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Influence of obstacle blockage on methane/air explosion characteristics affected by side venting in a duct

Shaojie Wan[a], Minggao Yu[a,b,*], Kai Zheng[a,**], Yongliang Xu[b], Zhuang Yuan[c], Chunyan Wang[a,d]

[a] State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400044, China
[b] State Key Lab of Gas Geology and Control-Cultivation Base, Henan Polytechnic University, Jiaozuo, Henan 454003, China
[c] Xi'an Thermal Power Research Institute Co., Ltd., Xi'an, Shanxi 710054, China
[d] Northwest Institute of Nuclear Technology, Xi'an, Shanxi 710024, China

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ABSTRACT

To study the influence of obstacle blockage on explosion venting, a small sized experimental duct containing an obstacle with different blockages in different positions was built, and the methane/air explosion characteristics affected by side venting in the duct were studied. The explosion characteristics, including flame propagation, propagation velocity and overpressure profile, were analysed. The experimental results indicated that as the flame propagates upstream of an obstacle, flame propagation is little affected by the obstacle; when the flame passes the obstacle, flame propagation velocity and overpressure will always increase due to the incentive effect of the obstacle. Enlarging the blockage ratio increases the promoting effect of the obstacle. The relative position of a side vent and an obstacle affects side venting effect and the incentive effect of the obstacle. For a side vent in front of an obstacle, the explosion can be effectively discharged through the side vent before the flame reaches the obstacle, thus greatly weakening explosion intensity and decreasing the sensitivity of the explosion to the obstacle blockage. Whereas a side vent behind an obstacle is a disadvantage for the side vent to discharge the explosion, and the explosion intensity is very sensitive to the obstacle blockage.

1. Introduction

With the wide use of natural gas in daily life and industrial production, gas explosion accidents often occur unexpectedly, causing casualties and property loss every year (Chen et al., 2016; Yin et al., 2017). To solve this problem, many methods have been proposed to suppress and mitigate gas explosions. However, because the actual situations are more complex than the experiment conditions, some suppression methods are still confined to the laboratory. As to the method of mitigating explosions, because it is easy to implement, explosion venting technology is widely used.

Many factors influencing explosion venting have been studied. The influences of vent burst pressure, vent size, and ignition position on explosion characteristics have been investigated by Chow et al. (2000), Kasmani et al. (2013), Fakandu et al. (2015) and Guo et al. (2016) in cylindrical vessels. Zhang et al. (2013) and Zhang et al. (2016) also studied the effect of the length of interconnected pipes and the transmission style of flame propagation on the discharge effect of an explosion in interconnected vessels. Guo et al. (2015) carried out experiments on the venting effect of a hydrogen/air explosion in a small cylindrical vessel with two symmetrical vents. Alexiou et al. (1996; 1997a; 1997b) focused on the effect of side venting on explosion characteristics in large L/D vessels and compared the side venting effect with the end venting effect in a vessel with and without an obstacle. Bao et al. (2016) studied the overpressure transients of a vented methane/air explosion in a 12 m^3 chamber. Bauwens et al. (2010) and Chao et al. (2011) focused on the effects of ignition location, vent size, and obstacle on overpressure development of methane and propane explosions in a 63.7 m^3 chamber. Ajrash et al. (2018) studied the flame deflagration of methane/air mixture in a 30 m side-vented detonation tube, and they found flame propagation and pressure development were significantly affected by the vent location.

The above literature describes several methods to reduce the loss caused by a gas explosion under many different conditions, which plays an important guiding role for the efficient prevention of gas explosions. However, in a real scene, some mechanical equipments, testing instruments or some unforeseen obstacles may exist in the venting ducts, which will enhance the explosion severity on a large scale (Park et al., 2008; Na'inna et al., 2017). And this makes it more difficult to a safety relief. On this issue, Oh et al. (2001), Bauwens et al. (2010) and Tomlin

* Corresponding author. State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400044, China.
** Corresponding author.
E-mail addresses: mg_yu@126.com (M. Yu), zkcqu@cqu.edu.cn (K. Zheng).

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et al. (2015) conducted some relevant experimental studies on safety venting in an end-vented duct containing an obstacle. Their results demonstrated that an obstacle can significantly enhance the explosion intensity and make it more difficult to a safety venting. Even in some cases, due to the incentive effect of the obstacles, deflagration may be translated to detonation in a tube (Valiev et al., 2010). Side venting seems a feasible way to discharge a gas explosion in a duct containing an obstacle. And in our previous study, the influence of side venting position on methane/air explosion characteristics in an end-vented duct containing an obstacle was studied (Wan et al., 2018). However, how the obstacle blockage affects the side venting effect of a gas explosion is still unknown. Based on this, a small experimental device was set up to simulate a methane/air explosion. The explosion characteristics, including flame propagation, propagation velocity and overpressure, were analysed to study the influence of the obstacle blockage on a gas explosion affected by side venting in a duct.

