Journal of Loss Prevention in the Process Industries xxx (2017) 1–6

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Experimental study on the effect of bifurcations on the flame speed of premixed methane/air explosions in ducts

Chuan-jie Zhu [a, b, *], Zi-shan Gao [a], Xi-miao Lu [a], Bai-quan Lin [a], Chang Guo [a], Yu-min Sun [a]

[a] Faculty of Safety Engineering, China University of Mining and Technology, Xuzhou, Jiangsu, 221116, PR China
[b] State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing, 100081, PR China

ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form
20 May 2017
Accepted 21 May 2017
Available online xxx

Keywords:
Flame speed
Flame acceleration
Bifurcation
Gas explosion

ABSTRACT

Bifurcations in process industries can significantly affect gas explosions in pipelines, ducts or underground roadways. Previous studies have addressed gas explosion propagation in bifurcations with two right angles. Three different types of bifurcations with different angles and incorporated positions were adopted in our experiments. The flame speeds were found to decrease dramatically in the bifurcation sections. Meanwhile, the bifurcation led to a strong flow reversal and turbulence, which enhanced premixed methane-air explosions in the ducts and reached a higher maximum flame speed as a result. The flame speeds and maximum values in two branches are close in ducts with two symmetrical branches. However, the maximum flame speed in the acute branch of the bifurcated duct was the highest. Upon shortening the bifurcation position, the minimum flame speeds in different types of bifurcated ducts were close, and the flame speeds seemed higher in ducts with a closer bifurcation position at the same distance.

1. Introduction

Methane is globally recognized as a green, clean energy source and has been widely explored and utilized in the past few decades. Methane is mainly drained from a coalbed by underground or surface boreholes and then transported by pipes or ducts (Moore, 2012). In addition, it is widely used in the process industries involved with different sizes of confinement, vessels, or pipelines (Mittal, 2017; Zhang et al., 2017; Zuo et al., 2017). Because of the explosion risk of methane, which can lead to dramatic economic losses and casualties, the explosion propagation characteristics of premixed methane-air in pipes, ducts and other industrial processes have been widely studied (Bauwens et al., 2007; Ciccarell and Dorofeev, 2008; Jr. Zipf et al., 2014). Recent studies have focused on the effects of process constructions on flame acceleration or explosion overpressure. These constructions include obstacles, bends, and diameter changes, which can enhance gas explosions (Blanchard et al., 2010; Emami et al., 2013; Frolov et al., 2007; Xiao et al., 2014).

Among such constructions, the effect of bifurcations on gas explosions is complex and has been addressed in several studies. One group conducted a detailed numerical simulation using FLACS on a methane explosion that occurred within the Upper Big Branch mine (UBB, US) (Davis et al., 2014). The geometry model of tunnels adopted contains many bifurcations, such as crosscuts and "tee" geometries. The authors found that the horizontal velocities of the flame front often reached a maximum value as the flame passed a crosscut containing fuel; however, the "tee" geometry decreased the flame speed due to flow reversals and reflections. (Zhang et al., 2010) also observed these flow reversals and reflections in numerical simulations. (Sklavounos and Rigas, 2006) studied the effect of bifurcations (branches) on explosion relief using computational fluid dynamics code CFX 5.7.1 and found that the use of branch vents provided an effective method for shock wave attenuation. However, the explosion source was an equivalent of 100 kg of TNT that generated only a shock wave without a chemical reaction of heat transfer, which is different from explosions in a tunnel filled with gaseous fuel. (Zhang et al., 2013) compared methane explosions in a straight tunnel and in tunnels with different numbers of branches. In their experiments, the flow velocity declined near the first measurement point after the branch section; then, it increased with an increasing flame surface induced by the branch section. (Ye and Jia, 2014) also found that the flame speed increased sharply after propagation through the bifurcation.

The current studies mainly adopted bifurcations with 90-degree

* Corresponding author. Faculty of Safety Engineering, China University of Mining and Technology, Xuzhou, Jiangsu, 221116, PR China.
E-mail address: anq021@126.com (C.-j. Zhu).

http://dx.doi.org/10.1016/j.jlp.2017.05.016
0950-4230/

branches. Bifurcations incorporated in pipes, ducts, or roadways in process industries always have branches with different degrees, which may strongly affect the flame acceleration. In this study, we designed three different types of bifurcations to investigate the effect of the bifurcation type and position on premixed methane-air explosions in ducts.

2. Experimental apparatus

Experimental setup, which includes an experimental duct, an ignition system, a vacuum pump, a data acquisition system and a gas preparation system, is given in Fig. 1. Three bifurcations used in our experiments are shown in Fig. 2. Each bifurcation was incorporated into three duct sections by flanges. The cross-sections of both the ducts and bifurcations were 8 cm × 8 cm. The methane concentration was 10% by volume in all experiments and was first prepared in an air pocket. The duct was pumped to vacuum; then, the prepared explosive mixture flowed into the experimental duct under the pressure difference.

Premixed methane-air was ignited by an ignition system (XDH-20L) that can generate an electrical spark with an energy of 2J. The flame arrival time was recorded by flame transducers (CKG100) placed along the centerline of the duct and validated by a schlieren system. The average flame speed between the two transducers was determined and. These transducers were linked to a data acquisition system (TST 6300).

