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Research Article

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Design and application of a foam system used for dust control on fully mechanized heading face

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ABSTRACT

A foam dust suppression system for fully mechanized heading face was designed, which mainly composed of foaming agent storage tank, pressured water pipe, compressed air pipe, water-air linkage valve, foaming agent adding device (jet proportional mixer), foam generator, foam dispenser and foam nozzles. In this system, pressured water and compressed air was taken as the driving force without any electric device, and the water-air linkage valve was used to simultaneously control the pressure-water pipe and compressed-air pipe. This new foam system integrates water-air linkage control, foaming agent automatically adding, foam generation and foam injection parts, with the characteristics of inherent safety and convenient operation, which makes it suitable for controlling cutting dust at heading face of underground coal mines.

Key words: foam system; dust suppression; heading face; underground coal mines

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INTRODUCTION

Overexposure to respirable mine dust can lead to coal workers' pneumoconiosis (CWP), a disabling and fatal lung disease [1,2,3]. Dust, produced in the cutting process of roadheader on fully mechanized heading face, has long been known to be a serious health threat to miners. For example of China, More than 85% of CWP's working place is on excavation working face [4]. Therefore, taking effective measures to reduce dust concentration of heading face and limit worker exposure to respirable dust to prevent development of these diseases is of great importance.

Aiming to control dust on excavation working face, water spray system mounted on roadheader are widely used, which have played an important role in reducing the dust exposure of coal miners. However, mine dust has certain hydrophobicity and the surface tension of water is high, which causing water sprays have much low capture efficiency on respirable dust and large water consumption [4,5]. With the increase of mechanized driving intensity, the amount of respirable dust generation rises rapidly. So it is necessary to develop efficient dust control equipments. Compared to water sprays, suppressing mine dust with foam has obvious advantages. Due to the larger contact area, higher wet speed and better adhesion properties, foam have stronger ability to capture respirable mine dust, and its water consumption is much less [6]. When compared to water sprays at a belt transfer point, the foam showed a 30% increase in dust reduction [7]. It was found that the foam released from a longwall shearer drum cut the dust by 50% when compared to conventional sprays on the drum, and the amount of water used was one-half that of the conventional sprays [8,9,10]. Thus, to control respirable mine dust with foam is a promising method. However, up to date, efficient foam systems for fully mechanized heading face are still lacking, which mainly face the following problems [4,11].
1) Using extra electric pump to add foaming agent, there is a hidden danger of electric spark which usually lead to coal dust and methane explosion accidents, and also lead to the large amount of foaming agent used.

2) Using net-type foam generator to form foam, the net is easily to be clogged that makes the reliability of foam system poor.
3) Conventional water spraying nozzles are used to spray foam, which leads to foam atomization and rupture, reducing the dust capture efficiency.
4) The components are scattered layout and controlled respectively, making the system complex and unsafe.
So there is an urgent need to enhance the performance of foam dust suppression system. In this paper, a new foam system was designed based on the idea of safety, reliability and efficiency. First, the composition and working principle of the foam system were proposed. Then, the main components were respectively designed. At last, the system's dust suppression effect was tested through actual application on a fully mechanized heading face in Zhuxianzhuang Coal Mine.

2. Composition and working principle

As shown in Fig. 1, the new foam dust suppression system consists of a foaming agent storage tank, a water-air linkage valve (combined control switch), a foaming agent automatic adding device (jet type proportional mixer), a foam generator, a foam dispenser, several foam nozzles and connecting pipes. In which, the water-air linkage valve, foaming agent tank, proportional mixer and foam generator are combined into the integrated foam generating device, as illustrated in Fig. 2.

