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Influence of side venting position on methane/air explosion characteristics in an end-vented duct containing an obstacle

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ABSTRACT

To improve the discharging efficiency of a gas explosion in an end-vented duct containing an obstacle, a side vent in different positions was introduced to a duct with the internal dimensions of 100 × 100 × 1000 mm^3. The flame propagation characteristics and overpressure profiles of a methane/air explosion were analyzed to study the influence of side venting position on a gas explosion in an end-vented duct containing an obstacle. The experiment results showed that, the explosion can be efficiently discharged by a side vent in a duct containing an obstacle, and the discharging effect can be enhanced significantly with shortening the distance between the side vent and the ignition point. Besides, the relative position of a side vent and an obstacle has significant influences on the venting effect of a side vent. For a side vent located in front of an obstacle, the explosion can be effectively discharged by the side vent before the flame reaches the obstacle, thus dropping the incentive of the obstacle on flame propagation, and resulting in a great venting effect. Whereas for a side vent located behind an obstacle, before the flame reaches the side vent, the flame propagation will be strongly motivated by the obstacle and maintained at a high speed to pass the side vent, which is not conducive for a side vent to discharge the explosion. In addition, when the explosion overpressure induced by an obstacle is much higher, the discharging effect of a side vent on explosion overpressure can be further enhanced, resulting in a greater venting efficiency.

1. Introduction

The prevention of a gas explosion is still an important issue in many industrial process. Once a gas explosion accident occurs, it will cause huge losses, and threat the industrial safety and personnel safety [1–2]. For now, many techniques to prevent and control a gas explosion have been widely studied by researchers, including inhibiting the explosion using water mist, inert gases and foam ceramics et al. [3–8]. Particularly, among these techniques for preventing and controlling a gas explosion, due to its easy implementation and the effective discharging, the explosion venting technology has been widely concerned [9–12].

Typically, Zhang et al. [13–14] undertaken the experimental research on the venting process of a closed and vented methane explosion affected by transmission style, pipe length and ignition position in interconnected vessels. Kasmani et al. [15] carried out the experimental study on the maximum overpressure and flame speed of a vented explosion influenced by vent burst pressure and ignition location. Tomlin et al. [16] studied the effect of vent size and congestion on gas explosion in a large-scale experimental building. Bao et al. [17] studied the effects of gas concentration and venting pressure on the overpressure transients during the vented methane/air explosion in a 12 m^3 concrete chamber. Ugarte et al. [18] performed a parametric study of vented hydrogen explosion using a computational platform for gas explosion venting, and the computational model was extended to vented methane explosion scenarios by Sezer et al. [19]. Specially, for side venting, Alexiou et al. [20–21] studied a side-vented gas explosion compared with an end-vented explosion in large L/D vessels with different side venting positions.

The above-described literature have studied the discharging effect on a gas explosion influenced by many factors in different types of vessels. However in practice, there may exist some obstacles in a duct which can significantly enhance the destruction capacity of a gas explosion. Tomlin et al. [16] and Oh et al. [22] conducted relevant experimental studies on safety venting in an end-vented duct containing an obstacle. The results indicated that the existence of an obstacle can increase the difficulty of safety venting. Even in some cases, deflagration may be translated to detonation induced by obstacles in a tube [23]. Therefore, to reduce the hazards caused by a gas explosion in an

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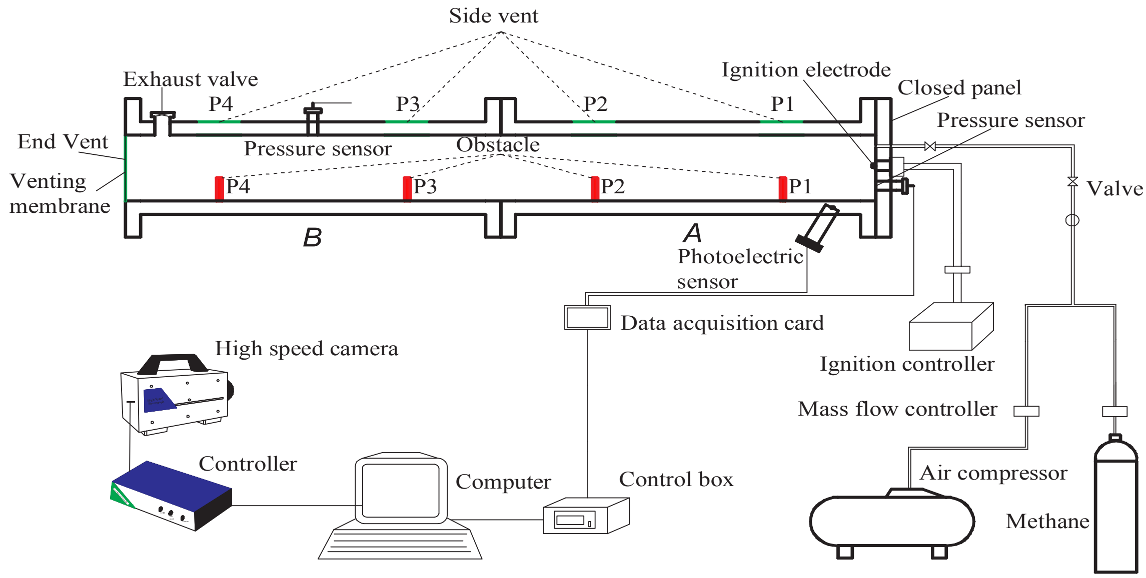

Fig. 1. Experimental system schematic of a methane/air explosion in a duct containing an obstacle.

end-vented duct containing an obstacle, some further researches about safety venting are necessary.

