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Experimental studies on interactions between a freely propagating flame and single obstacles in a rectangular confinement

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Abstract

Experimental investigations were performed to assess the effects of different shaped obstructions on flame propagation in a rectangular confinement, 235 mm in height, with a 1000 × 950 mm cross section and a large top-venting area of 1000 × 320 mm. Four different single obstacles were used: rectangular, cylindrical, triangular, and square cross-sections with blockage ratios of 5 and 10%. Temporally resolved flame front images were recorded by a high-speed video camera to investigate the interaction between a propagating flame and the obstacle. The local flame displacement speeds and their probability density functions (pdfs) were obtained for the different obstacles. Before the freely propagating flame impinges on the obstacle, the flame propagation speed remains close to the laminar burning velocity, regardless of the obstacles used. As the propagating flame impinges on the obstacle, the local propagation speed increases due to the expansion of the burnt gas and the blockage of the obstacle. This local speed increase becomes larger in going from a circular to a triangular and to a square obstacle. The averaged flame displacement speeds were not significantly different with different blockage ratios for the same obstacle investigated in this work, nor were they significantly different for different shapes at the same blockage ratio investigated in this work. However, the fastest increase in the averaged flame speed with time was observed for the rectangular plate. In order to explain why the results obtained from this work were different from those published in the literature for large L/D, a discussion of both the flame speed and pressure was given.

Keywords: Obstacles; Flame displacement speed; Explosion pressure

1. Introduction

Over the past decade, the majority of both large- and small-scale experiments to investigate the interaction between the propagating flame and obstacles of

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various geometries have been performed with a large length-to-diameter ratio (L/D), such as in vessels and cylindrical tubes, where L was the length of the cylinder along the direction of a propagating flame, and D was the diameter of the cylinder. With experiments in cuboid compartments, L was the height of the chamber along the direction of flame propagation, and D was the width of the chamber.

The large-scale experiments with L/D of approximately 4 by Moen et al. [1,2] and Hjertager et al. [3] revealed that the existence of obstacles had a profound effect on flame propagation due to the generation of turbulence. The flame propagation speed was found to depend on the size of obstacles and the fuel/air mixtures. The experiments of Urtiew et al. [4] were conducted in partially confined geometries with L/D of 6. The influence of a single obstacle such as an orifice, circular plate, or wire gird on flame propagation were investigated in cylindrical tubes with an L/D between 3 to 5 by Starke and Roth [5]. These experiments indicated that obstacles increase the speed of flame propagation and the effects of an obstacle depend on its position in the rig. The effects of a single baffle on flame speeds and rates of pressure rise with varying blockage ratio (20–80%) were studied in long tubes with L/D as large as 21.6 by Phylaktou and Andrews [6]. The studies of explosion overpressures and imaged flame front location were made by Pritchard et al. [7] in a vessel where baffle plates were placed at various distances along the wall of the enclosure with L/D ratios of 4. These studies have shown that the flame speed and the rate of pressure rise were enhanced downstream of the baffle, and the relative effect of the baffle increased with an increasing blockage ratio. The experimental studies of Alexiou et al. [8] performed in a cylindrical vessel with an L/D of 15.4 studied the effect of side-venting position on the overpressure development for 10% methane in air explosions. It showed that higher flame speeds and overpressures occurred as the distance from the vent position to the spark was increased, because more unburnt gas was present for combustion between the ignition source and the vent. The experiments of Dobashi [9] looked at the effects of gas flow turbulence and flame front instability on gas explosion behavior in small-scale explosion vessels (80 × 80 × 80 mm, 80 × 80 × 440 mm). These showed that the gas flow turbulence increases the flame propagation velocity and the rate of rise of pressure. It was also shown that flame front instability generated by the interaction between the flame and a pressure wave causes rapid flame acceleration. Studies by Fairweather et al. [10] in a cylindrical tube with an L/D of 2–3 where obstruction rings were placed at various axial locations on the wall of the cylinder have shown that significant overpressures were generated in the later stages of explosions. This is because of rapid turbulent combustion in the shear layers and recirculation zones induced by the obstacles. In recent years the effects of obstacle types on flame propagation and explosion pressure were examined in a vertical vessel with an L/D of 2.8 by Masri et al. [11], Ibrahim and Masri [12], and Ibrahim et al. [13]. Their results showed that both the flame and pressure developments were sensitive to both the obstacle types and the blockage ratios. This is due to different turbulence levels generated by vortex shedding and local wake/recirculation.

As mentioned above, most investigators have studied the interaction of the flame propagation and obstacles in L/D ratios greater than 2. Their results revealed that the existence of obstacles in the way of the propagating flame front generates turbulence in the unburnt mixture in front of the propagating flame, and the flame/turbulence interaction greatly enhances the speed of flame propagation and hence increase the rate of pressure rise.

However, in practical enclosures with small L/D ratios and a large rectangular venting area, the flame-front characteristics around different obstacle obstructions have not been extensively studied. The interaction between the flame and various obstacles is quite likely to be different from that in enclosures with large L/D ratios. The present work was aimed at providing experimental data necessary for the development of a physical submodel of combustion for CFD (computational fluid dynamics) and at investigating the underlying mechanisms of the interactions between the propagating flame and the obstacle in these types of enclosures. The flame displacement speeds and their probability density functions (pdfs), the explosion pressures, and a discussion of both the flame velocity and pressure through different obstacles are reported for a rectangular enclosure with small L/D ratios and a large vent area.

2. Experimental

Fig. 1 shows a schematic diagram of the experimental set-up. The explosion chamber is 235 mm in height and 1000 × 950 mm in cross section and has a large top-venting area, A_v, of 1000 × 320 mm, giving a total volume V of 223 L of explosive mixture. This results in a value of 0.87 for $A_\mathrm{v}/V^{2/3}$ and an L/D value of 0.25. The chamber was made of 20-mm-thick transparent chemiglass restrained by bolted flanges and strong adhesives. The flammable gas (99.95% CH_4 by volume) and air entered the calibrated gas flow control system (TEI, Model GFC 521) and was mixed by recirculation inside the system. The mixture volume flow rates were monitored by the sys-