Experimental Thermal and Fluid Science 80 (2017) 270–280

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Effects of hydrogen addition on methane-air deflagration in obstructed chamber

Kai Zheng [a], Minggao Yu [a,b,*], Ligang Zheng [b], Xiaoping Wen [c], Tingxiang Chu [a,b], Liang Wang [a]

[a] State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400044, PR China
[b] School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo 454003, PR China
[c] School of Mechanical and Power Engineering, Henan Polytechnic University, Jiaozuo 454003, PR China

ARTICLE INFO

Article history:
Received 1 March 2016
Received in revised form 5 August 2016
Accepted 27 August 2016
Available online 29 August 2016

Keywords:
Hydrogen/methane
Premixed flame
Deflagration
Obstacles

ABSTRACT

In this paper, we report the result of an experimental study of the effects of hydrogen addition on methane-air deflagration in an obstructed chamber. For these experiments, a vented combustion chamber was constructed, and up to three obstacles were tested by arranging them with spacing of 100 mm from the ignition end. Tests were performed for five hydrogen fraction (0%, 25%, 50%, 75% and 100%) at equivalence ratios of 0.8, 1.0 and 1.2, respectively. In our experiment, the key parameters that reflect the propagation characteristics of the premixed flame, e.g., the flame structure, flame speed and overpressure were obtained. The results demonstrate that there are similar trends in the flame evolution structure obtained from both equivalence ratios and hydrogen fractions of the same configuration. The addition of hydrogen can increase the flame front speed and speed up the arrival of the flame to the vent. In most hydrogen fractions, the flame speed exhibits a similar trend for the same configuration except for hydrogen fractions of 75% and 100%. Additionally, we observed a significant increase in the overpressure in the presence of the hydrogen fraction. For the configuration that had fewer obstacles, the maximum overpressure also has a similar trend to that of the laminar flame speed.

1. Introduction

Understanding the nature and the physical mechanisms of flame acceleration in ducts has important applications in industrial safety. In most gas explosions, flame acceleration occurs via deflagration which usually starts by a weak ignition in a combustible mixture. Under certain conditions, a slow deflagration flame can accelerate and transition to detonation unusually referred to as a DDT (Deflagration to Detonation Transition) [1]. When the flame starts to propagate away from its ignition source, weak turbulence, which is unable to affect the flame propagation, starts to develop [2]. In the absence of obstacles, the flame can spontaneously accelerate and exhibit different behavior, therefore forming the so-called “tulip” flame proposed by Clanet and Searby [3]. However, the flame acceleration can be increased even when it interacts with obstacles. It is widely accepted in the scientific community that the flame-obstacle interactions can distort the flame, making it turbulent and increasing the combustion rate of the reaction, thus, resulting in much faster flame acceleration and an even easier transition to detonation [4–6].

Recently, a substantial number of the experimental studies have been conducted to understand the nature of the effects of obstacles on premixed flame propagation in explosion ducts [7–15]. Some of the earlier works mainly focused on large-scale applications, i.e., industrial scale experimental studies, from which the parameters that were key for understanding and predicting the process of flame acceleration could be obtained. However, those experiments were extremely costly and mostly unpractical because it was difficult to complete the detailed measurements. Recently, with the development of testing techniques, numerous experiments have been conducted based on small-scale platforms. For example, studies of studies of Ibrahim, Marsi and Hall et al. [8,9] have focused on the flame/solid interactions as well as the position and frequency of obstacles on premixed flame propagation. Experimental investigation performed by Park et al. [10] examined the effects of flame interactions with different multiple obstacles within ducts with different L/D ratios. Wen et al. studied the effects of cross-wise obstacle position on flame propagation characteristics [11]. Note

---

* Corresponding author at: State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400044, PR China.

E-mail address: mg_yu@126.com (M. Yu).

http://dx.doi.org/10.1016/j.expthermflusci.2016.08.025
0894-1777/

that these experiments were often available for optical access to the flame structure evolution and thus, allowed for detailed measurements and an understanding of the complex mechanism of flame-obstacle interaction and verification of the validity of numerical calculation.

Meanwhile, because of the enhancement of computational power, the modelling of premixed flame acceleration, particularly in large eddy simulation (LES), has advanced significantly in recent years, and therefore, numerical simulations of flame propagation in obstructed ducts has become an effective tool to understand the mechanisms responsible for flame acceleration [2,4,5,16–22]. In LES, various sub-grid scale (SGS) combustion models based on the flame surface density (FSD) approach have been used to simulate the propagation and acceleration of premixed flame in obstructed chambers [16–19]. Moreover, Di Sarli and Wen et al. have performed assessments of these models [2,20]. Both studies have demonstrated the simulation results from the SGS models that qualitatively matched the premixed flame propagation with that obtained with the experiments.

