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Controlling the coal dust at transshipment point: A study of the foam-sol foaming device

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ABSTRACT

In order to effectively control the dust at the transshipment point with foam-sol, this paper attempted to study the characteristics of dust diffusion at transshipment point and the foam-sol foaming device with diffusion outlet was also designed in this paper. To study the diffusion rules of coal dust, fluent discrete phase model was utilized in the numerical simulation, as the coal dust was thrown down at a horizontal velocity of 2.5 m/s. A foam-sol foaming device was designed, through which foaming agent could be automatically sucked into the Venturi by the negative pressure. The automatic controller was also equipped, which could transform the energy of the compressed air into the constant pressure difference so that the gelling agent could be qualitatively added into the gel container. The diffusion outlet that could spray out foam-sol in a continuous, conical and 3D manner was also designed. Moreover, this paper also carried out the contrast experiments on dust removal efficiency among water, aqueous foam and foam-sol. The results clearly show that the symmetrical whirlpools appeared below the inlet where the largest whirlpool diameter was 0.52 m, and the horizontal distance from swirl range to the inlet was approximately 0.69 m. By using the self-designed foaming device, the foaming was multiplied by 30 times and the volume ratio with water and foaming agent reached 95%:5%. In this context, the gas pressure was controlled at 0.3 MPa, with gas flow at 15 m^3/h and water flow at 0.5 m^3/h, with water pressure controlled between 0.34 and 0.36 MPa. The foam-sol has the highest dust removal efficiency than other agents.

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1. Introduction

Dust has become one of the major issues that are produced in the course of coal production, transportation and storage and so on, seriously affecting production safety and causing occupational hazards, environmental pollution and economic losses [1–4]. Statistical data have shown that 106 coal dust explosions have occurred since 1949, resulting in 4613 casualties [5]. Globally speaking, unwanted events with coals and coal dust were respectively 171 and 39 fatalities from the beginning of the new century to 2011 [6]. At present, the pneumoconiosis cases caused by coal dust in China have reached more than 50 million, accounting for more than 50% of the total pneumoconiosis patients in China [7,8]. Each year, more than 10000 pneumoconiosis patients who worked in key state-owned coal mines are registered. On average, 2500 Chinese miners die from pneumoconiosis every year in *Eleventh Five-Year Plan of Coal Mine Safety*. The direct economic losses caused by pneumoconiosis in China are more than 1 billion Yuan per year. Coal dust is one of the main factors that can cause foggy and hazy weather and its impacts on environmental pollution cannot be ignored.

In order to control the dust concentration at the transshipment point, methods such as water spraying and chemical dust suppression agent have been used [9–12]. The conventional methods have played an important role in reducing dust concentration, but they still have obvious drawbacks. Water spraying is not only low-efficient on respirable dust, but also consumes large amounts of water, considering the water has a larger surface tension [13,14]. Despite its effectiveness, chemical agent spraying for dust suppression is at a high cost and tends to cause soil acidification or calcification.

Currently, aqueous foam-based dust removal is an effective and low-cost method; however, it is incapable to suppress the moving dust, mainly because aqueous foam liquid film is low cohesiveness and elasticity, causing that liquid film touching the moving dust may be easily pierced [15–19]. For the purpose of addressing the deficiency of aqueous foam-based dust removal, the paper presents a foam-sol-based dust removal method. The method utilizes

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aqueous foam as the carrier, and makes aqueous foam liquid film gel to reinforce the cohesiveness and elasticity of foam film. The purpose is to absorb dust settlement at the transshipment point.

Applying the foam method to dust control at the actual production, mechanical method has been widely used for generating foam. However, it is mature to generate aqueous foam, mostly depending on three power sources [5,17,19,20]. The foaming system with such three power sources is easy to implement quantitative control and has higher reliability, but a number of power sources and potential safety hazards are also seen in mine application.

In order to control dust in a more effective manner, an applicable foam-sol generating system is proposed in this paper based on the aqueous foam foaming device.

2. Coal dust diffusion at transshipment point

Due to air turbulence, drops, and the fine dust Brownian motion, coal transported at the transshipment point can result in dust diffuseness [21]. At the transshipment point, dust will be thrown down from the belt at a uniform velocity, which is equivalent to the speed of belt movement no matter whether the dust has been thrown down from the belt. In order to study the diffusion movement of coal dust in the coupling process with air, a numerical simulation of the coal dust trajectory was conducted by utilizing the fluent discrete phase model (DPM) [22–24].

