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Design and application of device to add powdered gelling agent to pipeline system for fire prevention in coal mines

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ABSTRACT

In China, 47.3% of state-owned coal mines are endangered by coal seam spontaneous combustion that threat to the safety of mining. A new technique using foam-gel was developed to control coal spontaneous combustion. In this study, an adding device was designed to facilitate the addition of a powdered gelling agent to pipeline system to form foam-gel. The experimental system was constructed and experiments were carried out to test the performance of the adding device in laboratory. The experimental results showed that the optimum parameters of the inlet pressure and air flow were in the range of 1.6−1.8 MPa and 40−44 m^3/h respectively, and the negative pressure ranged from −0.16 MPa to −0.22 MPa accordingly. The average adding rate of powdered gelling agent was 2.06 kg/min and 2.31 kg/min, respectively in lab scale experiment and field application. The adding device was tested at a coal working area and successfully controlled the coal spontaneous combustion occurred in the process of equipment removing. The results of the application promised that the adding device is structurally simple, compact, and easy to operate, and also the foam-gel has a remarkable effect for fire prevention.

1. Introduction

Coal spontaneous combustion is one of the major hazards at coal mines in China (Qin et al., 2009; Zhou and Wang, 2009). It is not only widely distributed but also very serious. Many accidents caused by coal spontaneous combustion had resulted in enormous casualty and property loss (Qin et al., 2014; Zhou et al., 2007). To prevent and overcome this hazard, various traditional techniques have been developed, including the injection of nitrogen, grouting, the infusion of gel and three-phase foam, etc(Michalski, 2004; Liang, 2009). However, these techniques have many disadvantages, and they cannot prevent the spontaneous combustion of coal during mining production effectively (Qin, 2008; Wang, 2009). In order to overcome these disadvantages of existing technologies, a new technology named foam-gel was developed by authors, and its high efficiency in controlling and extinguishing even severe cases of fire has been demonstrated(Ren et al., 2015). The key technique for foam-gel production lies in the adding process of the powdered gelling agent to the pipeline system.

The gelling agent is a kind of powdered solid which can absorb water significantly and easily forms gel once it mixed with water. By contrast and analysis, adding the powdered gelling agent by pneumatic conveying is the best choice.

In the context of adding the powdered gelling agent by pneumatic conveying, horizontal spiral feeders, rotating blade feeders, and venturi feeders are most widely used to transport and add powders in the powder industry(Lian, 2009; Lou and Lin, 2008; Gao, 2009; Xie and Wu, 2007); however, these feeders still suffer from a few drawbacks. The horizontal spiral feeder transports powders along a transmission pipeline depending on the weight of the powders and the thrust of the helical blade. It is sensitive to overloading, which can easily lead to blockage of the pipeline. The rotating blade feeder suffers from poor air-tightness, which leads to fluctuations in the quantity of the powder being transported, thereby eventually leading to the stoppage of material transportation. The venturi tube is limited by the outlet resistance, and therefore, it is difficult to generate stable negative pressure in most cases. However, the venturi tube is easy to construct, and it is adaptable to the complex environment of underground coal mines. In this study, we propose a new powder adding device based on the venturi tube aiming to solve the problem of adding powdered gelling agent. A modified venturi feeder is used to generate the

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stable negative pressure needed for different working range conditions in mines. The authors analyzed the design and optimization of the powder adding device, and determined its optimum working range conditions in this paper.

2. Working principle and structural parameters of the powder adding device

2.1. Basic principle

When the venture-tube-based device (Fig. 1) is used in underground coal mines, the high-speed pressurized air inlet is connected to the air supply pipeline. The static pressure is transformed to dynamic pressure due to the diameter reduction of the inlet when high-speed air flows into the converging tube. When the air flowing through the nozzle, jet is formed. The static pressure is minimum and the dynamic pressure is maximum at the nozzle zone. Negative pressure region is formed due to the reduction in static pressure near the nozzle, which “sucks” the powdered gelling agent into the suction chamber (Wang, 2004; Wang et al., 2014, 2012). The mixture of the gelling agent and air flows into the throat that is connected with the suction chamber. The powdered gelling agent and the air are forced to mix uniformly by the fluctuation of high speed airflow in the diffusion chamber, which is placed close to the exit of the throat to increase the delivery pressure (Xie and Wu, 2007; Li and Qi, 2007; Zhi-lin et al., 2009). Finally, the powdered gelling agent is delivered to the pipeline.

2.2. Internal structure

Fig. 1 illustrates the proposed powder adding device, which is composed of gelling agent suction tube, pressurized air inlet, converging tube, nozzle, suction chamber, throat, diffusion chamber, and other important parts. The structure of converging tube is shown in Fig. 2.

