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A novel spraying/negative-pressure secondary dust suppression device used in fully mechanized mining face: A case study

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ABSTRACT

Aiming at improving the spraying dust suppression performances between the coal cutter hydraulic supports, a novel spraying/negative-pressure secondary dust suppression device was developed. In this device, the nozzle's atomization performance including atomizing angle, spraying range and droplet diameter were measured so as to select the optimal nozzle. A nozzle with optimal overall atomization performance was selected among 4 kinds of nozzles with hollow and solid cone-shaped spraying fields. At the optimal spraying pressure of 8 MPa, the spraying field of the developed dust suppression device can almost cover all the space between coal walls and hydraulic support's columns, and effectively absorb the dusty airflow in the footway. Field measurements indicated that, compared with the original dedusting method, the dust suppression rates of total coal dust and respirable dust in the fully mechanized mining face by the developed novel spraying device can be enhanced by 26.2% and 27.3% respectively and reach efficiencies up to 82.0% and 80.9%, respectively. The dust suppression rates of total coal dust and respirable dust in the working area for supports moving workers can be enhanced to 81.5% and 80.1%, respectively.

1. Introduction

Coal is one of the most important basic resources and especially in China the consumption of coal occupies over 60% of the total energy demand. The problem of dust pollution is fairly serious in coal mining. During the coal mining process dusts are mainly produced in fully mechanized mining faces. High concentration dusts may spread over the whole working space and the local dust concentration can be up to 3000 mg/m^3 (Kissell, 2003; Cheng et al., 2011; Lee, 2011; Zhou, 2009), severely affecting the safety of the workers and the coal production. Dusts in the mechanized mining faces are mainly produced from roll cutting of the coal cutter machine and from the movements of hydraulic supports, both of which can produce 90% of the total dust production. If the coal miners work in this high-concentration dust environment for a long time, they will be susceptible to pneumoconiosis. According to statistics by the National Health and Family Planning Commission of the People's Republic of China (PRC), there were 26,393 reported cases of occupational diseases all over the country in 2013, among which 23,152 patients suffered from pneumoconiosis. This number equals the total number

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of pneumoconiosis patients in all other countries worldwide. The number of pneumoconiosis patients and silicosis patients among Chinese coal miners is 13,955 and 8095, respectively. Hence, miners have a fairly high risk of suffering from pneumoconiosis in fully mechanized mining faces.

Currently, in some major coal-mining countries such as China, America and Australia, widely adopted dedusting methods include dust suppression by water spraying, coal seam water injection, chemical dust depression and the use of dust collectors (Zhou, 2009; Seibel, 1976; Li et al., 2013; Ji et al., 2016). Using coal-seam water injection, the pressurized water is injected into the coal through the drilled holes and thus the coal's physical and mechanical properties can be changed because of the increased moisture in coal, thereby reducing the production of coal dusts. Chemical dust suppression refers to the use of some chemical reagents such as surfactants to wet and coagulate the dust particles. In recent years, foam dedusting technology appeared successfully in some coal mining countries such as America, Japan and China. A foam generation system is used, in which the chemical reagent and water are mixed at a certain ratio, and the formed foams can cover the dust generation sources so as to effectively suppress the dusts (Ji et al., 2016; Xi et al., 2014; Seibel, 1976). Wang et al. (Wang et al., 2015a and Wang et al., 2015b) developed a series of novel foam systems for dust prevention and control in the coal mine's fully mechanized excavated faces. This novel device could successfully overcome the disadvantages of the previous foam generator such as great water consumption and poor stability and enhance the dust removal efficiency in chemical dust depression. Although favorable dust removal results have been attained using both chemical dust depression and coal seam injection, they exhibit some shortcomings. The chemical reagents used in chemical dust depression are generally costly, and more seriously, they may not be totally “green” and environmentally friendly. As to the coal seam water injection method, some processes are in conflict with the site production process, and water injection is difficult in low-permeability coal seams, which has limited the promotion and application of this method. Using dust collectors, the special dust removing equipment should be installed but the complex underground environment has severely limited their applications.