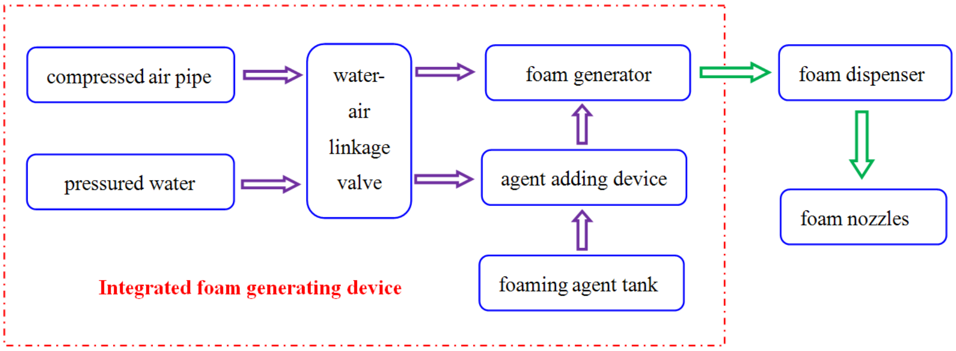


Fig. 1. Overall composition diagram of the foam dust suppression system

Fig. 2. Integrated foam generating device

The storage tank is fabricated by stainless steel plate of 5mm thickness, and the liquid filling opening is arranged on its above surface. The water-air linkage valve, foaming agent automatic adding device and foam generator are arranged on the three sides of the storage tank, which minimizes the device's occupied space, making it very suitable for the narrow work places on fully mechanized heading face. The output pipe of the integrated foam generating device is connected to the foam dispenser (Fig. 3), which linked with foam nozzles and their bracket, as shown in Fig. 4.

Fig. 3. A kind of foam dispenser

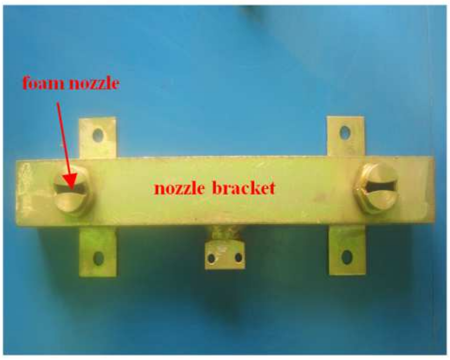


Fig. 4. The foam nozzles and bracket

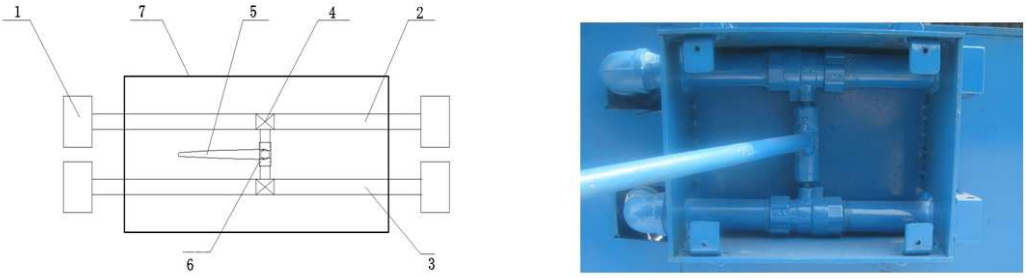
The working principle of the foam system can be briefed as follows. It is powered by pressured water and compressed air, and controlled by water-air linkage switch. When open the linkage control switch, the piped pressured water and compressed air run into the system. With the power of pressured water, the jet type proportional mixer generates a stable negative pressure to automatically add foaming agent into water pipe to form well mixed foaming liquid. Then, foaming liquid comes into foam generator and meets compressed air, forming a strong gas-liquid turbulence, thereby generating two-phase foam. Next, the two-phase foam flow into the foam dispenser by foam conveying pipe, in which foam can be distributed evenly. Afterwards, the foam arrives at foam nozzles fixed on their bracket, and inject to dust sourc to efficiently reduce the dust concentration.

3. The design of the main components

As mentioned above, the foam dust suppression system is mainly composed of four parts, namely the water-air control part, foaming agent automatic adding part, foam generation part and foam injection part.

3.1. Water-air linkage valve

In order to make the system's operation convenient, the authors presented a linkage valve which can simultaneously control the switch of the water inlet pipe and air inlet pipe. As shown in Fig. 5(a), the linkage valve includes quick fittings, pressured water inlet pipe, compressed air inlet pipe, ball valve, valve handle, quadrilateral bite as well as the valve shell. In which, two ball valves with diameter 25mm are respectively arranged on the air inlet pipe and the water inlet pipe, whose import and export both extend to the outside of the valve shell, welded with quick fittings. The upper surface of the valve shell has a groove for valve handle moving, and quadrilateral bite extends into shell, whose two ends respectively stuck with the two valve core of ball valve. When the valve handle moves in the groove, the two valve core of ball valve are driven to rotation, realizing the function of open or close the two valves at the same time. In this way, the pressured water and compressed air are controlled simultaneously, which is very convenient for miners to operate the system. Fig. 5 (b) is the real object photo of the fabricated linkage valve.



