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Study on the characteristics of gas explosion affected by induction charged water mist in confined space

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A B S T R A C T

To investigate the suppression effect of charged water mist on gas explosion, a small charged water mist generator and a gas explosion simulation device were designed based on the principle of electrostatic induction. Experiments for testing characteristics of the gas explosion in a confined space under different charged polarities, charged voltages and mist fluxes were carried out. Experimental results indicated that, compared with the normal water mist, the explosion peak overpressure and the flame propagation speed could be more effectively reduced by the charged water mist. And this suppression effect could be promoted by increasing the charged voltage. To visualize the effect of the charged water mist's polarity on gas explosion, comparative experiments were conducted. The results showed that the explosion peak overpressure, the overpressure rising rate, and the propagation speed of the flame were reduced by 64.7%, 33.0% and 19.4%, respectively, when a +8 kV charged voltage was applied. In situation where a -8 kV charged voltage was applied, 64.1%, 26.5% and 16.0% reductions were achieved for the explosion peak overpressure, the overpressure rising rate, and the flame propagation speed respectively. Comparison of this data leads to the conclusion that the gas explosion could be more efficiently suppressed by the positively charged water mist.

1. Introduction

As the necessity for increasing the depth and intensity of coal mining in China, the prevention of gas explosion has become increasingly vital. Besides, the most common dust explosion occurs in underground coal mines. In coal mine tunnel, coal dust explosion is usually caused by gas explosion. Moving at the speed of sound, pressure wave resulting from gas explosion lifts the deposited coal dust in the air. Then gas flame reaches the coal dust causing a dust explosion which is more severe than the first one (Soltaninejad et al., 2015; Bidabadi et al., 2015, 2014, 2013; Dizaji et al., 2014). Gas explosion suppression is an effective method to reduce or control gas explosion hazards. The high-overpressure water curtain, the rock powder shed, the water bag, the dry powder extinguishing agent and the fire insulation grid quenching are conventional methods for gas explosion suppression. Recently, the water mist for extinguishing fire has been widely recognized as a new technique with broader applications (Blanchard et al., 2014; Liu and Kim, 1999; Meng et al., 2012; Zhang et al., 2016). It has been proved that the water mist under certain conditions has a good suppression effect on the propagation of the explosion flame (Cao et al., 2015; Yoshidaa et al., 2015).

Fire extinguished by water mist has been investigated comprehensively (Hostikkaa and McGrattan, 2006; Qin et al., 2003; Yu et al., 2007; Zhao and Wang, 2012). It was found that the charged water mist has a better extinguishing effect on oil pool fire than ordinary water mist. Wingerden and Wilkins (Wingerden and Wilkins, 1995) experimentally studied the suppression effect of water mist on explosion fire in a confined space, and the experimental results indicated that the accelerating flame overpressure could be weakened by fracturing the water mist droplets. Thomas et al. (Thomas et al., 1991; Thomas, 2000) characterized the

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suppression effects of the water mist as a result of heat and mass transfers which were caused by the destruction of the water mist droplets in the induction flow field at the front of the flame array in the combustion area.

Based on the reaction equilibrium theory, Lu and Qin et al. (Lu et al., 1998; Qin et al., 2001) experimentally confirmed that the water reduced the gas explosion reaction ability ration through breaking the chain carrier of the gas explosion chain reaction. Gu et al. (Gu et al., 2010) studied the suppression phenomena of different volumes superfine mist on the explosion of gas with different methane concentrations, and preliminarily determined the critical volume of the superfine mist which can suppress methane explosion. Qin et al. (Qin et al., 2012) studied the variation of the gas explosion overpressure under the action of the superfine mist.

The charged water mist is mainly generated by contact charging, induction charging or corona charging, to realize its application in specific fields. By applying the external AC or DC electric field and changing the related parameters to reflect the stability or extinguish of flame, M.K. Kim, Mruthunjaya Uddi and S.H. Won et al. (Kim et al., 2010; Uddi et al., 2009; Won et al., 2008) illustrated that external electric field could significantly influence the flame combustion.

The charged water mist was applied to suppress smoke diffusion by R.G. Maghirang, X.D. Xiang and R. Yadav et al. (Maghirang and Razote, 2009; Xiang and Colbeck, 1997; Yadav et al., 2008). Also, E. A. Almuhanna and L. F. Gaunt et al. (Almuhanna et al., 2008; Gaunt et al., 2003) used the pre-charged water mist to dedust by improving the contact ability between the water mist and industrial dust.