2.1. Motion equation of coal dust

The force balance equation of DPM in the Cartesian coordinates can be expressed as follows [25,26]:

$$du_p/dt = F_D(u - u_p) + g_x(\rho_p - \rho)\Big/\rho_p + F_x \tag{1}$$

$$F_D = 18\mu/\rho_p d_p^2 \cdot C_D R_e\Big/24 \tag{2}$$

$$R_e = \rho d_p|u_p - u|\Big/\mu \tag{3}$$

$$C_D = a_1 + a_2/R_e + a_3\Big/R_e^2 \tag{4}$$

$$F_x = F_a + F_t + F_b + F_s \tag{5}$$

where u is the fluid velocity, m/s; u_p the dust velocity, m/s; μ the fluid dynamic viscosity, $Pa{\cdot}s$; ρ the fluid density, kg/m^3; ρ_p the dust density, kg/m^3; d_p the dust diameter, m; R_e the relative Reynolds number; C_D the drag coefficient; g_x the X direction acceleration of gravity, m/s^2; F_X the X direction other force, N; F_a the apparent mass force, N; F_t the thermophoresis force, N; F_b the Brownian force, N; and F_s the Saffman force, N.

The density (ρ_p) of coal dust is greater than that of air (ρ), so the apparent mass force (F_a) can be negligible. Considering the transshipment point is an open space, the temperature is assumed as a constant average value, so the thermophoresis force (F_t) can be ignored. The application range of Brownian force is submicroscopic dust, and the particle diameter of selected dust is low 0.0001 m, so Brownian force (F_b) and Saffman force (F_s) can be ignored.

2.2. Diffusion model of coal dust

Figs. 1 and 2 show the model drawing and the grid drawing which were drawn by the Gambit software. Model geometry ($a \times b \times c$) is 2.5 m × 2.5 m × 1.5 m. The inlet is set on the right-side surface, of which the vertical height from the bottom surface is 0.5 m. The Model attribute is set as follows: outlet for the top surface; wall for the bottom surface; escape for each other surface. Table 1 shows the other parameters of DPM.

2.3. Result analysis

Fig. 2 shows the dust trajectory diagrams of Face 1, Face 2, and Face 3 through 400 iterations (four seconds), where Face 1 is taken as the inlet corresponding side, Face 2 is taken as the inlet left side, and Face 3 is taken as the outlet side.

As the coal dust is thrown down at a horizontal velocity of 2.5 m/s and due to the coupling effect of coal dust and the air, the analysis and measured dust trajectory diagrams conclude that symmetrical whirlpools will appear below the inlet, where the largest whirlpool diameter is 0.52 m, and the horizontal distance from swirl range to the inlet is approximately 0.69 m, as shown in Fig. 2.

3. Foam-sol foaming device

On the basis of the diffusion characteristics of the coal dust at the transshipment point, this paper has designed a foam-sol foaming device. Fig. 3 shows the structure.

As shown in Fig. 3, the device uses the compressed air and a suction pump as its minor and major power source. First, the compressed air is divided into two air flows, one of which passes through the automatic controller to form the stable pressure difference for quantitatively adding the gelling agent into the gel container, and the other goes directly into the venturi diffuser. Second, water is injected into the Venturi with the help of the pump, forming the stable negative pressure at the throat of the Venturi to automatically and quantitatively suck the foaming agent into the Venturi. Third, water–gas–foaming agent is mixed evenly through the mixer, which swiftly turns them into the high-performance aqueous foam. Fourth, the gelling reaction occurring between aqueous foam and gelling agent in the gel container can generate the foam sol. Fifth, foam can be sprayed directly through the outlet in the form of straight line, or through the outlet of conical diffuser in the form of conical shape. The outlet of conical diffuser is shown in Fig. 7.

Comparing with the previous aqueous foam foaming device, this foam-sol foaming device designed in this paper has three advantages: first, energy of the compressed air is transformed into the constant pressure difference via the automatic controller, so that the gelling agent can be automatically and quantitatively added into the gel container; second, the negative pressure at the throat of the Venturi that will be formed as the high-pressure water flows via the Venturi tube will automatically add the foaming agent into the Venturi, and this method can add the foaming agent into the foaming device without using pumps; third, foam-sol may be sprayed in a continuous, conical and 3D manner by using the foaming device with a conical diffuser outlet, so that the regional dust will be enclosed and the area exposed to dust may be increased.

3.1. Parameters of foam-sol foaming device

Table 2 shows the relation between the Venturi inlet pressure and the flow-sucked foaming agent. In order to multiply the foaming by 30 times, the gas pressure should be controlled at 0.3 MPa, with gas flow at 15 m^3/h and water flow at 0.5 m^3/h, and different water pressure should be adjusted via shunt tube, so that the foaming agent flow can be obtained, which will be automatically sucked by the negative pressure produced at the throat of the Venturi.

When the water flow maintains at 0.5 m^3/h, the foaming agent flow should be controlled at 0.0263 m^3/h in order to get the volume ratio (95%:5%) between water and foaming agent. Thus, the water pressure should be controlled between 0.34 and 0.36 MPa,

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