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Flame behaviors and pressure characteristics of vented dust explosions at elevated static activation overpressures

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ABSTRACT

Dust explosion venting experiments were performed using a 20-L spherical chamber at elevated static activation overpressures larger than 1 bar. Lycopodium dust samples with mean diameter of 70 μm and electric igniters with 0.5 KJ ignition energy were used in the experiments. Explosion overpressures in the chamber and flame appearances near the vent were recorded simultaneously. The results indicated that the flame appeared as the under-expanded free jet with shock diamonds, when the overpressure in the chamber was larger than the critical pressure during the venting process. The flame appeared as the normal constant-pressure combustion when the pressure venting process finished. Three types of venting processes were concluded in the experiments: no secondary flame and no secondary explosion, secondary flame, secondary explosion. The occurrence of the secondary explosions near the vent was related to the vent diameter and the static activation overpressure. Larger diameters and lower static activation overpressures were beneficial to the occurrence of the secondary explosions. In current experiments, the secondary explosions only occurred at the following combinations of the vent diameter and the static activation overpressure: 40 mm and 1.2 bar, 60 mm and 1.2 bar, 60 mm and 1.8 bar.

1. Introduction

A combustible dust explosion hazard may exist in a variety of industries, including food (e.g., candy, starch, flour, feed), plastics, wood, rubber, furniture, textiles, pesticides, pharmaceuticals, dyes, coal, metals (e.g., aluminum, chromium, iron, magnesium, and zinc), and fossil fuel power generation (Dizaji et al., 2014). 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 (Bidabadi et al., 2014; Bidabadi et al., 2013).

Venting is one of the most widely used mitigation measures against violent explosion overpressure when a dust explosion occurs in a confined enclosure. Despite of the numerous research focused on the explosion overpressure inside the enclosures, few researchers paid attention to the pressure waves and flames vented into the surroundings. Cooper et al. (1986) performed gas explosion venting experiments, and confirmed the existence of several pressure peaks. Harrison and Eyre (1987) systemically studied the external explosions that occurred outside a 30 m^3 chamber during gas explosion venting. In their research, the static activation overpressures of the vent device were unclear, but should be very small. The explosion hazard induced by the external explosions during gas explosion venting was studied by Van Wingerden et al. (1993) in a 38.5 m^3 room. Large-scale experiments were inconvenient for systematically studying the influencing factors on the external explosions. A small cylindrical tube of 195 L was used by Chow et al. (2000), to study the influences of the vent area, the static activation overpressure (called vent failure pressure in this paper), ignition position, gas species, and the tube orientation on the flame speeds and the overpressures in vented gas explosions. The effect of the ignition of a flammable mixture vented outside the vessel was discussed. The static activation overpressures ranged from 7 mbar to 126 mbar. Forcier and Zalosh (2000), focusing on the external pressures generated by gas and dust explosion venting, established the blast wave models to predict the values. However, the models did not incorporate the effects of the external combustions, which was obviously inappropriate because the hazards caused by external explosions and combustions could lead to disaster (Taveau, 2011). Jiang et al. (2005), Chen et al. (2006) conducted

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experimental research on the external pressure during gas explosion venting in a 7.6 L cylindrical vessel. Proust and Leprette (2010) observed the formation and combustion of the external gas cloud, using the stoichiometric methane-air mixture with a 1 m^3 vessel and a 0.15 m^2 vent. The static activation overpressure was not mentioned in the paper, but was believed to be nearly 0 bar. Taveau (2010) gave an excellent overview on the correlations for the blast effects from vented dust explosions.

Despite the above research, two problems still exist. Firstly, secondary explosions (also called the external explosions) usually occur in both gas explosion venting and dust explosion venting processes. However, the occurring conditions of the secondary explosions still remain unanswered. Does secondary explosion still occur in the elevated static activation overpressures larger than 1 bar? Secondly, the flame behaviors during dust explosion venting at different venting parameters and static activation overpressures are still not clear. This paper presents the flame behaviors and the pressure characteristics during the dust explosion venting process at elevated static activation overpressures larger than 1 bar. The occurrence conditions of the secondary explosions were discussed.

