Journal of Loss Prevention in the Process Industries 40 (2016) 82–88

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Effect of the vent burst pressure on explosion venting of rich methane-air mixtures in a cylindrical vessel

Jin Guo [a], Changjian Wang [b, *], Quan Li [c], Dongdong Chen [c]

[a] College of Environment and Resources, Fuzhou University, Fuzhou 350116, PR China
[b] School of Civil Engineering, Hefei University of Technology, Hefei 230009, PR China
[c] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei 230027, PR China

ARTICLE INFO

Article history:
Received 31 August 2015
Received in revised form
10 December 2015
Accepted 10 December 2015
Available online 13 December 2015

Keywords:
Explosion venting
Methane
Vent burst pressure
Flame propagation
Helmholtz oscillation

ABSTRACT

The effect of the vent burst pressure on explosion venting of a rich methane-air mixture was experimentally investigated in a small cylindrical vessel. The experimental results show that Helmholtz oscillation of the internal flame bubble of the methane-air mixture can occur in a vessel with a vent area much smaller than that reported by previous researchers, and the period of Helmholtz oscillation decreases slightly when the vent burst pressure increases. The maximum overpressure in the vessel increases approximately linearly with the increase in the vent burst pressure; however, the pressure peaks induced by Helmholtz oscillation always remain approximately several kilopascals. The external flame reaches its maximum length in a few milliseconds after vent failure and then oscillates in accordance with the pressure oscillation in the vessel. The maximum length of the external flame increases, but its duration time decreases with the increase in the vent burst pressure.

1. Introduction

Explosion venting is an effective method to protect equipment, pipes or buildings against accidental internal gas explosions. The key problem in venting lies in the reasonable choice of vent parameters for effective pressure relief while simultaneously avoiding secondary disasters resulting from explosion venting.

As is well known, the burst pressure of a vent cover (p_v) is one of the most important vent parameters, and it has a critical effect on the process of vented explosions. It has been found that p_v significantly affects the pressure profile and that several pressure peaks form in vented vessels during the process of explosion venting (McCan et al., 1985; Cooper et al., 1986; Ponizy and Leyer, 1999a,b; Ferrara et al., 2008; Chao et al., 2011; Ponizy et al., 2014). For example, Cooper et al. (1986) found that the amplitude of the first pressure peak in a vessel increases with increases in p_v, and the difference between the first pressure peak and p_v was small for low p_v values and remains at approximately tens of kilopascals when $p_v > 3$ kPa. However, for duct-vented explosions, the difference between the first pressure peak and p_v was discovered to be much larger (Kasmani et al., 2007, 2013; Ponizy and Leyer, 1999a,b), and Molkov (1994) found that the peak pressure increases with increases in p_v for $p_v < 200$ kPa, whereas it decreases for higher p_v.

One important flame phenomenon in a vented vessel is Helmholtz oscillation, in which the bubble of the burnt gas in a vessel undergoes bulk motion towards and away from vent (Cooper et al., 1986). Previous researchers have found that Helmholtz oscillation, which affects the pressure profile in a vessel, occurs under certain conditions (McCan et al., 1985; Cooper et al., 1986; Kordylewski and Wach, 1988; Bauwens et al., 2010; Rocourt et al., 2014). For example, McCan et al. (1985) found that Helmholtz oscillation was absent for small vent areas. Rocourt et al. (2014) reported that Helmholtz oscillation was observed only when ignition was performed near the vessel wall opposite to the vent.

External explosion may occur outside a vented vessel due to the quick combustion of the vented unburnt gas mixtures (Cooper et al., 1986; Ferrara et al., 2008; Harrison and Eyer, 1987; Catlin, 1991; Zhihua et al., 2006; Molkov et al., 2006; Bauwens et al., 2008), which reduces the efficiency of pressure relief (Ponizy and Leyer, 1999a,b; Harrison and Eyer, 1987; Molkov et al., 2006; Ferrara et al., 2006) and may cause secondary disasters. For example, the external overpressure or flames may cause damage to nearby equipment or personnel. The maximum external overpressure has been found to increase with increases in the speed of the vented flow (Harrison and Eyer, 1987) and the vent burst

---

* Corresponding author.
E-mail address: chjwang@ustc.edu.cn (C. Wang).

http://dx.doi.org/10.1016/j.jlp.2015.12.006
0950-4230/

pressure (Zhihua et al., 2006; Xiaohai et al., 2005).

Apart from these previous reports, many aspects of the effect of p_v on explosion venting have not been studied or solved yet. For example, how does external flame propagate after vent failure? How does p_v determine the maximum length of the external flame? Thus, work should be performed to identify the hazardous area into which the explosion is vented because it must be sufficiently far from other equipment to prevent fire and explosion hazards (EN 14994, 2007). In this paper, first, the propagation of internal flame was investigated using high-speed photography before and after vent failure. Second, the pressure-time histories in a vessel were measured to elucidate the effect of p_v on the maximum internal overpressure and the behavior of an internal flame bubble. Third, the propagation of an external flame was examined to determine the dependency of the maximum flame length on p_v.

2. Experimental details

2.1. Apparatus

Experiments were conducted in a cylindrical vessel with a 10-cm-long neck in the middle of it, as shown in Fig. 1. Both the internal diameter and the length of the cylindrical vessel were 25 cm. The cross section of the neck was 7 cm × 7 cm. At both ends of the vessel, two quartz windows were fitted to allow optical access necessary for the schlieren system.

