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Experimental investigation into the vented hybrid mixture explosions of lycopodium dust and methane

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ABSTRACT

Vented hybrid mixture explosions were conducted in a 20-L chamber with different venting diameters and static activation pressures. Simultaneously, the maximum explosion pressure and the maximum rate of pressure rise of hybrid mixtures were also determined. It was found that the addition of methane to lycopodium dust led to an increase in both the maximum explosion pressure and the maximum rate of pressure rise and a decrease in the optimum dust concentration. Both the maximum explosion pressure and the maximum rate of pressure rise of hybrid mixtures were higher than those of lycopodium dust, but lower than those of methane. Similarly, the addition of methane to lycopodium dust led to an increase in the maximum reduced pressure, and the maximum reduced pressure increased with increase of the methane concentration. This effect was more pronounced for small vents and high static activation pressures. The maximum reduced pressure of the hybrid mixture was higher than that of lycopodium dust, but lower than that of methane. This was consistent with the relationship of the maximum explosion pressure between the three different systems. However, the increase in the maximum reduced pressure of lycopodium dust taken by the additional methane was obviously higher than that in the maximum explosion pressure, indicating that the influence of methane on the maximum reduced pressure of lycopodium dust was more significant. Adding methane to lycopodium dust increased the longest vented flame length and decreased the duration time of the external flame. Similar to the maximum reduced pressure, the longest flame length of the hybrid mixture was longer than that of lycopodium dust, but shorter than that of methane. However, it is the converse for the duration time of the external flame.

1. Introduction

Explosion venting is a method used most often to prevent or minimize damage to an enclosure during an accidental explosion (Bauwens et al., 2010; Telmo Miranda et al., 2014). Its main aim is to limit the development of internal overpressure in the event of an explosion, maintaining it below a threshold value that the vessel is capable of resisting. The basic problem in the vent design is to determine the vent area so that the explosion overpressure does not exceed the maximum allowable overpressures of the enclosure. Over the past decades, many test programs have been conducted and analytical models and empirical correlations for vent design have been developed (e.g., Barton, 2002; Bradley and Mitcheson, 1978; Eckhoff, 2003; Molkov et al., 1999; Tamanini, 2001), some of which have been included in engineering guidelines, such as the most accepted venting standard in the USA (as stated in NFPA 68 (2007))and in Europe (as stated in EN 14491 (2007) and EN 14994). However, these standards are not completely reliable due to the complex nature of the phenomena and the limited set of existing experimental data on which they are based (Bauwens et al., 2010; Chao et al., 2011; Qi et al., 2016). A number of factors have significant effects on the explosion vented flame and overpressure, such as vent size, ignition location, geometry and volume of the explosion vessel, initial turbulence, congestion or obstacles inside the chamber and so on. Hence, in recent years a series of tests have been initiated with the goal of producing a set of experimental data focused on the effects of these factors on the vented flame and overpressures inside or outside the explosion vessel, aiming to develop new models and engineering tools. For example, Bauwens et al. (2010) examined the effects of the ignition location, vent size and obstacles on the development of overpressure during vented explosions for stoichiometric propane–air. Daubech et al. (2013) investigated the effect of the concentration, vent size, ignition position and homogeneity of the mixture on the vented overpressure and flame for hydrogen–air mixture. Rocourt et al. (2014) reported the effects of the ignition location on the amplitude of pressure peaks in a transparent cubic encloseure with a volume of 3375 cm^3 for a 30 vol.% H_2 in air mixture. Experimental data from vented explosion tests using gasoline–air mixtures with concentrations from 0.88 to 2.41 vol.% were presented by Qi et al. (2016)

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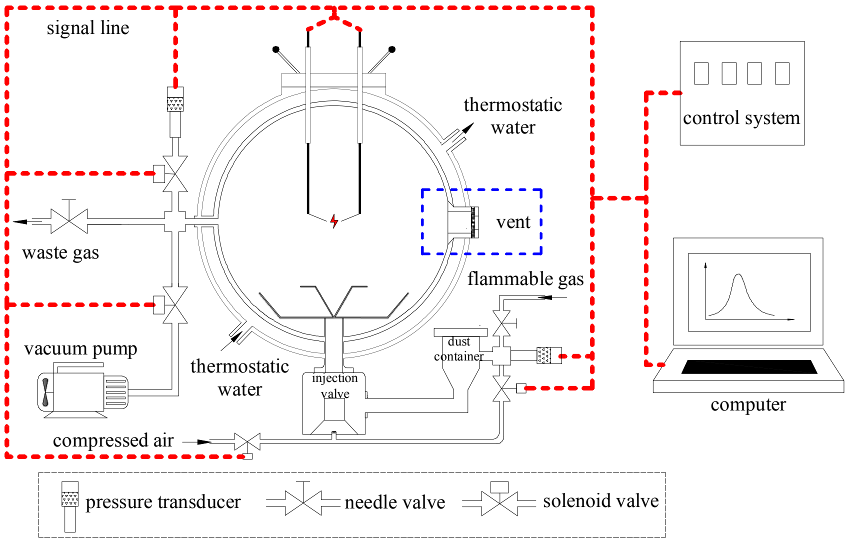

