water	None	0%	1030	1100	1065
0.3%SDS+0.3%AEC-9Na	None	0%	160	152	156
	STPP	0.1%	89	90	89.5
		0.3%	77	84	80.5
		0.5%	74	73	73.5
		0.7%	85	97	91
		0.9%	132	148	140
	APG	0.1%	138	151	144.5
		0.3%	72	74	73
		0.5%	85	79	82
		0.7%	85	100	92.5
		0.9%	151	99	125

From the test results, the addition of wetting agent will accelerate the dissolution of coal powder, in the addition of wetting agent STPP and APG test, the mass concentration of both in the range of 0.3% to 0.5% wetting time is the shortest, but the difference between the two is not obvious, taking into account that the addition of wetting agent also affects the foaming performance of foaming agent, so to further explore in the concentration of the addition of wetting agent on the foaming performance of the test, the test. The results are shown in the figure below:

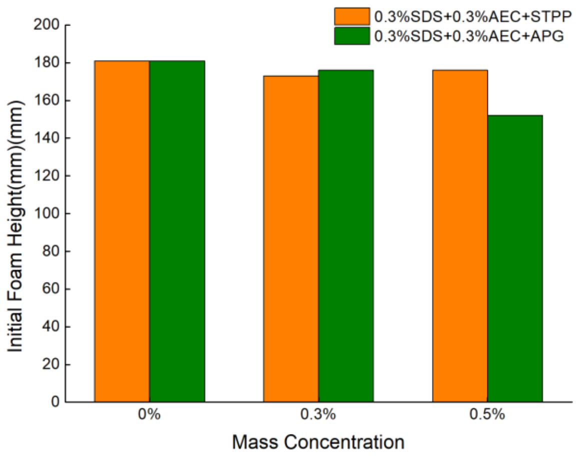

Figure 7: Wetting agent compounding test foaming ability diagram

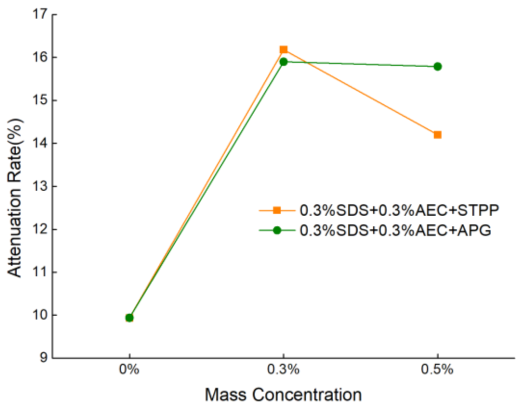

Figure 8: Stability chart of wetting agent compounding test

The test results show that after adding the wetting agent, the foaming ability of the compound solution is improved with the increase of STPP concentration, and reduced with the increase of APG concentration, and the foaming performance of the compound solution is the best when adding 0.5% of STPP, and the stability of the foam at this point in time is also optimal in combination with the view of Fig.8, therefore, we choose the quality concentration of 0.5% of STPP as the wetting agent. However, from Fig.7, it can also be found that the foaming performance of the original compound solution was also reduced after the addition of wetting agent.

Preferred Foam Stabiliser Test

In order to be more durable adhesion wetting coal dust, need to further improve the stability of the foam, this paper selects two stabilizers, in the above test on the basis of the preferred foam stabilizer. The concentration of the stabilizers was 0.1%, 0.2%, 0.3%, 0.5%, 0.7%, and the test results of foam foaming performance and foam decay rate after adding stabilizers are shown below.

