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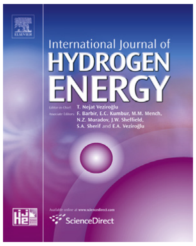

Explosion venting of rich hydrogen-air mixtures in a small cylindrical vessel with two symmetrical vents

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ABSTRACT

The safety issues related to explosion venting of hydrogen-air mixtures are significant and deserve more detailed investigations. Vented hydrogen-air explosion has been studied extensively in vessels with a single vent. However, little attention has been paid to the cases with more than one vent. In this paper, experiments about explosion venting of rich hydrogen-air mixtures were conducted in a small cylindrical vessel with two symmetrical vents to investigate the effect of vent area and distribution on the pressure buildup and flame behavior. Experimental results show that venting accelerates the flame front towards the vent but has nearly no effect on the opposite side. The maximum internal overpressure decreases while the maximum external flame length increases with the increase of the vent area. Two pressure peaks can be identified outside the vessel, which correspond to the external explosion and the following gas jet, respectively. Compared with the case of single vent, the use of two vents with same total vent area leads to nearly unchanged maximum internal and external overpressure but much smaller external flame length.

Introduction

Hydrogen is a promising clean energy carrier, but it is considered to be dangerous because of its extensive flammable range, low ignition energy and large burning rate. Explosion might occur once hydrogen-air mixtures are presented in confined spaces. Therefore, explosion venting is often recommended to prevent or mitigate explosion damage to the enclosures.

As is well known, one key issue of explosion venting is to select the appropriate vent area so that the explosion overpressure does not exceed a maximum permissible value. The effect of vent area on explosion venting of gas mixtures has been investigated extensively [1–11]. The experimental results of Cooper et al. [1] show that, with the decrease of vent area, the first, the third and the fourth pressure peak increases, but the second pressure peak first increases and then decrease. McCan et al. [5], Kordylewski and Wach [6] and Rocourt et al. [7] found that Helmholtz oscillation occurs only in vessels with large vent areas. Special attention is paid to the

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effect of vent area on the peak internal overpressure [8,9], and it is found that smaller vent area leads to higher peak internal overpressure in direct vented vessel. But it is more complex in the presence of a vent duct. For example, Kordylewski and Wach [6] and Molkov et al. [10] found that an increase in duct diameter was followed by peak overpressure decrease; however, the experimental results of Ponizy and Leyer [11] revealed that an increase in vent area does not always result in a decrease in peak overpressure, which was numerically reproduced by Ferrara et al. [12] and was explained as the outcome of the competition between the burning rate and the venting rate. In other researches [13–15], critical effect of vent area on the formation of external combustible cloud and the external pressure profile was found.

In addition to the experimental investigations, numerical works about the effect of vent area on explosion venting have also been conducted to describe pressure buildup and flame propagation [12,16–20]. In the model given by Molkov et al. [21–24], the ratio of turbulence factor to discharge coefficient was introduced to account for the pressure buildup. Based on the extensive experimental and numerical works, NFPA 68 [25] and EN 14994 [26] provide the correlations for calculating vent area.

In most of the previous investigations, explosion venting in vessels with only a single vent was concerned; however little attention has been paid to the cases with more than one vent. Solberg et al. [8] found that explosions with vent openings on one wall will result in Taylor instabilities and the vent areas were suggested to be placed on as many sides of the vessel as possible. Crowhurst et al. [27] noted that the maximum overpressures of dust explosion are reduced when using several relief vent openings with the same total area and provided an empirical correlation between the external flame length and the numbers of vent, which can also be found in NFPA 68 [25]. So far, some important issues of explosion venting of hydrogen-air mixtures in vessels with more than one vent still have not been studied; for example, how does pressure buildup and how does flame propagate in and outside a vented vessel in the case of two vents? And how much is the difference between the cases of single and two vents with same total vent area? In this paper, experiments on explosion venting of rich hydrogen-air mixtures in a small cylindrical vessel with two symmetrical vents were conducted to address the questions.

Experimental

Fig. 1 is a schematic of the vented vessel in present study. Experiments were conducted in a stainless cylindrical vessel with two symmetrical short ducts at its waist. Both the inner diameter and the length of the cylindrical vessel are 25 cm, and two quartz windows were mounted at both ends of the vessel allowing optical access necessary for the schlieren system. The length and the cross section of the ducts are 10 cm and 7 cm × 7 cm, respectively. The actual vent area (A_v) was determined by the orifice plates with central square hole fitted at the exits of the short ducts. Each experiment was conducted twice, and the reproducibility of the pressure profiles, peak overpressures and flame behavior was found to be good. The experimental conditions are summarized in Table 1. In test 1 and 2, the vent area being zero means constant volume explosion; in test 3–10, one vent was used and the vent area in test 11–18 is the total of the two square holes.

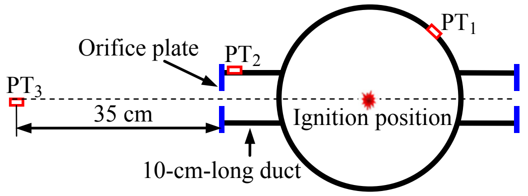

Fig. 1 – **Schematic of the vented vessel. (PT$_1$–PT$_3$: pressure transducer).**

The hydrogen-air mixtures were ignited at the center of the vented vessel via steel electrodes which were 2 mm in diameter and 1.5 mm in gap width, and the ignition energy is kept about 500 mJ. Three piezoelectric pressure transducers were employed to record the pressure-time histories in and outside the vessel, which were fitted respectively in the vessel wall (PT$_1$), 2 cm away from one exit (PT$_2$) and 35 cm away from the exit outside the vessel (PT$_3$), as shown in Fig. 1.

The experimental layout can be found in our previous study [28]. The schlieren system combined with a high-speed camera was adopted to visualize the explosion flame in the vessel. Another high-speed camera was used to record the explosion flame in and outside the vented vessel. The frame rate of the high-speed cameras was 10,000 fps. Firstly, the vessel was sealed with blind flanges and then evacuated by a vacuum pump; secondly it was filled with hydrogen-air mixture with equivalence ratio of 2.0. Just before ignition, the blind flanges were removed quickly and a piece of paper was lightly glued to seal the vents. And then the high-speed cameras and the oscilloscope were triggered simultaneously using transistor–transistor logic (TTL) signal from a signal synchronizer to ignite the hydrogen-air mixtures and to record the flame images and the pressure-time histories, respectively. The initial pressure and temperature of the hydrogen-air mixture in all tests were 1 atm. and 280 K, respectively.

Results and discussion

Flame propagation in vessel

Fig. 2 shows typical schlieren images of the internal flame for different vent areas. In the early stage after ignition, the flame

Table 1 – **Summary of the experimental conditions.**

Test no.	Number of vent	Vent area (cm^2)	Vessel volume (cm^3)	Duct length (cm)
1,2	0	0	12,266	10
3,4	1	6.12		
5,6	1	12.25		
7,8	1	24.5		
9,10	1	49		
11,12	2	6.12 × 2 = 12.24		
13,14	2	12.25 × 2 = 24.5		
15,16	2	24.5 × 2 = 49		
17,18	2	49 × 2 = 98		

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