(a) structure design diagram

(b) real photo

Fig. 5. The water-air linkage control switch. 1. quick fittings;2. air inlet pipe;3. water inlet pipe; 4. ball valve;5. valve handle;6. quadrilateral bite;7. valve shell

3.2. Foaming agent adding device

In view of the shortage of existing adding device, a small quantity foaming agent automatic adding device was designed based on jet theory. The new adding device mainly comprises an ejector, a main pipe, a branch pipe, a suction tube and several valves. Fig. 6 is the real object photo of the new adding device.

Fig. 6. Real object photo of foaming agent adding device

The adding principle of the new adding device can be briefed as follows. It takes the pressured water as the power without any extra electric power. When the high speed jet ejecting from the nozzle, a strong negative pressure is formed in the conical cavity with the effect of turbulent diffusion and jet entrainment. Then the foaming agent is imported under the action of atmospheric pressure, and the foaming agent confluence with water in the throat of mix chamber, forming the foaming liquid. Afterwards, the static pressure of foaming liquid recovers quickly with the velocity decreases in diffusion tube. By using the parallel structure, the cavity vacuum degree of ejector as well as its outlet pressure can be changed through adjusting the stop valve. And the foaming agent adding content can also be adjusted through the needle valve. This finally have foaming agent be added at a low ratio (e.g. 0.5-1.0%) stably.

3.3. Foam generation part

In view of the poor reliability of the net-type foam generator, the authors proposed to use the foaming method of negative pressure suction with jet pump according to physical foaming process of foam. As shown in Fig. 7, the new foam generator mainly comprises compressed air inlet, jet pump (including air nozzle, liquid inlet, hollow throat, mixing chamber and diffusion chamber), cylinder, spoiler and foam outlet, in which the spoiler is obliquely arranged on the fixed axis in the cylinder. Compressed air/foaming liquid flow into foam generator through main/branch pipe respectively.

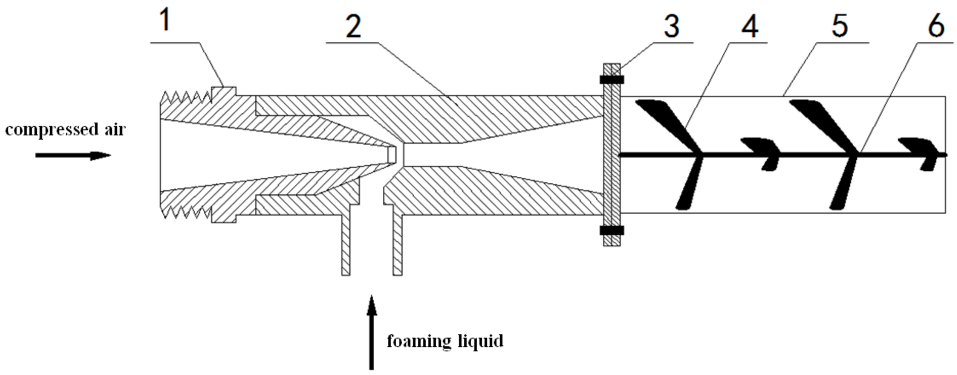


Fig. 7. Structure of the foam generator. 1. air nozzle; 2. jet pump; 3. fixed plate; 4. spoiler; 5. cylinder; 6. fixed axis

Fig. 8 is the installation diagram of the new foam generator. Its foaming principle can be briefed as follows. When compressed air flowing flow through the nozzle of the jet pump, its static pressure decrease while velocity pressure increase, and respectively arrives at the minimum and the maximum value at the throat. The foaming liquid with certain pressure flow into the jet pump though the branch pipe under the double action of jet negative pressure of high speed air and its self pressure, forming a gas-liquid mixed flow. Foaming liquid and compressed air are contacted and mixed in the jet pump, generating foam partially. Afterwards, the remaining foaming liquid moves forward into the cylinder, where the gas-liquid mixed adequately and foam generated eventually under the effect of spoiler's turbulence.