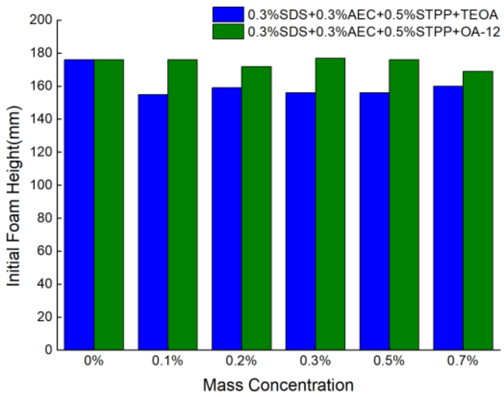

Figure 9: Stabiliser compounding test foaming capacity chart

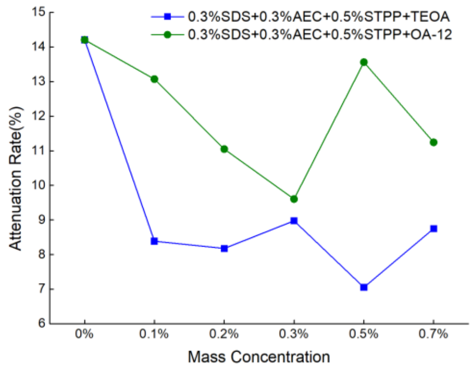

Figure 10: Stability performance diagram of stabiliser compounding test

Combined with the decay rate of the foam of the compound solution in Fig.10, the decay rate of the foam was reduced after the addition of the stabiliser TEOA and OA-12. From Fig. 9, it can be found that the foaming performance of the foam was significantly reduced after the addition of the additive TEOA, but after the addition of the stabiliser OA-12, the foaming performance of the foam was basically able to be maintained around the foaming capacity of the original compound solution, and the foam foaming capacity of the foam was reduced at the concentration of OA-12 of When the concentration of OA-12 was 0.3%, the foaming ability of the foam was the strongest and the stability was the best, so OA-12 with a mass concentration of 0.3% was chosen as the stabilizer.

Preferred Polymer Test

In 2019, Veljko Krstonošić et al [24], Serbia, explored whether there were interactions between xanthan gum and solutions formed with sodium dodecyl sulphate (SDS) and Tween80, respectively, as well as the mechanism of the interactions, through the use of a variety of techniques such as descriptive electron microscopy and Fourier transform infrared absorption spectroscopy. The experimental results showed that the addition of xanthan gum enhanced the adsorption capacity of SDS at the gas-liquid interface. Through reading the literature, it is understood that adding polymers to the foamer can improve the foaming efficiency of the foam, and it can also act as a foam-fixing agent, which will make the foam more stable and make the foam last longer, so that it can better wet the coal dust, which is more conducive to the removal of dust. The role of adding polymers and other foaming agents complement each other, it is necessary to consider what kind of polymer and the concentration of polymer, after reviewing the literature, the more common polymers, respectively, according to the mass concentration of 0.01%, 0.03%, 0.06% for the preparation and added to the preparation of the compound solution. The following figure shows the contact angle test of two different polymers with coal dust.

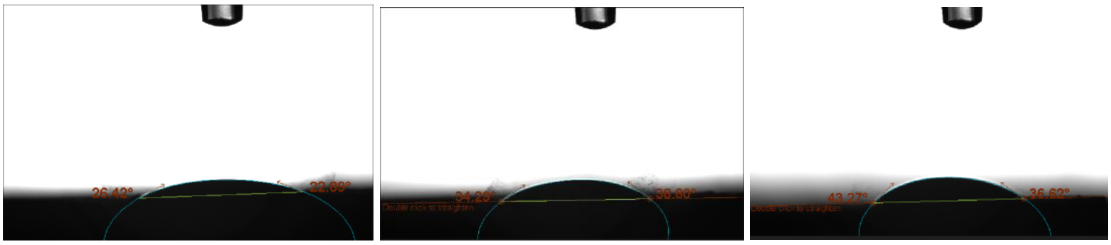

Figure 11: Contact angle of foam solution without polymer at different concentrations (0.01%, 0.03%, 0.06% by mass from left to right)

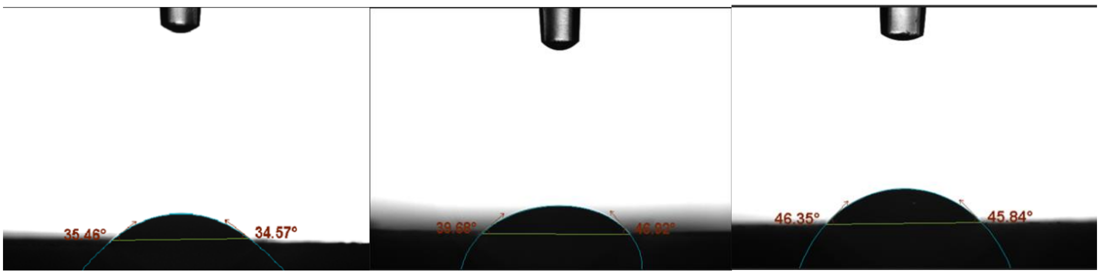

Figure 12: Contact angle at different concentrations after addition of xanthan gum (0.01%, 0.03%, 0.06% by mass from left to right)

