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Experimental investigation on Influencing Factors of air curtain systems barrier efficiency for mine refuge chamber

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ABSTRACT

Air curtain systems for mine refuge chambers prevent harmful gases in the tunnel from entering the chambers, but their barrier efficiency is affected by their structural parameters, installation location and air flow angle as well as the size of the chamber door. Previous studies focused on air curtain systems installed on the top of the door frames of the mine rescue capsule, but no studies have investigated air curtain systems installed on two or three sides of the door frames. To improve the barrier efficiency of air curtain systems for refuge chambers, this study conducted an experimental investigation of the effects of the structural parameters, installation location, and air flow angle on the barrier efficiency for a constant size of the door frame. The results demonstrate that air curtain systems with air curtains installed on two sides of the door frame behind the door wall that ejected air parallel to the door frame provided a relatively good barrier effect; an air curtain system that used pipeline air curtains with a nozzle diameter of 1 mm and a nozzle distance of 15 mm exhibited a relatively good barrier effect and a barrier efficiency of 55–60%. In air curtain systems that use air knives, the air knife gap should be 0.1–0.2 mm wide. Under reasonable parameters and installation conditions, there was no significant difference between the barrier effects against CO_2 of air curtain systems that use pipeline air curtains and those that use air knives.

1. Introduction

With the development of mining technologies and the popularization of advanced safety equipment in recent years, major progress has been made on mine safety. However, mining accidents that threaten the safety of miners, such as mine collapses, fires, dust explosions, coal mine gas outbursts and explosions, still occur occasionally (Zhao et al., 2012). According to a statistical analysis of numerous mining accidents, the majority of those involved in mining accidents died from CO poisoning or suffocation (Meng et al., 2011). To reduce the number of casualties in mining accidents, countries with developed mining industries, including South Africa, Australia, the US, Chile, and China, have constructed emergency refuge systems in underground mines that provide a safe refuge for miners during an accident (Zhang et al., 2014a). These emergency refuge systems can not only resist high-temperature smoke and gases and prevent the entrance of toxic and harmful gases from outside the refuge but can also provide oxygen, food and water to the miners, eliminate toxic and harmful gases, and provide basic living conditions inside the refuge and time for emergency rescue missions (Margolis

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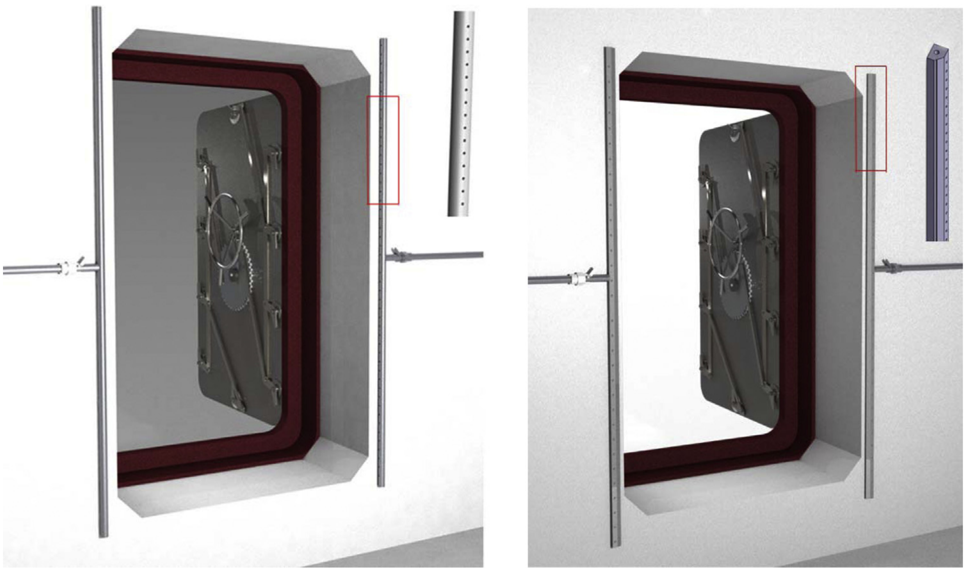
et al., 2011). Mine refuge systems include two main types of refuge facilities: refuge chambers and mobile rescue capsules (Meng et al., 2011). Refuge chambers in a mine are constructed by excavating caverns from the strata on the sides of the escape route or equipping the cross headings in the mine with necessary refuge facilities and equipment. A refuge chamber consists of a transition room and a living room. Miners in distress enter the living room from the tunnel via the transition room and wait to be rescued (Yang, 2010a). Healthy air quality is the basic guarantee for the safety of personnel in the mine refuge chamber. In America, the average concentration of CO_2 in mine refuge chamber is not higher than 1%, the highest concentration within 24 h is not more than 2.5%, the CO concentration is not greater than 0.0025% (Robert Regan, 2011). In China, CO_2 concentration is less than 1% and CO concentration is not greater than 0.0024% for mine refuge chamber. After a fire or explosion occurs in an underground mine, the tunnels are filled with high concentration of harmful gases, including CO_2 and CO (Yang, 2010b, 2011; Mejías et al., 2014). To avoid the effects of harmful gases in the mine tunnels after an accident, several countries, including the US, South Africa, and China, have installed air curtain systems on the frames of the airtight blast doors between the refuge chamber and the tunnel. These doors have a shock resistance capacity greater than 0.3 MPa and prevent toxic and harmful gases in the tunnel from entering the refuge chamber, which reduces the air purification load during the initial period after the miners enter the refuge chamber. However, no clear requirements for the structural parameters, modes of installation and air supply parameters of air curtain systems have been specified in standard documents for mine refuge chambers.

