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Optimization and implementation of a foam system to suppress dust in coal mine excavation face

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ABSTRACT

Foam technology is more efficient than water sprays for dust control in coal mines, but the traditional foam system is complex and poses problems related to foam production and spraying application, with high water consumption, unstable equipment and relatively low utilization efficiency of foam. This paper describes an optimized foam system which overcomes these disadvantages. The proposed foam generator has a self-suction unit that uses a turbulent-flow water jet to automatically draw in ambient air and foaming agent, thereby eliminating the need for compressed-air hoses and pipes. As well as simplifying the system, it solves the current problem of water backflow created by high-pressure compressed air. A refined foam spraying structure was developed for use in conjunction with an operating roadheader as it produces and diffuses dust. The structure consists of foam distribution supports and arc-fan nozzles. It can produce a more focused, continuous and uniform coverage at the source of the dust. The optimized system consumes less water and foaming agent, and achieves greater dust-suppression efficiency than methods in current use.

1. Introduction

At the present time, about 90% of coal is produced in underground mines in China (Lin, 2014). With the development of mechanized mining technology, 'super' coal faces now have an annual output as high as hundreds or even thousands of tonnes (Wang, 2010b), substantially increasing annual excavation roadway consumption. Efficient mechanized excavation technology has become a necessary condition to guarantee high production rates and high mining efficiency. In recent years, comprehensive mechanized excavation technology, especially the use of boom-type roadheaders, has been widely applied in many state-owned coal mines in China (Wang, 2010c). The number of roadheaders purchased in China has been reported to have increased from 72 in 1999 to 1311 in 2009 (Wang, 2010d), illustrating a rapidly increasing annual trend. Complete mechanization has greatly enhanced production efficiency in coal mines; however, large amounts of dust are produced when a roadheader is operating, and accounts for more than 80% of all dust produced at the excavation face (Jing et al., 2010). Such volumes of dust are a ready cause of pneumoconiosis in workers. Fig. 1 shows the growing number of coal pneumoconiosis patients in China from 2003 to 2010 (Chen et al., 2013). In fact, most pneumoconiosis patients are from coal mine excavation face in China.

The conventional method of dust control at the excavation face is the use of water spray to capture dust particles in the air (Kissell, 2003; Colinet et al., 2008; Han et al., 2014). It is difficult to suppress the dust well in this way because of the large quantity of dust and its rapid diffusion when the

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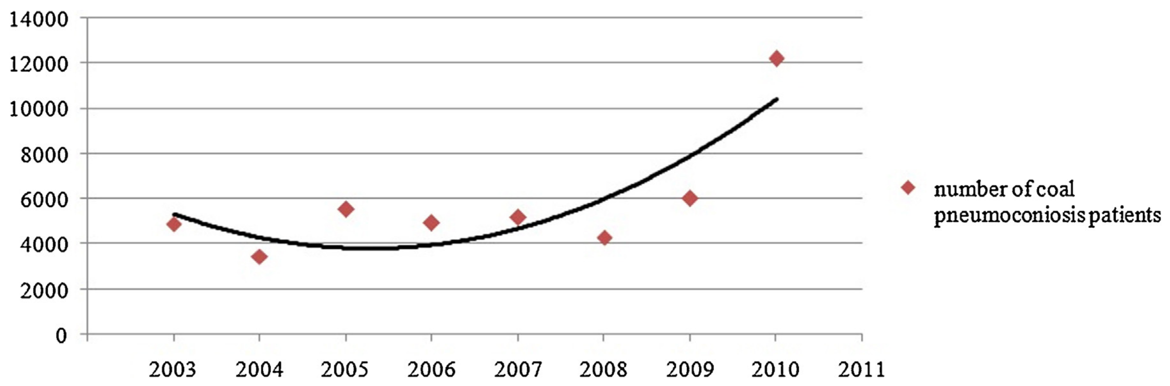

Fig. 1 – The number of coal pneumoconiosis patients in China from 2003 to 2010.

