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Technical note

Experimental study and implementation of a novel internal foam spraying system for roadheaders

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ABSTRACT

Foam technology utilizes the good coverage of foam to form a closed space around dust sources. The foam then wets the dust particles, causing them to adhere before they spread into the air, resulting in better dust control than with water sprays. In the process of foam dust control at a heading face, the foam spray trajectory is highly influenced by the wind, making it difficult to focus foam on the dust sources, which wastes the foam and reduces dust control efficiency. To resolve this problem, the idea of transporting foam to the cutting head through the roadheader's inner pipeline is proposed. To adapt to the high resistance of foam delivery in the roadheader's inner pipeline, according to the water and air supply of the heading face, a table water-jet suction device and porous spiral coupling foaming device were designed, and the working conditions were tested using a self-designed experiment system in the laboratory. The results showed that the foaming agent could be automatically added into the device at a working water flow rate of 1–1.6 m^3/h at a ratio of 1%. The optimum air flow was 45–50 m^3/h, in which range the foam expansion ratio reached the maximum and the outlet pressure demand was satisfied. Field application showed that the new foam method had a better dust control efficiencies than traditional foam methods.

1. Introduction

Large amounts of dust are produced when roadheaders cut into coal or rock, which is a serious threat to workers' health; this dust can even cause explosions. According to statistics, more than 85% of pneumoconiosis patients work in heading faces, which is where coal dust explosions most often occur (Liu et al., 2014). The most common dust control method during roadheader cutting is water spraying (Han et al., 2014; Kissell, 2003; Colinet et al., 2008). However, because a significant amount of dust is generated and the diffusion velocity is fast, the water mist cannot capture and suppress the dust very well, resulting in low dust control efficiency (Hu et al., 2013; Kurnia et al., 2014). With roadheaders, dust is mainly produced close to the cutting head, and so the best way to control dust is to effectively cover the cutting head using a fluid medium that has good coverage performance. Foam is formed by an insoluble gas dispersed in a liquid. It therefore has a greater surface area for covering the dust sources and stronger wetting and adhesion capabilities for dust particles, making it more suitable for dust control. Research on foam technology around the world has proven that it is a very good way to control dust. The technological process of conventional foam technology is as follows. First, foaming agent is mixed with water in certain proportions to form a foaming agent solution. The air and foaming agent solution are then imported into the foam generator to produce foam. The produced foam is sprayed onto the dust sources through nozzles (Price, 1946; Mullins, 1950; Mukherjee and Singh, 1984; Page and Volkwein, 1986; Park, 1971; Ren et al., 2014; Wang et al., 2015). With roadheaders, the injection devices of the traditional foam method are generally installed in the body of the roadheaders, which is 2–3 m away from the dust sources (Wang et al., 2013; Lu et al., 2015b).

Because the wind speed in the heading face is usually high and the foam has small density and a high gas content, the foam spray trajectory is highly influenced by the wind, making it difficult to focus the foam on the dust sources, resulting in significant waste of foam and relatively low dust control efficiency. To resolve this problem, a new idea of transporting foam to the cutting head through the roadheader's inner pipeline is proposed. This novel method reduces the influence of wind flow and maximizes the foam dust control effects.

Fig. 1 shows the foam supply pipe inside the roadheader. The diameter of the pipeline in the roadheader is usually 15 mm and it is curved. Thus, the resistance is higher during foam delivery as compared to the traditional foam technology, which transfers foam through a nearly straight pipe with a diameter of 25 mm (Wang et al., 2015).

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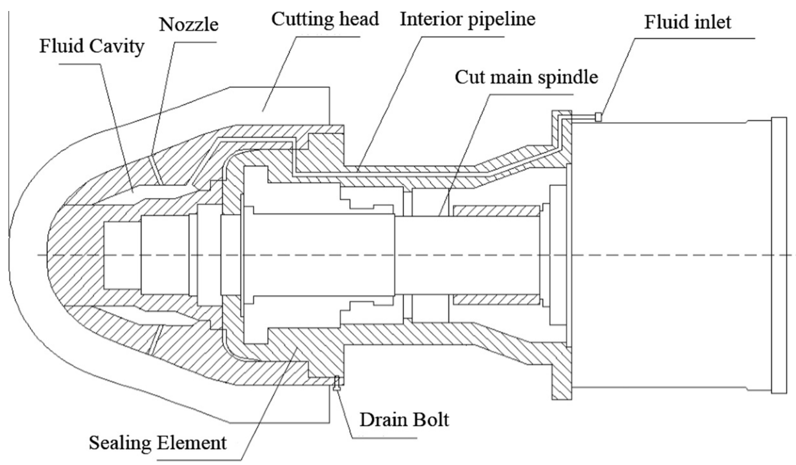

Fig. 1. Foam supply pipe inside the roadheader.