For a side vent installed in a duct, it can discharge the explosion in time, thus efficiently venting the explosion [20–21]. It seems the introduction of a side vent to an end-vented duct containing an obstacle is a feasible method to discharge the explosion effectively. To present, little studies have focused on the discharging effect of a side vent in an end-vented duct containing an obstacle. Based on this, an experimental end-vented duct with an obstacle in different positions was built, and a side vent was introduced at the upper plate of the duct with different positions, to study the influence of side venting position on methane/air explosion characteristics in an end-vented duct containing an obstacle. Specially, in consideration of the transverse propagation of flame, the influence of the relative position of a side vent and an obstacle was concerned.

2. Experimental apparatus and method

The experimental system schematic used in this experiment is showed in Fig. 1. The duct was made of transparent organic glass, which could withstand a maximum overpressure as 1.5 MPa, with the internal dimensions of $100 \times 100 \times 1000\,mm^3$. To facilitate the establishment of platform, the duct was divided into the two same parts of duct A and duct B. The right end of the duct was closed by a panel, with installing a high frequency pressure sensor (model as MD-HF, range of −0.1–0.1 MPa, indicated as front overpressure), an ignition electrode and a gas inlet. The left end of the duct was an end vent. On the upper plate of the duct, 4 same side vents were set, with both having an area as $80 \times 80\,mm^2$. The side vent and the end vent were sealed by venting membranes with a thickness of 0.3 mm. The distances between the center of 4 side vents and the right end of the duct were 125, 375, 625 and 875 mm, respectively. In the duct, 4 same obstacles were installed on the bottom plate of the duct, just right below the side vent 1–4, respectively, both with the size of $10 \times 35 \times 100\,mm^3$. Considering the important influence of the blockage ratio of an obstacle on gas explosion [24], a moderate blockage ratio of 35% on cross-section was chose. For each test, only a side vent and an obstacle in specific positions were used, and the end vent was always used. In addition, another pressure sensor was arranged at the central position on the upper panel of duct B, to record the explosion overpressure in the rear of the duct, represented as back overpressure. A photoelectric sensor (RL-1) was fixed on the duct, used to record the ignition signal. The ignition electrode was located at the center of the plate fixed on the right end of the duct, with a working voltage as 6 V (DC). A data acquisition card was used to collect the pressure signal and photoelectric signal. The methane/air premixed gas, with methane concentration as 9.5% configured by two mass flow controllers (with a concentration error as ± 0.1%), could be introduced into the duct by the gas inlet using the displacement method. The pressure of premixed gas in the duct was kept at the atmospheric pressure. In the experiment, a high speed camera was used to record the propagation process of an explosion, with a working frequency of 2000 frames/s. The propagation time between two adjacent propagation images was 0.5 ms. Flame front position could be obtained by enlarging the image, with a maximum error as 0.45% (for the nonsymmetrical flame shape, the front position referred to the furthest distance of flame front). Then the propagation distance between two adjacent images could be obtained. Accordingly, the instantaneous propagation velocity could be calculated by dividing the propagation distance by the propagation time (0.5 ms).

The experimental configurations include: an obstacle located at positions 1–4, respectively; a side vent installed in positions 1–4, respectively, and a case without a side vent. Here, configurations of an obstacle located at positions 1 and 3, respectively, were used to analyzed. After the premixed gas was let in, wait 20 s to eliminate the gas turbulence inside the duct. Then activate the data acquisition card and the high speed camera, and ignite the premixed gas. The flame propagation images, flame propagation velocities and overpressure profiles under different conditions were analyzed, to study the influence of side venting position on explosion characteristics in a duct containing an obstacle.

3. Experimental results and analysis

3.1. Visualization of flame propagation process

Fig. 2 shows the flame propagation processes of methane/air explosions affected by different side venting positions in a duct with an obstacle in position 1. From Fig. 2, for a configuration without a side vent, after ignition, the premixed gas was ignited and gradually propagated as a finger shape [25]. At this time, the flame accelerated in the early stage, which was detailedly studied by Valiev et al. [26]. After 20 ms, the flame gradually became distorted due to the inducement of the obstacle. When the flame just passed through the slit of the obstacle, the flame propagated from top to bottom, forming an anticlockwise