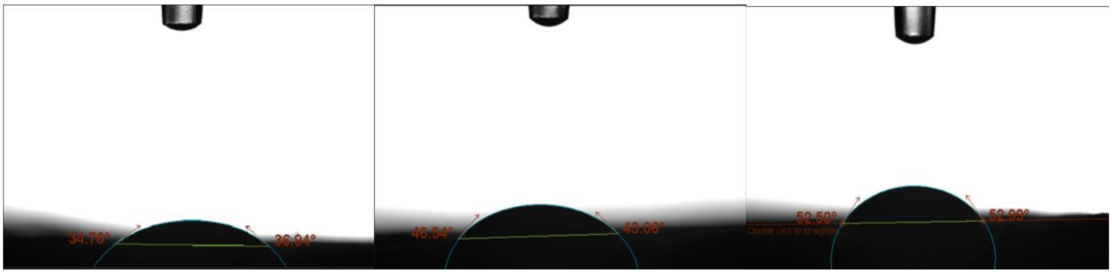

Figure 13: Contact angle at different concentrations after addition of hydroxyethyl cellulose (0.01%, 0.03%, 0.06% by mass from left to right)

From the contact angle test, it can be seen that the addition of polymer will increase the contact angle with coal dust, i.e. the wettability will be reduced, and compared with the contact angle test without adding polymer, the lower the mass concentration, the smaller the contact angle, and the better the wettability will be. From the test data, it is known that the contact angle sizes of foam solutions with different concentrations of polymer not added and coal chips are 24.66°, 36.55°, 39.95°, respectively, and the contact angle sizes of foam solutions with concentrations of 0.01%, 0.03%, and 0.06% of XG added respectively are 35.02°, 43.3°, and 46.10° in order, and the contact angle sizes of foam solutions with different concentrations of HEC added are 35.02°, 43.3°, and 46.10° in order. The contact angle size of the foam solution with different concentrations of HEC was 35.85°, 44.8°, 52.75° in that order. The contact angle of XG was smaller and the wetting effect was better when both XG and HEC were at a mass concentration of 0.01%, so XG at a mass concentration of 0.01% was chosen as the best polymer. The following figure shows the line graph of foam height and foam decay rate with concentration after adding XG.

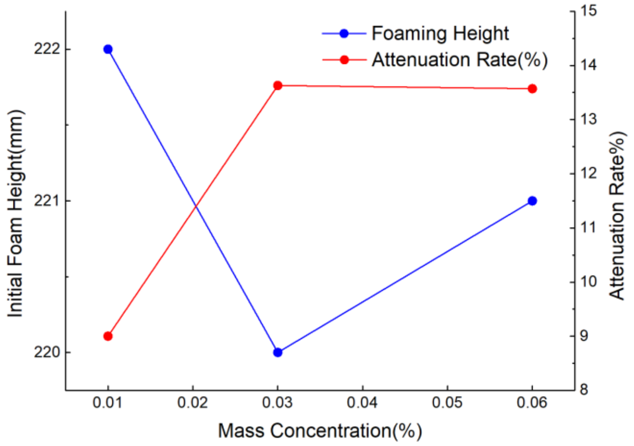

Figure 14: Foaming properties with different mass concentrations of xanthan gum addition

From the above graph and analysis of the data, the addition of XG at a mass concentration of 0.01% resulted in a 30% increase in the foaming height and a 10% decrease in the attenuation rate compared to the original compounded solution.

4. Conclusions

(1) Among the three surfactants selected in this paper, SDS as an anionic type has the best foaming performance, followed by non-ionic surfactants.

(2) Through the test to determine the dust removal foam formula: 0.3% SDS + 0.3% AEC-9Na + 0.5% STPP + 0.3% OA-12 + 0.01% XG.

(3) The test showed that after adding XG, the foaming performance of the compounded foam solution was improved, the stability of the foam was better, the existence time was longer, the foaming height was increased by 30% and the decay rate was reduced by 10% compared with the original compounded solution. In order to obtain a foam solution with higher dust removal efficiency, it is necessary to try more different formulations and conduct many tests with different ratios.

References

[1]. China's energy production, consumption, import and export in 2021 [J]. Coal chemical industry, 2022, 50(01):4.

[2]. LI Dewen, ZHAO Zheng, GUO Shengjun, et al. "The 13th Five-Year Plan "Coal Mine Dust Occupational Hazard Prevention Technology and Development Direction" [J]. Mining safety and environmental protection, 2022, 49(04): 51-58.