Studies of air curtain systems have mainly focused on three areas: heat insulation (Foster et al., 2006, 2007; Jaramillo et al., 2009; Elicer-Cortés et al., 2009), dust insulation (Liu et al., 2010; Wang et al., 2011a) and smoke insulation (Gupta et al., 2007; Guyonnaud et al., 2000; Rivera et al., 2011). Primarily due to their smoke insulation capacity, air curtain systems are used to control the flow of smoke when a building fire occurs. Through experimentation and numerical simulations using a fire dynamics simulator, Hu et al. (2008) demonstrated that air curtain systems can effectively control the spread of smoke and temperature along the evacuation passageways when a fire occurs. Luo et al. (2013a, 2013b) used experiments and numerical simulations to study an opposite double-jet air curtain for high-rise buildings and showed that in contrast to traditional air curtains, opposite double-jet air curtains both protected stairwells from smoke and CO and accelerated the expulsion of smoke and CO from the fire source. Air curtain systems are mainly used in mines to control dust on the mine face. Wang et al. (2011a) performed a field study and found that air curtains installed on a shearer exhibited a notable dust insulation effect and had a barrier efficiency of more than 70% against respirable dust.

According to a field survey of the construction of mine refuge chambers in China, refuge chamber door frames commonly have dimensions of 0.80 m (width) × 1.60 m (height), and the door walls are generally more than 0.50 m thick. The two main types of air curtain systems for mine refuge chambers in China consist of pipeline air curtains and air knives (Fig. 1). Air curtain systems are mainly installed on the top and the three sides (upper, left and right) of the refuge chamber's door frames. There are still relatively large differences in the structural parameters and gas flow angles of the different air curtain systems that are used for mine refuge chambers, and it is difficult to determine the barrier effect of an air curtain system against harmful gases. After the construction of mine emergency refuge systems was made compulsory, researchers in China began studying the application of the barrier effect of air curtain systems in emergency refuge facilities. Using numerical simulations, Ma et al. (2012) studied the application of air curtain systems in rescue capsules. They concluded that an air curtain system could effectively prevent the entrance of harmful gases into the refuge chamber only when the air flow velocity at the air curtain outlet was 10 m/s and that the system exhibited the optimal barrier effect when the air was ejected at an angle of 15°. Wang et al. (2011b) and Zhang et al. (2014b) experimentally studied the barrier effects of air curtain systems in rescue capsules against CO and CO_2, respectively. They found that the barrier performance of an air curtain system that consisted of pipeline air curtains was related to both the nozzle diameter and the nozzle distance and that the air curtain system reached a relatively stable barrier effect against



(a) Pipeline air curtain. (b) Air knife.

Fig. 1 – The two main air curtain structures for mine refuge chambers.