Recently, there are no references to demonstrate if the charged water mist could suppress coal mine gas explosion. In this paper, we used a charged water mist generator and gas explosion simulation platform to monitor the gas explosion overpressure and flame, and analyzed the effect and mechanism of charged water mist on gas explosion under different charged polarities, charged voltages and mist fluxes.

2. Experimental system

2.1. Generation method for inductive charged water mist

In this experiment, the water mist droplets are charged by induction. The mean particle size of the water mist droplets is 100 μm. To keep the best charging effect and avoid security problems caused by the electrode discharge, the produced mist volume from the charged water mist generator is 1.32 L/min under the standard condition. The cross-sectional area of circular copper wire electrode is 2.5 mm^2 and the inner diameter is 30 mm. The distance between the nozzle and the electrode is 12 mm.

As shown in Fig. 1(a), the negative spray is formed when the output terminal of the high voltage supply was connected to the sprayer while the earth terminal was connected with the copper ring electrodes. On the contrary, the positive spray is obtained when the connection positions of the output terminal of the high voltage supply and the earth terminal are exchanged as shown in Fig. 1(b). In this way, the electric field region can be formed between the copper ring and the sprayer. The water mist can be positively or negatively charged when it passes through the electric field.

The charged voltage was set between 0 and 8 kV, and the water mist could be either positively charged or negatively charged by changing the grounding method of the electrodes.

2.2. Experimental devices and systems

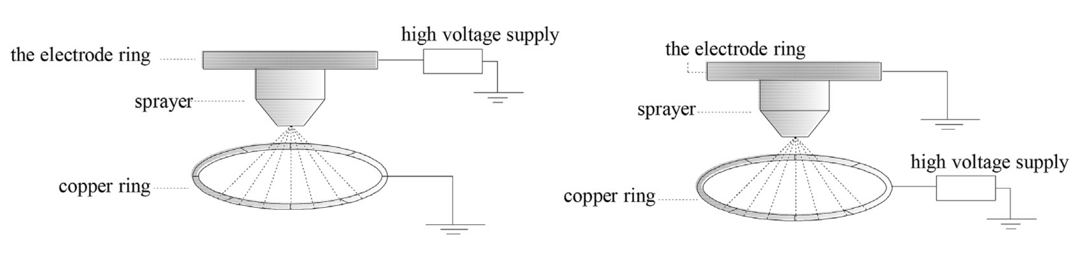
The experiment system is shown in Fig. 2. This system mainly consists of the pipelines, the charged water mist generator, the adjustable high voltage DC power supply, the gas distribution system, the high speed camera and the data acquisition device.

The experimental pipeline consists of two square plexiglass pipes which both are 500 mm in length, 100 mm in width, 100 mm in height and 20 mm in thickness. One end of the pipeline is electric spark ignition which is sealed with a screw flange. The other end, used to relieve overpressure, is a free side covered by two layers of PVC plastic films with a thickness of 0.31 mm. As seen in Fig. 2, the pipeline is separated into two parts labeled as pipe A and pipe B by a 0.31 mm thick PVC membrane. The pipe A is used to fill with water mist, while the premixed air-methane mixture which contains 9.5% methane by (volume or mass) can be filled into the pipe B.

The nozzle of the charged water mist, 200 mm away from the free end, is fixed at pipe A. The high-frequency overpressure sensor MD-HF, which has a measuring range from −0.1 MPa to 0.1 MPa, a response time of 0.1 ms and a measurement accuracy of 0.25%FS, is arranged at the sealed end. The photoelectric sensor RL-1 is applied to record the instantaneous optical signal when gas explodes, which also can control the initial time of overpressure and image capture. The high-speed camera DAVIS7.2 has a frequency of 2000 frames/s as the resolution is 1024 × 1024 pixels and can collect the transmission images of the gas explosion flame under different experimental conditions.

2.3. Experimental procedure

The experiment cannot be done normally when the voltage above 8 kV due to discharging. Therefore, the voltage below +8 kV was chosen to study the effect of the charged mist on the gas explosion suppression. The output voltage of the high voltage power supply was set as 0 kV, ±2 kV, ±4 kV, ±6 kV, ±8 kV to obtain the



a. nozzle with negative charge b. nozzle with positive charge

Fig. 1. Nozzle generating the charged water mist.