Fig. 8. Installation diagram of foam generator

3.4. Foam injection part

In order to use foam to cover dust source at a wide range and far distance, special foam nozzle with inner convex arc bevel and "V" type groove structure was designed, based on the compression and expansion properties of foam. As Fig. 9 shows, the foam nozzle includes shell body, end cover, nozzle groove, tooth plate and screw. The foam entrance is arranged at one end of the nozzle body, and the other end sealed with end cover which connected with shell body into a whole. The nozzle groove, narrow in the middle and wide in two sides, was opened along the center of end cover, which looks like "V" font. By the inner convex arc incline, the outlet velocity of foam is increased and the phenomenon of foam doesn't inject evenly avoided. And the diffusion angle of foam injection can be increased with the "V" type groove.

The nozzle's working principle can be briefed as follows. When foam flow into the shell body, its velocity pressure increase for the block action of the pipe wall and the end cove. While flowing through the nozzle groove, the pressure gets release. As the groove is narrow in the middle, wide at two ends, and the depth greater than the of the end cover's thickness, it can be injected like fan-shape with large diffusion angle.

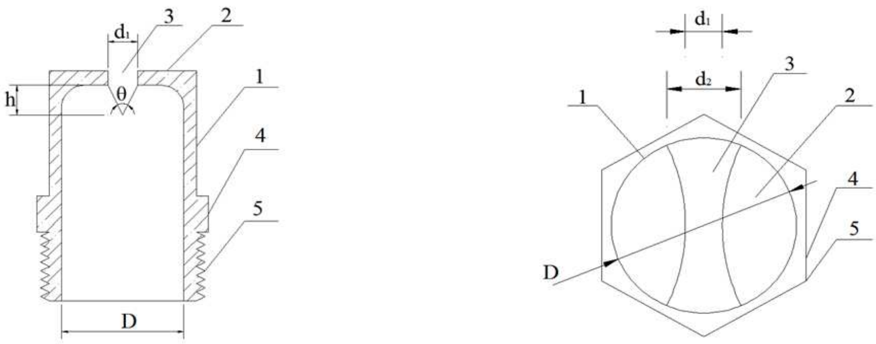


Fig. 9. Structure of the special foam nozzle. 1. shell body; 2. end cover; 3. nozzle groove; 4. tooth plate; 5. Screw

Seen from Fig. 9, the nozzle's structure can be determined by the five parameters, which are the entrance diameter (*D*), the intermediate width of "V" type groove (d_1), the two ends width of "V" type groove (d_2), the cutting depth of "V" type groove (*h*) and the injection angle (α). In this paper, the diameter of nozzle entrance was selected as 25mm according to the actual situation in underground coal mines.

As shown in Table 1 and Table 2, this paper used the orthogonal trial method, taking α as the target function. After preliminary determining the range of foam nozzles, experiments of nozzle flow quantity and pressure were made in this range to obtain the reasonable size parameters of the foam nozzle.

Table 1 Levels and factors of orthogonal table

Level / Factor	1	2	3
A (d_1)	2mm	5mm	8mm
B (d_2)	10mm	10mm	10mm
C (h)	6mm	10mm	10mm

Table 2 Results of orthogonal experiments

Column No. / Experiment No.	1 (A)	2 (B)	3 (C)	Experimental group	α (°)
1	1	1	1	$A_1B_1C_1$	55-70
2	1	2	2	$A_1B_2C_2$	95-118
3	2	2	1	$A_2B_2C_1$	60-75
4	2	3	3	$A_2B_3C_3$	100-120
5	3	1	1	$A_3B_1C_1$	70-85
6	3	3	2	$A_3B_3C_2$	90-110

According to the actual need of suppressing dust with foam, the injection angle (α) should be much large. It can be inferred from Table 2 that both $A_1B_2C_2$ and $A_2B_3C_3$ can reach the larger injection angle of 120°. Thus, a further flow and pressure experiments were conducted for the two group data, and results was shown in Fig. 10.