2. Experimental apparatus and method

The experimental device used in this study consists of four parts: a duct, an ignition switch, an air distributing device and a data monitoring system, as shown in Fig. 1. The duct was made of transparent glass with internal dimensions of $1000 \times 100 \times 100\,mm^3$. The right end of the duct was closed by a panel, and the left end was an end vent. On the upper plate of the duct, a side vent with a cross section of $80 \times 80\,mm^2$ was installed at 4 different locations, represented as P_v 1 to P_v 4. The distances from the 4 location centres to the right end of the duct were 125 mm, 375 mm, 625 mm and 875 mm, respectively. The side vent and the end vent were covered with a venting membrane. The static burst pressure of the membrane was 1.973 kPa. Just below the side vent in 4 different positions, an obstacle could be located in 4 different positions, represented as P_o 1 to P_o 4. The cross section of the obstacle was $10 \times 100\,mm^2$, and the height could be set as 20, 35 and 50 mm, giving a blockage ratio of 0.2, 0.35 and 0.5, respectively. The flammable gas used in this experiment had a methane concentration of 9.5%, which was prepared using two mass flow controllers. The gas inlet was installed on the closed panel on the right end of the duct. The premixed gas was introduced into the duct by the displacement method. The methane concentration at the exhaust valve was measured to check the premixed gas concentration in the duct. The initial pressure in the duct was maintained at atmospheric pressure. And the ambient temperature was kept at 20 °C. A spark ignition device was used to ignite the premixed gas by a remote-control ignition switch, with the ignition electrode installed on the right end of the duct. And the working voltage of the ignition electrode was 6 V (DC). The data monitoring system included a photoelectric sensor (RL-1), two pressure sensors (MD-HF, −0.1 MPa-0.1 MPa), and a high-speed camera. The photoelectric sensor faced the ignition electrode to record the moment of ignition. Two pressure sensors were installed at two different locations inside the duct: one was fixed on the right end of the duct to record the overpressure at the ignition point, referred to as front overpressure; the second was installed on the upper panel of the duct at a distance of 750 mm from the right end of the duct to record the overpressure in the rear of the duct, referred to as back overpressure. The high-speed camera was the "High Speed Star 4G" high-speed camera produced by German LaVision company, used to record the flame propagation process in the duct, with a frequency of 2 frames/ms. The propagation time between two adjacent propagation images was 0.5 ms. Flame front position could be obtained by enlarging the image using PhotoShop CS6, with a maximum error of 0.45% calculated by dividing the minimum resolution scale by the image scale. 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). For each test, only a side vent and an obstacle in the specified positions were used; the end vent was always used.

3. Experimental results and analysis

3.1. Flame propagation image

Figs. 2 and 3 show the flame propagation images of methane/air explosions in a duct with an obstacle in P_o 2 and a side vent in P_v 1 and P_v 3, respectively. As can be seen in Fig. 2, after the premixed gas was ignited, the flame gradually developed and accelerated (Bychkov et al., 2007; Valiev et al., 2013). As the flame reached the side vent, the flame was vented through the side vent, and the flame propagation slowed down. For the configuration without an obstacle (blockage ratio of 0), the flame needed 570 ms to propagate through the duct. For the configurations with an obstacle, the flame became distorted as it propagated near the obstacle. When the flame passed the slit of the obstacle, an eddy formed behind the obstacle, which induced turbulence and caused acceleration of the flame propagation (Oh et al., 2001; Park et al., 2008). However, for configurations with an obstacle in Fig. 2b–d, when the flames reached the obstacle, the explosions had been discharged for relatively long times (more than 100 ms, which could be seen in the figure). At this moment, the explosion intensities of these configurations were weak. Therefore, the acceleration induced by the obstacle on flame propagation was weak. And the flames of these configurations still needed long times to propagate through the duct

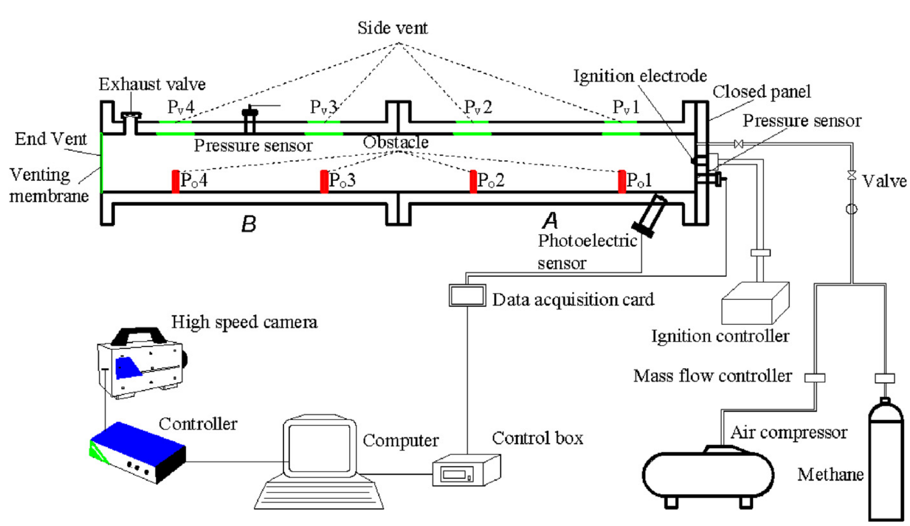

Fig. 1. Schematic of experimental system to conduct methane/air explosions in a duct containing an obstacle.