The fluid flow between sections 1-1 and 2-2 in the converging tube is given by the Bernoulli equation:

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}=\frac{p_2}{\rho g}+\frac{\phi_1^2 v_2^2}{2g} \tag{1}$$

Equation (1) can be rewritten as the following equation:

$$p_2=p_1+\frac{1}{2}\rho\left(v_1^2-\phi_1^2 v_2^2\right) \tag{2}$$

According to air continuity equations, we have

$$Q_0=\frac{1}{4}\pi d_1^2 v_1=\frac{1}{4}\pi d_2^2 v_2 \tag{3}$$

The change in pressure Δp can be deduced from Eqs. (2) and (3), and it can be expressed as the following equation:

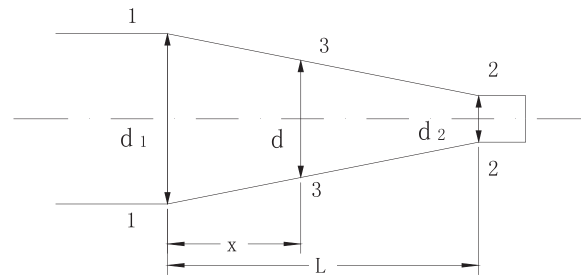

Fig. 2. Converging tube used in the powder adding device.

$$\Delta p=\frac{8\rho}{\pi^2}Q_0^2\left(\frac{1}{d_1^2}+\frac{\phi_1}{d_2^2}\right)\left(\frac{1}{d_1^2}-\frac{\phi_1}{d_2^2}\right) \tag{4}$$

Here, p_1 and p_2 denote the air pressure (in units of MPa) at sections 1-1 and 2-2, respectively. The parameter Δp denotes the pressure difference (in MPa) between sections 1-1 and 2-2. The parameters d_1 and d_2 denote the diameter (in units of m) of the converging tube inlet and the nozzle diameter, respectively. Further, ϕ_1 denotes the velocity coefficient and Q_0 the air volume flow (in m^3/s). The parameters v_1 and v_2 denote the average air velocity (m/s) in sections 1-1 and 2-2, respectively.

The radius of the converging tube at any cross section (in Fig. 2) is given as (Cao et al., 2007; Liu et al., 2000):

$$\frac{d-d_2}{L-x}=\frac{d_1-d_2}{L} \tag{5}$$

Upon setting $x=L/2$, we have

$$d=(d_1+d_2)/2 \tag{6}$$

$$\text{Further, } d_3=\sqrt{m}d_2 \tag{7}$$

Here, m denotes the ratio of the throat area to the nozzle area, and we set $m=4$ on our experience. d_3 denote the diameter of the throat.

Upon setting the air pressure at the inlet as$p_1=0.6$ MPa with the volume flowQ_0 = 60 m^3/h (as per practically used values),d_1,d_2,andd_3 can be determined using Eqs. (4) and (7).

In general, the applied empirical value of the converging angle α ranges from 6° to 15°, the range of the diffusion angle β is 5°–13°, and $L/d_3=2.17-2.89$, where L denotes the throat length (in m) (Tang, 1984; Long et al., 2010; Jiang et al., 2010; Xiang et al., 2012).

Three adding devices with different parameters (showed in Table 1) were determined primarily via both theoretical calculation and many experiments.

We made an optimal selection from three adding devices by testing the performance of each one under identical working

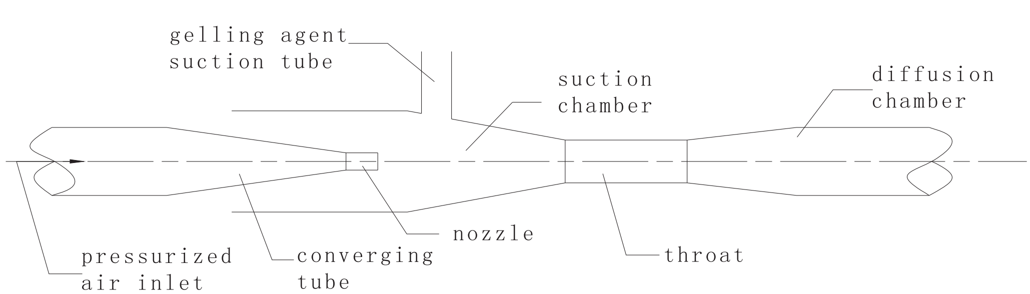

Fig. 1. Internal structure profile of the proposed powder adding device.