Fig. 2 shows a schematic of the experimental apparatus. Methane-air mixtures were ignited at the center of the vented vessel via electric spark with an ignition energy of approximately 500 mJ. The schlieren system combined with high-speed camera 1 was used to visualize the internal explosion flames. High-speed camera 2 was used to record the flame behaviors inside and outside of the vented vessel. The frame rate of the high-speed cameras was 1000 fps. Two piezoelectric pressure transducers were used to determine the pressure histories during the venting process. One (PT_1) was installed in the vessel wall opposite to the vent, and the other (PT_2) was fitted in the wall of a neck 2 cm from the vent, as shown in Figs. 1 and 2. Both pressure transducers were coated with a thin layer of silicon grease to avoid thermal effects on pressure measurements.

2.2. Procedures

Layers of paper of different thicknesses (δ) were used as vent covers to seal the vent; for each paper, the time of paper rupture was determined from the interruption of an electrical circuit by breakage of a thin metal strip fixed on it. The vessel was evacuated by a vacuum pump and then filled with a methane-air mixture with an equivalence ratio (ϕ) of 1.4. Later, the ignition unit, high-speed cameras and oscilloscope were triggered simultaneously using a transistor–transistor logic (TTL) signal outputted by a signal synchronizer to ignite the methane-air mixture and to record the experimental data. For the experiment with no vent cover, the paper used to seal the vent was removed just before ignition. In all experiments, the initial pressure and temperature of the methane-air mixture were 1 atm and 300 K, respectively.

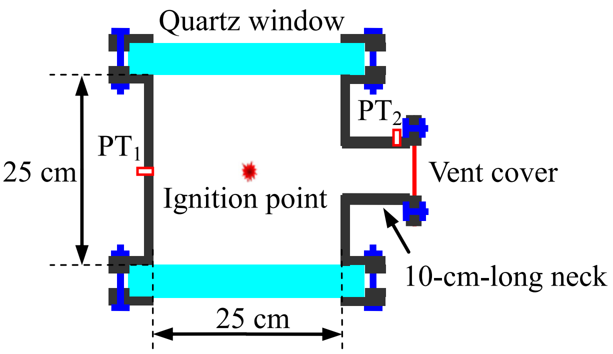

Fig. 1. Schematic of the vented vessel.

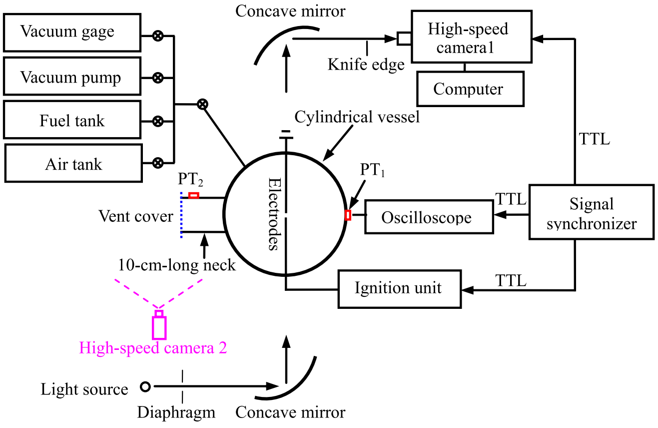

Fig. 2. Schematic of the experimental apparatus.

3. Results and discussion

3.1. Determination of the vent burst time and pressure

It is necessary to obtain accurate values of both the time of vent failure (t_b) and the vent burst pressure (p_v) to investigate the characteristics of the pressure profile and the propagation of the explosion flame before and after vent failure. t_b was determined from the interruption of an electrical circuit by the breakage of a thin metal strip fixed onto the vent cover (Cooper et al., 1986). As shown in Fig. 3, when the thin metal strip was interrupted, the voltage fell sharply to zero, indicating vent failure. At the same time, the pressure near the vent (PT_2) can be regarded as approximately p_v because PT_2 is only 2 cm away from the vent cover. t_b and p_v determined by the above method are given in Fig. 4. As shown in Fig. 4, p_v increases nearly linearly as δ increases from 0.075 mm to 0.9 mm. t_b also increases as δ increases, but the difference becomes

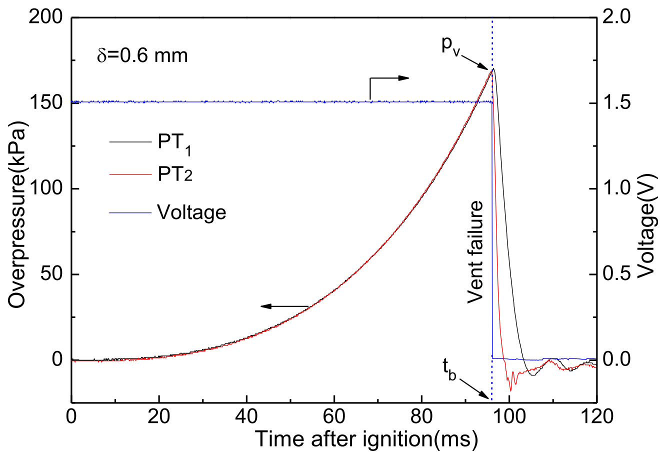

Fig. 3. Determination of the vent failure time t_b and the vent burst pressure p_v.