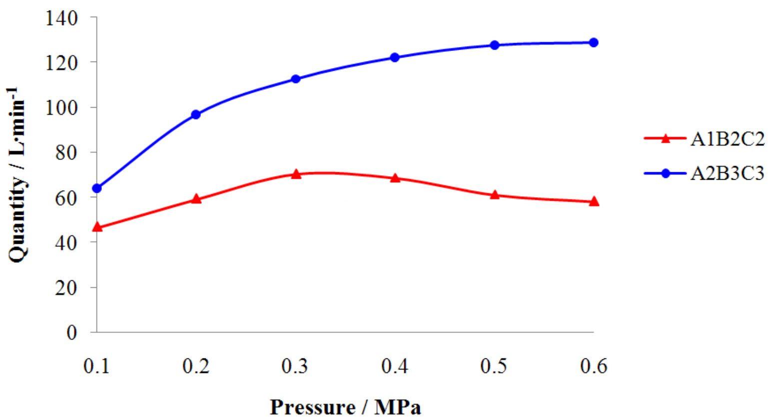


Fig. 10. The relationship curves between quantity and pressure of four group experiments

See from Fig. 10, the flow quantity of $A_1B_2C_2$ increases first and then decrease with the increase of pressure. While the $A_2B_3C_3$ fulfills the requirements well, whose quantity rises up along with the pressure's raising. So, $A_2B_3C_3$ is the reasonable parameters for the foam nozzle. When D=25 mm, d_1=5 mm, d_2=10 mm and h=10mm, the nozzle not only has large nozzle injection angle (120°), but also the foam particles can be dispersed evenly, without clogging, atomization and rupture. Fig. 11 shows the real object photo of the fabricated foam nozzle and its injection effect.

Fig. 11. Special foam nozzle and its injection effect

4. Application case

Zhuxianzhuang coal mine is one of the largest mines of Huaibei mining area, whose designed output is 2.45 million t/a. The 810 main return airway is under excavation from April 2012. It is a typical large section rock tunnel with sectional area of 15.84m^2. And high concentration dust was produced in the cutting process of a high-power roadheader (Fig. 12). The initial concentration of total dust can reach 1300mg/m^3, and the dispersion degree is high (most dust are smaller than 5μm). When the external/internal water spray is employed, the dust suppression efficiency is as low as 25%. A lot of respirable rock dust diffused in the working surface, which causes serious harm to the health of workers. In order to control the dust of the tunneling face efficiently, Zhuxianzhuang coal mine employed foam dust suppression technology. The foam system mentioned above was installed on the roadheader. Seen from Fig. 13, when producing and spraying foam through several foam nozzles around the cutting head of roadheader, dust was suppressed effectively.

Fig. 12 High concentration cutting dust

Fig. 13 Suppressing dust by injecting foam

The test results from the driver point show that the dust suppression efficiency of foam on the total dust and respirable dust reached more than 80%, approximately 3~4 times of external/internal water spray. Seen from Fig. 14, as dust concentration greatly reduced by foam, the visibility and operation environment of the heading face was significantly improved. In addition, the water flow of the foam system was about 40% of the water spray consumption, which saved precious water resources and guaranteed the quick tunneling of 810 main return airway.

Fig. 14 The heading face after suppressing dust by foam

CONCLUSION

A foam dust suppression system for fully mechanized heading face was designed, which integrates air-water linkage control, foaming agent automatic adding, foam preparation and foam injection. The conclusions could be summarized as follows.

1) A foaming agent adding device of small flow quantity was fabricated based on the jet theory, which powered by the existing pressured water, dramatically improving the system's safety. It generates a negative pressure to suck foaming agent automatically and mixes into foaming liquid evenly. This new device can add foaming agent as low ratio as 0.5%-1.0%, which reduce the running cost of foam system.

2) A foam generator used for dust control on fully mechanized heading face was invented, which can ensure the efficient mixing of gas-liquid. Its interior has no moving parts and foaming-net which easily to be clogged, making it more reliable compared to the conventional net-type foam generators.

3) A special foam nozzle was developed, whose outlet has the structure of convex arc bevel and "V" font groove. It can inject foam fluently with wide cover range and far injection distance and avoid the atomization and rupture of foam, providing the guarantee for foam to cover the dust sources effectively.

4) The application practice on a fully mechanized heading face in Zhuxianzhuang mine indicates that this foam system can overcome the defects of the roadheader spray system and have realized the goal of reducing total dust and respirable dust effectively. Hence, the visibility of workplace was significantly enhanced by injecting foam, which provides a new key technology for the effective prevention of dust explosion and coal miners' pneumoconiosis disease.

Acknowledgments

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