Fig. 1. The 20 L spherical experimental apparatus.

to clarify the effect of vent size and concentration in vented explosions. The effect of the ignition location on the external explosion in hydrogen–air explosion venting was investigated by Cao et al. (2017). Experiments on the explosion venting of rich hydrogen–air mixtures were conducted by Guo et al. (2017) in a small cylindrical vessel with two symmetrical vents to investigate the effect of the vent area and distribution on the pressure buildup and flame behaviour. Guo et al. (2015, 2016) also investigated the effect of the vent burst pressure on the internal pressure and flame evolution during explosion venting of rich hydrogen–air mixtures with an equivalence ratio of 2 in a cylinder. Fakandu et al. (2015) investigated the effect of the vessel volume and vent burst pressure on the vented gas explosion reduced pressure. Tascón and Aguado (2015) numerically studied the influence of the initial dust cloud, the size and position of the dust cloud, and the ignition location on the pressures generated during dust explosion venting. Experiments were performed by Scheid et al. (2006) on the influence of pre-ignition turbulence on the course of vented gas and dust explosions. Over the past years, we have also performed many studies on vented dust explosions. The effects of burst pressure, vent size and dust particle size on the vented pressure and flame were examined (Yan and Yu, 2014; Gao et al., 2015, Guo et al., 2016).

It is obvious that most of the existing research on explosion venting is mainly focused on vented dust or gas explosions, while few studies pay attention to vented hybrid mixture explosions. Actually, hybrid mixtures are often encountered in industrial processes. Typical examples include mixtures of pigments and diluents in paint factories, coal dust and methane in the mining sector, excipients and solvents in pharmaceutical industries, and wheat dust and fermentation gases in food industries (Dufaud et al., 2008; Sanchirico et al., 2011). Currently, more research is concerned with hybrid mixture explosions and is mostly focused on the explosion sensitivity and severity. Authors such as Dahn et al. (1986) studied the effects of small percentages of flammable vapours (gasoline) on the explosion severity of RDF (Refuse Derived Fuel) dust. Chatrathi (1994) investigated the effects of low propane concentrations on the explosibility of optimum cornstarch concentrations. Pilão et al. (2006) examined the explosibility of hybrid methane/cork dust mixtures. Denkevits (2007) investigated the explosibility of hybrid hydrogen/graphite dust mixtures. Dufaud et al. (2009, 2011) presented the results of hybrid explosions involving pharmaceutical dust and their associated solvents. Garcia-Agreda et al. (2011) characterised the explosibility of nicotinic acid dust as a function of methane concentration. Sanchirico et al. (2011) compared the explosion severity of hybrid mixtures with pure dust and vapour explosions. Kosinski et al. (2013) studied the explosion of carbon black and propane hybrid mixtures. Landman (1995), Britton (1998), Khalili et al. (2012) and Addai et al. (2015, 2016a, 2016b) investigated the effects of combustible gas introduction on the minimum ignition energy (MIE), minimum explosion concentration (MEC) and minimum ignition temperature (MIT) of dust clouds.

These existing investigations on hybrid mixtures have shown that hybrid mixtures exhibit obviously different explosibilities compared with pure gas and dust, such as the higher potential explosion sensitivity and severity. Therefore, it can be deduced that the venting characteristics of hybrid mixture explosions are also different from those of single gas and dust explosions. Though NFPA 68 (2007) (chapter 8: venting of deflagrations of dusts and hybrid mixtures) and EN 14491 (2007) (chapter 5: sizing of vent areas) have taken hybrid mixtures into account, it is still necessary to pay more attention to vented hybrid mixture explosions, due to their more complex explosion mechanisms and explosibility.

This paper describes the venting experimental results in a standard 20 -L chamber with hybrid mixtures of lycopodium dust and methane. The vented pressure and the vented flame behaviours of the hybrid mixture explosion were experimentally investigated with different vent sizes and different static activation pressures, and compared with those of vented dust and gas explosions. The aim of this research is to clarify the explosion venting characteristics of hybrid mixtures and find out the relationship of explosion venting characteristics between hybrid mixtures and single substances.

2. Experiments

2.1. Experimental set-up

The experimental set-up used in this study is shown in Fig. 1. More details on the equipment can be found in our previous work (Yan and Yu, 2014). It consisted of a standard 20 -L spherical explosion chamber in accordance with the principles of the standard E 1226-10 (2010) and a venting device. A fast-acting valve driven by compressed air is placed under the bottom of the vessel. The other end of the valve is connected to a 0.6 L dust container. In order to accomplish the hybrid mixture explosion venting experiments, after the dust was first placed in the 0.6 L container, the premixed methane/air mixture at 2 MPa pressure was added using the partial pressure method. The dust was then dispersed through a rebound nozzle into the vacuum chamber at −0.06 MPa via the premixed methane/air mixture. The ignition delay time was 60 ms. When conducting the lycopodium dust/air explosion venting experiments, the dust was first placed in the 0.6 L dust container, followed by the addition of the compressed air at 2 MPa pressure. The dust was then dispersed into the vacuum chamber at