3. Results and discussion

3.1. Flame speed in bifurcated and straight ducts

The flame accelerations in straight and bifurcated ducts were compared in this study. The bifurcated duct, which has three sections (T, T1, and T2), all 6 m long, is shown in Fig. 3. The straight duct is 12 m long with the same cross-section. Additionally, flame transducers are arranged along the centerline of one surface of the duct. Fig. 4 gives the measured flame speeds in both the bifurcated and straight ducts. Because sections T1 and T2 are symmetrical, we only compared the flame speeds in sections T and T1.

The flame speeds shown Fig. 4 indicate that the flame evolutions in the straight and bifurcated ducts are quite similar before the bifurcation. The flame speeds in the straight duct increased until reaching the measured maximum value of 219.76 m/s at 9.28 m and then decreased slightly as a result of the open end. In the bifurcated duct, in contrast, the flame speed dropped dramatically in the bifurcation section. It was 110.56 m/s at 5.23 m immediately before the bifurcation and decreased to 15.31 m/s at 6.45 m after passing through the bifurcation. This finding is similar to the results obtained by (Davis et al., 2014). The authors stated that the "tee" geometry could induce a flow reversal, decreasing the flame speed. In our experiments, a flow reversal was also indirectly observed, as seen from the reflection wave shown in Fig. 4.

The flow reversal induced by the reflection wave can generate strong turbulence, which will enhance combustion in the flame tip (Zhu et al., 2016). Although the flame speed was significantly decreased by the bifurcation, it seemed to increase more quickly due to turbulence compared to the straight duct. When the flame arrived at 9.45 m in the bifurcated duct, the flame speed was 225.78 m/s, which was slightly higher than in the straight duct. Then, the flame continued accelerating and reached a maximum value of 299.89 m/s at the end of the duct.

3.2. Effect of bifurcation type on flame speed

In process industries or underground coal mining, the bifurcation type differs. Gas explosions are greatly affected by the gas flow behind the shock wave. Meanwhile, the gas flow is easily influenced by the geometries of the ducts, pipes or roadways. It is difficult to design all of the types of bifurcations in our experiments. Instead, we used three different types of bifurcations, as shown in Fig. 2, and compared their effects on gas explosions. The right-angle bifurcation duct and the corresponding layout of flame transducers are shown in Fig. 3. Another two bifurcated ducts are shown in Fig. 5, with bifurcations placed at 6 m and flame transducers arranged along the centerline of the ducts.

Figs. 6–8 give the flame speeds in different types of the bifurcated ducts. As shown, the flame evolutions are similar. The flame speeds all decreased in the bifurcation section. The flame speed at 6.45 m in the right-angle bifurcation duct was only 15.31 m/s, a reduction of 89.73%. The flame speed decreased by 59.13% in the obtuse bifurcation duct. In the acute-obtuse bifurcation duct, the flame speeds in the acute and obtuse branches were reduced by 87.07% and 83.73%, respectively.

In addition, the flame speeds in two branches are quite similar in ducts with two 90-degree branches and with obtuse branches, as shown in Figs. 6 and 7. The maximum flame speeds in T1 and T2 of the right-angle duct are 299.89 m/s and 294.38 m/s, respectively, and are 293.21 m/s and 296.25 m/s, respectively, in the obtuse duct. However, the flame speeds in the T2 section are higher than in the T1 section in the acute-obtuse bifurcation duct. The maximum flame speed in the T2 section is 315.95 m/s, which is higher than in the T1 section, where the value is 260.42 m/s.

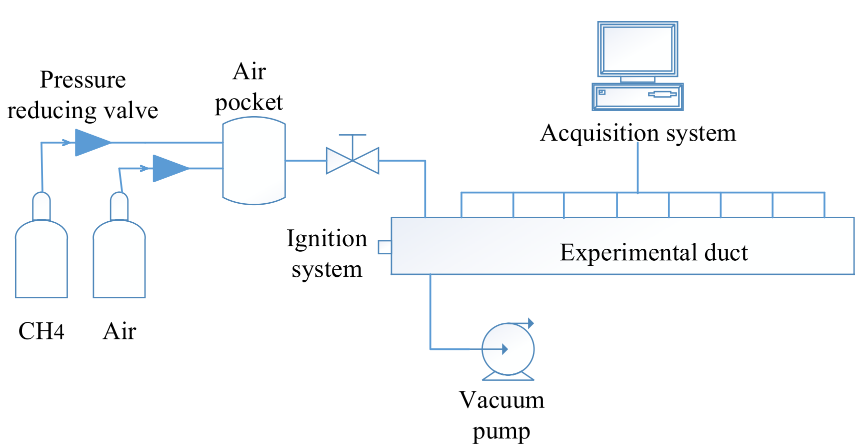

Fig. 1. Sketch of Experimental setup.

Please cite this article in press as: Zhu, C.-j., et al., Experimental study on the effect of bifurcations on the flame speed of premixed methane/air explosions in ducts, Journal of Loss Prevention in the Process Industries (2017), http://dx.doi.org/10.1016/j.jlp.2017.05.016