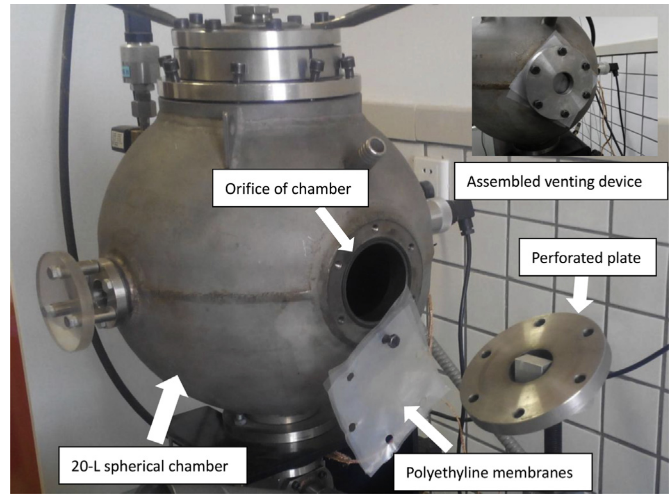

Fig. 2. Picture of the experimental device and the venting device.

2. Experimental details

2.1. Apparatus

Figs. 1 and 2 show the schematic and picture of the dust explosion venting experimental apparatus. The apparatus consisted of a 20-L spherical explosion chamber and a venting device assembled on the right-hand side of the chamber wall. The structures and functions of the 20-L chamber are not described here because this chamber is a widely used experimental apparatus in dust explosion research. Unlike the standard 20-L chamber proposed by E 1226 (2010), an orifice with the diameter of 110 mm was reserved on the right-hand side of the wall.

The venting device of the apparatus was accomplished using a perforated carbon steel plate and polyethylene membranes. The membranes, with the single thickness of 0.06 mm, were placed between the orifice of chamber and the plate. Six bolts were used to connect the chamber, the membranes and the plate tightly (upper right-hand corner in Fig. 2). As a result, the vent diameter in each experiment equaled the diameter of the plate orifice, varying among 15 mm, 28 mm, 40 mm and 60 mm. The number of the membrane layers also varied. The precise values of the static activation overpressures of the venting device are very important in explosion venting experiments. In this study, the static activation overpressure was concerned with the number of the membrane layers and the vent diameter, which was tested in advance by the compressed air overpressure experiments, given in Yan and Yu (2014).

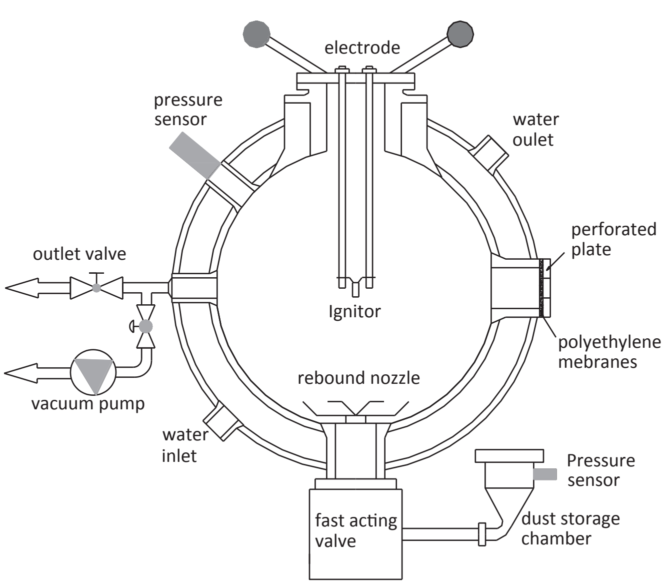

Fig. 1. Schematic of the 20-L dust explosion venting device (The control unit and data acquisition unit are not included).

An electric igniter with 0.5 kJ ignition energy, rather than a 10 kJ chemical igniter recommended in E 1226 (2010), was selected to ignite the dust cloud in the experiment. The reason was given in Yan and Yu (2014). The explosion overpressure was tested by a high-speed pressure sensor with a frequency of 5 kHz, placed at the back wall of the 20-L chamber. A high-speed camera (Photron Fastcam SA-4, 1000 fps) was used to record the flame appearance.

To indicate the moment at which the vent device was ruptured, a red plastic film was attached to the outer surface of the perforated plate after assembling all the components completely in each experiment. If the vent device was ruptured, the film would be floated by the pressure wave emitted from the vessel. Each experiment was repeated at least three times for repeatability.

2.2. Dust

Lycopodium dust purchased from dust supply manufacturer was used in the experiments. The mean diameter of the dust sample was 70 μm. The explosion parameters of the dust were tested before venting experiments, as shown in Table 1. The detailed process was described in Yan and Yu (2014). In the venting experiments, the optimum concentration of 750 g m^{-3} for P_{max} was adopted as a constant.

Table 1
Explosion parameters of 70 μm lycopodium dusts tested in 20-L chamber (Yan and Yu, 2014).

P_{max}	$(dP/dt)_{max}$	Optimum concentration		K_{St}
		for P_{max}	for $(dP/dt)_{max}$	
6.5 bar	283.0 bar s^{-1}	750 g m^{-3}	1000 g m^{-3}	76.8 bar m s^{-1}