However, almost all provided sources deal exclusively with the flame propagation of a single fuel, e.g., methane, hydrogen or propane, and the premixed flame of multicomponent fuel mixtures is seldom considered. From the point of industrial application, the multicomponent fuel is most widely used, it is more dangerous and has more serious disaster effects compared with the single fuel. Furthermore, recently with growing global energy needs and the threat of climate change, hydrogen, as a new powerful and clean fuel source, is getting the people's attention. But the large-scale industrialization use of hydrogen remains far off due to the significant obstacles for hydrogen energy extraction, storage and transportation and application [23]. As one effective measure to solve those problems, the addition of hydrogen in methane has attracted great interest from researchers. It has been suggested that the addition of hydrogen might lead to lower ignition energy, higher laminar flame speed, wider flammability limits, higher reactivity and burning temperature [24–28]. Obviously, these properties raise fear of explosion because of significant safety issues associated with the hydrogen/methane mixture utilization. Therefore, the explosion behavior of the hydrogen/methane mixtures has been investigated both experimentally and numerically [29–32]. Note that these investigations have mainly focused on the maximum pressure, the maximum rate of pressure increase and the flame propagation speed, the most important explosion parameters for adequate hazard assessment. However, these studies rarely addressed the process of the premixed flame propagation. The premixed flame propagation of the hydrogen/methane mixtures has been experimentally studied by Yu and Zheng et al. [33,34]. These articles contain a thorough investigation of the effects of hydrogen fraction, the equivalence ratio and the scale of the duct on premixed flame propagation of hydrogen/methane mixtures in smooth ducts. Unfortunately, there are still no studies of data from premixed flame propagation in obstructed ducts.

In this study, we conduct an experimental study of the premixed flame propagation in obstructed chambers with various configurations. The objective of this investigation is to extend our previous work [33,34] and add the experimental study of influence of obstacles placed inside the chamber on the premixed flame propagation of hydrogen/methane mixtures deflagration. In our experiment, we focus on the acquisition of the key parameters that reflect the propagation characteristics of the premixed flame, e.g., the flame structure, flame speed and overpressure. The experimental results can help us understand the effect of obstacles on the premixed flame propagation and have important implications for validating the numerical simulation results of hydrogen/methane mixture deflagration in the future.

2. Experimental methods

The experimental setup we used in this study is similar to that used in our previous study [11,33,34], as shown in Fig. 1, it was composed of a combustion chamber, an ignition device, a data acquisition system, a gas distribution device, etc. The combustion chamber was placed vertically and had dimensions of 100 × 100 × 500 mm, resulting in an aspect ratio of 5. Compared to our previous papers, the combustion chamber used in this experiment is much smaller to reduce the computational time for the subsequent numerical studies in the future. The combustion chamber was made from 20 mm thick perspex to allow optical access for high-speed flame visualization. The ignition device was primarily composed of a spark ignition source that was mounted in the center at the bottom of the chamber, which was closed by a 10 mm thick stainless steel plate. The ignition energy of the spark ignition source is 0.2J. The top of the chamber was completely open and covered with a thin PVC membrane with thickness of 0.1 mm, which was used to retain the hydrogen/methane mixtures in the chamber and resulted in an open boundary in the upper end of the chamber. In this study, the bottom and top of the chamber are referred to as the ignition and "venting" ends, respectively. In the chamber, up to three obstacles (100 mm × 50 mm × 10 mm) with 50% blockage ratio, which is defined as the surface area of the obstacle in the chamber over the cross section area of the chamber, could be placed with 100 mm spacing from the ignition end. For a flame propagating in an obstructed chamber, as a typical value that has been adopted in many previous studies [11–13,16,20], the 50% blockage ratio is sufficient large to support the recirculation zone exists between adjacent obstacles. Various configurations, i.e., configuration 1, 2, 3 and 4, which result from a progressive increase in the number of obstacles is shown in Fig. 2.

The data acquisition system was mainly composed of a piezoresistive pressure transducer, a photodiode transducer and a high-speed video camera. The pressure transducer with a measurement range of −1.0 to 1.0 bar, which was used to monitor the overpressure history, was located 20 mm from the center of the steel plate mounted on the ignition end. The photodiode transducer was

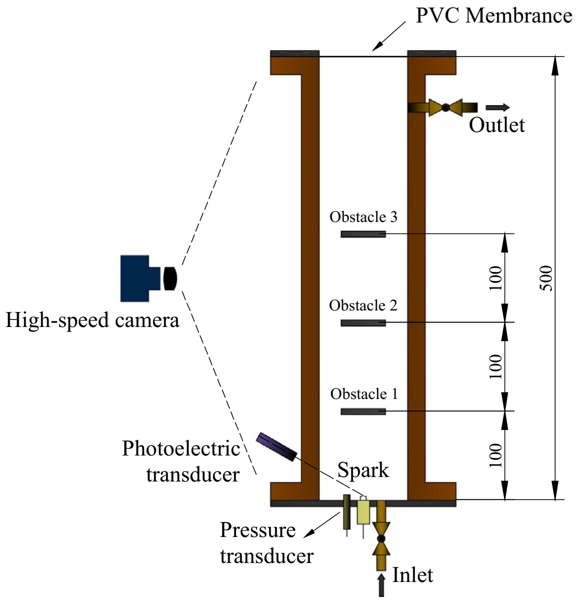

Fig. 1. Schematic diagram of the experiment setup.