Besides, other dust control methods such as magnetization dust depression and pre-charged water spraying for dust suppression exist. Using the pre-charged spraying technique, the liquid forms droplets under the action of a mechanical or aerodynamic force, and are subsequently charged via corona induction or the contact with charges. However, these methods all need specially designed and costly generators and complex devices (Ren et al., 2011; Colinet, 2010; Zhao, 2007; Fabiano et al., 2014; Xi et al., 2014). Therefore, these techniques have not yet been widely applied in China's coal mines. Spraying dust suppression is still the most widely used method in fully mechanized mining faces. The spraying is predominantly performed between hydraulic supports, inside and outside the coal cutters, among which the spraying between hydraulic supports is the most important measure for controlling dusts produced by support movements. Therefore, spraying between the hydraulic supports is one of the most important dedusting methods (Mukherjee and Singh, 1984; Cheng et al., 2012; Zhou et al., 2012; Li, 2010).

The key factor affecting the dust removal of this dedusting method is whether it can effectively remove the dusts in the whole section between the hydraulic supports. Zhou (2009) installed 6–10 nozzles on the forepoling bars, upper beams and shield beams of the hydraulic supports, and the obtained spraying field can basically cover the whole hydraulic support space. This technique has been successfully applied in the Dongtan Coal Mine, China. A similar technique also appeared in Australia. Specifically, 2–4 nozzles were added above the upper beam for generating the spraying field to wet the coals and thus the dusts produced during the movement of shifts could be effectively reduced (Ji et al., 2016). The full-face water spraying dust suppression method has a high dust removal efficiency, exceeding 76% according to the field measurement results. However, in field applications, this technique encounters two problems: (1) the miner's clothes are easily wetted by the sprayed water, and the spraying technique is difficult to directly use in the footway between hydraulic supports where the miners are mostly working; (2) a lot of nozzles are used and thereby a great deal of water is consumed, which affects the coal quality and miners' working environment. These two problems make the popularization of this technique difficult (Zhou, 2009; Mukherjee and Singh, 1984; Cheng et al., 2012; Zhou et al., 2012; Li, 2010).

The dusts can be entrained into the spraying field due to the spraying induced negative-pressure (below atmospheric), and the dust removal efficiency per unit mass water consumption can be enhanced. Using this principle, Xie et al. (2007) developed a negative-pressure dust suppression device that can be mounted at around the shearer's drum. This device used ultrasonic atomizing nozzles and thus could produce an obvious negative-pressure region at the shearer's drum so as to achieve remarkable dust control effects. However, this device also should be equipped with high-pressure gas and high-pressure water flow. Ren et al. (2011, 2013) developed a water-mist based system for dust mitigation on longwall faces, which can be installed on the forepoling bar or the cable trough. Such devices can entrain the dusts in the footway and significantly enhance the dust removal efficiency per unit mass water consumption. However, this device used ultrasonic nozzle embedded in a venturi body which is quite complicated in structure. The formed spraying field can only cover approximately 45% of the spatial section enclosed by the coal walls and the hydraulic support's columns, and the overall dust removal efficiency is lower than 50%.

In order to overcome the deficiencies of the above-described dedusting techniques, a novel spraying/negative-pressure secondary dust suppression device was developed. This device exhibits a series of advantages. Firstly, compared with the conventional full-face spraying technique between the hydraulic supports, only three nozzles were used, and the water consumption was reduced by approximately 50–70%. This device has a simple structure and strong practicality. Moreover, the formed spraying field can completely cover the space from the coal walls to the hydraulic supports in the fully mechanized mining face, and the high-concentration dusts on the footway can also be effectively removed, so that a full-face dust removal between the hydraulic supports can be achieved. On the other hand, the coal miners' clothes on the sidewalk are not easily wetted and the working conditions in the coal mining face are normal. Compared with the existing negative-pressure dust suppression devices, the developed device only uses high-pressure water flow in the coal mine and possesses several strengths including easy installation and operation, strong practicality and low development and operating costs.

The device has been successfully applied in 17 fully mechanized mining faces operated by the Zaozhuang Mining Group,