roadheader is operating (Hu et al., 2013; Kurnia et al., 2014). To effectively control the dust, however, a medium must be found that suppresses the dust close to the source, before it diffuses into the whole roadway space. Being a gas–liquid medium, foam has the unique advantages of greater surficial area, and stronger wetting and adhesion capability. Foam can quickly wet and adhere to dust particles. Since the mid-twentieth century, research on foam dust suppression technology has confirmed it to be an efficient way to control dust. Some British coal mines in 1946 injected foam into the drilling hole to wet the dust and inhibit its release into the air. The average dust control efficiencies reached 83.6%, achieving excellent effects (Price, 1946; Mullins, 1950). In the early 1980s, a compressed-air type of foam dust suppression device was developed by the United Sates Bureau of Mines. Compressed air, water and surfactant were mixed and forced through a metal mesh to created foam. The foam dust control efficiency was greater than 50% and water consumption was only 1/5 to 1/10 that of water spray devices (Mukherjee and Singh, 1984; Laurito and Singh, 1987). Japanese scholars in 1983 analyzed the working parameters of mesh-type foam devices and carried out dust control experiments in the coal mining machines. Their results showed the foam technology could reduce the suspended dust 40% to 50% more than water spray (Mei, 1984). In the 21st century, Wang (2013) put forward the Venturi-type foam generator and tested it in coal mines, achieving good effects (Wang, 2013; Ren et al., 2014).

2. Shortcomings of traditional foam dust suppression technology

However, the traditional foam dust suppression technology still has certain shortcomings both in foam production and spraying. In the aspect of foam production, many foam generators often use compressed air to produce foam (Page and Volkwein, 1986; Zhao, 2007; Park, 1971), and the use brings limitations to foam production at the excavation face: (1) the pressure of the compressed-air supply in an underground mine is often unstable and difficult to adjust, commonly resulting in high-pressure water backflow which affects the use of the equipment; and (2) compressed-air pipe to the foam generator takes up some space on a roadheader, increasing the complexity of the system, and making it difficult to use in narrow excavation faces. What is more, a quantitative additive pump is often used to add foaming agent for the traditional foam generator, making the system more complex and inconvenient.

To make full use of the foam, the shape of the foam flow must be similar to the shape of the dust source. In current spraying structures, solid cone nozzles and flat nozzles are commonly used to spray foam (Wang et al., 2011; Singh and Laurito, 2004; Wang, 2010a,b,c,d; Han et al., 2008). Because the cutting head of the longitudinal roadheader is roughly conical, the spray range of the nozzle should ideally be circular, approximating the largest circumference of the cutting head; therefore, the flow of foam through the solid cone nozzle and flat nozzle does not cover the dust source efficiently, resulting in low foam utilization efficiency.

3. The new foam dust suppression system

To overcome these shortcomings, the optimized foam generator, distribution support and nozzle were designed and subjected to laboratory and field tests, and achieved good results.

Fig. 2 shows the proposed foam generator. It consists of a self-suction part and a foam-producing part. The working process is as follows. For its power, it requires only the high-pressure water supply normally available in underground mines. First, the high-pressure water flow is passed through a jet nozzle to convert it to high-velocity turbulent fluid flow, automatically drawing ambient air and foaming agent into the mixing chamber. Then, the swirler accelerates the mixing of air and liquid to produce a high-quality foam. The advantages of the new version are as follows: (1) The compressed-air pipes and the extraneous equipment for adding foaming agent have been totally removed, making the whole system more simple and convenient. (2) The automatic suction of air and foaming agent into the mixing unit eliminates water backflow. (3) The swirler reduces resistance in the foaming process.

According to jet theory, the vacuum degree formed by a water jet will increase with an increase in water velocity. The increase of vacuum degree will then increase the amount of air entrained as well as the amount of foaming agent drawn into the mixing chamber.

To obtain the working parameters of the foam generator, we designed the related experimental system to test the self-suction capacity and foaming capacity. The ratio of air flow q_g to water flow q_w was used to evaluate the relative air-suction function. The ratio of foam flow q_f to water flow q_w is used to evaluate the foaming function. The percentage of added foaming agent flow q_a to water flow q_w is used to evaluate the added foaming agent property. The results are shown in Figs. 3 and 4.