[3]. MA Youying. Research on mineral foam dust collectors [D]. Jinan: Shandong University of Science and Technology, 2018.

[4]. LI Jiang. Study on Dust Prevention Technology in Underground Working Face and the Application[J]. Energy Technology and Management, 2019, 44(01): 58-59+94.

[5]. GE Shaocheng, WANG Zhuoyan, CHEN Xi, et al. Research and prospect of dust removal technology in coal mine. China Energy and Environmental Protection [J]. Energy and environmental protection, 2021, 43(12):1-8.

[6]. Wang Hetang, Chen Xinyi, Xie Ying, et al. Experimental study on improving performance of dust-suppression foam by magnetization [J]. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2019, 577:370-377.

[7]. Xi Z L, Feng Z Y, Li A. Synergistic coal dust control using aqueous solutions of thermoplastic powder and anionic surfactant [J]. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2017, 520(9): 864-871.

[8]. Wang Q G, Wang D M, Shen Y D, et al. Influence of polymers on dust-related foam properties of sodium dodecyl benzene sulfonate with Foamscan [J]. Taylor & Francis, 2017, 38(12): 1726-1731.

[9]. Wei X B, Wang H T, Xie Y, et al. An experimental investigation on the effect of carboxymethyl cellulose on morphological characteristics of dust-suppression foam and its mechanism exploration [J]. Process Safety and Environmental Protection, 2020, 135(C): 126-134.

[10]. O. Arjmandi-Tash, Anna Trybata, Mahdi F M, et al. Foams built up by non-Newtonian polymeric solutions: Free drainage [J]. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2017, 521: 112-120.

[11]. JIANG Zhongan, LI Huaiyu. Study on Froth Dedusting Technology and Its Application [J]. China Safety Science Journal, 1997(03): 56-60.

[12]. WANG Deming. Mine ventilation and safety [M]. Xuzhou: China University of Mining and Technology Press, 2007.

[13]. XU Panpan. Study on Dust Control Foam Proportion and Experiment of Roadway Driving [D]. China University of Mining and Technology, 2021.

[14]. ZHOU Hui, DAI Zhangyin, FAN Ruiwen. On the Efficiency of Foam Dust Removal Based on Analytic Hierarchy [J]. Mining engineering research, 2022, 37(03): 51-55.

[15]. CHEN Tengfei, HE Qilin, et al. Experiment and Research on Foam Dust Control Technology in Mine Heading Roadway [J]. Coal science and technology, 2011, 39(09): 60-62.

[16]. XI Zhilin, WANG Deming, LU Wei, et al. Study of Mechanism Aspirating with Foam [J]. Safety in Coal Mines, 2006(03):1-4.

[17]. LIN Minglei, LIU Jianguo, JIN Longzhe, et al. Synergistic wetting effect of composite surfactant on hydrophobic coal [J]. Safety in Coal Mines, 2023, 54(04):1-10.

[18]. WANG Daohan, ZOU Jialin. Study on the Effect of Compound Surfactant on Coal Dust Wettability [J]. Mining safety and environmental protection, 2019, 46(02): 25-28+33.

[19]. LIU Qiuzu, HAN Zhennan, WANG Zhijian, et al. Wetting Mechanism of Respirable Dusts and Experimental Study on Mixture of Wetting Agents [J]. Chinese powder technology, 2014, 20(02):1-5.

[20]. WENG Anqi, YUAN Shujie, WANG Xiaonan, et al. Study on application of surfactant compound in coal seam water injection for dust reduction [J]. China Safety Science Journal, 2020, 30(10): 90-95.

[21]. WANG Tai-xu, LAN Shu-yuan, ZHANG Sai, et al. Mechanism and application of efficient foam dedusting in fully mechanized excavation face [J]. Coal Engineering, 2016, 48(01): 70-73.

[22]. LIAO Maolin, JIANG Bingyou, ZHANG Xiaoyi, et al. Study on effect of coal dust particle size on wettability of surfactant compounding solution [J]. China Safety Science Journal, 2023, 33(03): 96-102.

[23]. ZHANG Jianguo, LI Hongmei, LIU Yiting, et al. Micro-wetting characteristics of coal dust and preliminary study on the development of dust suppressant in Pingdingshan mining area [J]. Journal of China Coal Society, 2021, 46(03): 812-825.

[24]. WU Jing, MA Youying, XU Rongxiao, et al. Formulation of Foam Dust Remover Abstract [J]. Shandong Chemical Industry, 2019, 48(20): 38-40.