When the existing foam preparation device is connected to the foam supply pipe inside the roadheader, the device cannot work properly. To adapt to the high resistance in the roadheader's inner pipeline and the water and air supply underground, a stable water-jet suction device was proposed according to the principle of a liquid jet pump (Lu et al., 2015a). Combining the advantages of baffle-type foaming and net-type foaming, a porous spiral coupling foaming device was designed, which could realize foaming with low resistance and high efficiency. The working conditions of the new foam-producing equipment were tested by a self-designed experiment system in the laboratory. Field application showed that the new foam method had a better dust control efficiency than the traditional foam method.

2. Structure and working principle of the new foam- producing equipment

The new foam-producing equipment mainly consists of a foaming agent-adding device and a foam generator, which are shown in Figs. 2 and 3.

Fig. 2 shows the structural representation of the water-jet suction device, which is composed of a water inlet, a jet nozzle, a suction chamber, a mixing chamber, a diffusion chamber, and a mixture outlet. The structural dimensions related to the device are shown in Table 1. The working principle is as follows. First, the pressure water flows into the jet nozzle and is converted to high-velocity turbulent flow, which produces negative pressure in the suction chamber; Second, when the pressure is lower than the outside barometric pressure, the foaming agent is sucked into the mixing chamber automatically by the turbulent flow and mixed thoroughly with the water; Third, the velocity of the mixture decreases in the diffusion chamber, which facilitates foaming. For the water-jet suction device, ensuring that the suction pressure is at negative pressure, no cavitation phenomenon occurs and that the foaming agent can be added steadily under the given working conditions are key points in designing the device.

Fig. 3 shows the structural representation of the porous spiral coupling foaming device, which includes the jet nozzle, intermixture inlet, gas–liquid mixing chamber, diffusion chamber, porous spiral vane, and foam outlet. Table 2 shows the structural dimensions related to the device; the working process is as follows. The velocity of the compressed air increases as it flows into the jet nozzle, reaching a maximum at the nozzle exit. The boundary layer of the air jet entrains ambient air and draws the intermixture in from the suction device. As the mass, momentum, and energy are exchanged between the air and liquid in the mixing chamber and the pressure increases in the diffuser chamber, preliminary mixing of the gas and liquid occurs and a few bubbles will appear in the mixture. When the bubbles flow through the porous spiral vane, the foaming process begins. The function of the porous spiral vane is to turn one-dimensional flow into three-dimensional flow, which can increase the gas–liquid mixing strength (Li et al., 2000). The meshes on the vane ensure a continuous foaming process. The unique design of the foaming device can provide stronger foaming ability and less pressure loss as compared to conventional foaming devices.

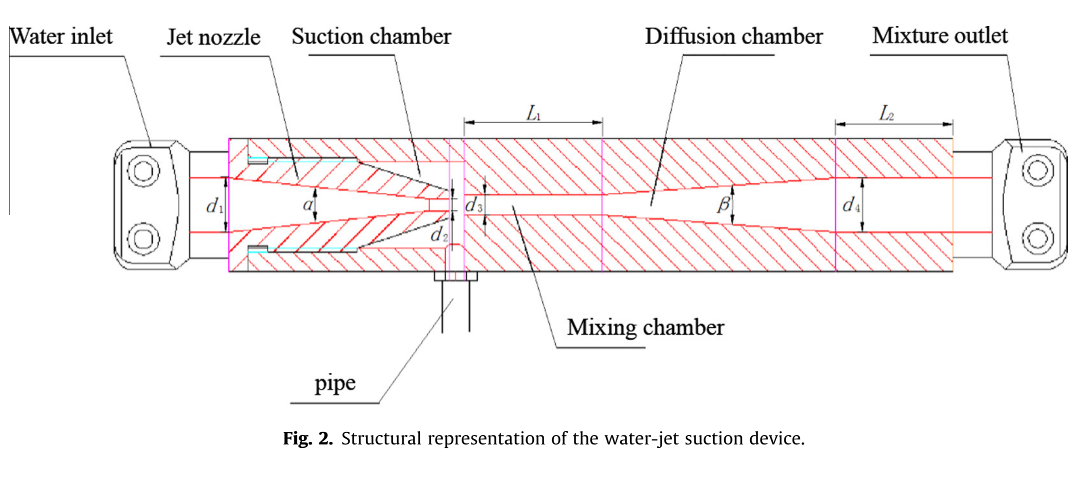

Fig. 2. Structural representation of the water-jet suction device.