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ORIGINAL ARTICLE

A technique for promoting detonation transmission from a confined tube into larger area for pulse detonation engine applications

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Abstract A simple method of detonation transmission from a small tube to a large area is presented. This technique involves placing obstacles which create slight blockages at the exit of the confined tube before the planar detonation emerges into the larger space, thereby generating flow instability to promote the detonation transmission. In this experimental study two mixtures of undiluted stoichiometric acetylene-oxygen and acetylene-nitrous oxide are examined. These mixtures can be characterized by a cellular detonation front that is irregular and representative of those potentially used in practical aerospace applications. The blockage ratio imposed by the obstacles is varied systematically to identify the optimal condition under which a significant reduction in critical pressure for transmission can be obtained. A new perturbation configuration for practical use in propulsion and power systems is also introduced and results are in good agreement with those obtained using thin needles as the blockage ratio is kept constant.

1. Introduction

Recent focus on the development of detonation-based propulsion systems for high propulsive efficiency such as pulse detonation engines (PDE) [1–6], has led to a renewed interest in the problem of detonation diffraction, i.e., detonation waves propagating from tubes of one size or geometry into another variable cross-section [7–9], especially for the design of tube initiator geometries, e.g., when a detonation

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transmits from the small pre-detonator to the main thrust tube of the pulse detonation engine [10]. For the successful and steady operation of the PDE, repetitive initiation of detonation waves is required. The pre-detonator tube diameter should be made above a critical value known as the critical tube diameter [11], to ensure successful initiation in the larger detonation or thrust chamber tube and avoid detonation failure during diffraction. The objective of this work is to investigate the effect of hydrodynamic disturbance generated by small blockages on the detonation diffraction problem and propose a new practical design of the injector connecting the small tube section to a larger area, as it can have a beneficial effect for enhancing successful transmission of the detonation from different areas for PDE applications to aerospace propulsion and power systems.

Although no complete predictive theory has yet been developed, the criterion for successful transmission of a self-sustained detonation from a confined tube to an open area is often understood from the description of the failure mechanisms during detonation diffraction. Common hydrocarbon mixtures in which detonations are unstable with highly irregular cellular structures, successful transmission is often found to originate from a localized region in the failure wave, which is eventually amplified to sustain the detonation propagation front in the open area. Hence, failure is invariably linked to the suppression of instabilities at which localized explosion centers are unable to form in the failure wave when it has penetrated the charge axis [12,13].

The importance of instability for detonation transmission was demonstrated recently by a simple experiment performed by Mehrjoo et al. [14]. This study investigates the effect of finite perturbation generated by placing a small gauge needle that serves as an obstacle with a small blockage ratio ($BR = 0.08$ defined as the cross-sectional area of the needle divided by the inside cross-sectional area of the confined tube) at the tube exit diameter just before the detonation diffraction, and observing the phenomenon's response. For special mixtures such as highly diluted argon mixtures which are stable with regular cellular patterns, the results using this small needle perturbation seem to exhibit little variation in detonation pressure for both perturbed and unperturbed cases. This can be attributed to the minimal effect of the perturbations on global curvature for the emergent detonation wave. However, results show that the small perturbation can have a significant effect in undiluted hydrocarbon mixtures resulting in the decrease of the critical pressure for successful detonation transmission. In other words, the disturbance caused by the small obstacle promotes transmission and this result supports that local hydrodynamic instabilities are significant for detonation diffraction in typical undiluted unstable mixtures considered for detonation-based propulsion systems. Using different needle arrangements at the exit of the confined tube, this study [14] also demonstrates that the perturbation effect is independent of the blockage geometry, and suggests that it is only a function of its imposed blockage area. In other words, as the blockage ratio is kept constant, regardless of its configuration, the resulting perturbations show an almost identical behaviour for wave transmission in irregular mixtures whilst not affecting regular ones.

In the present study, the effect of disturbance on the critical tube diameter problem in undiluted stoichiometric acetylene-oxygen and acetylene-nitrous oxide mixtures are investigated. The originality of this work is to systematically observe the effect of different blockage ratios with BR varied from 0.05–0.25. It is worth noting that the tested mixtures have a detonation instability nature representative to those potentially used in experimental PDE such as hydrogen or ethylene-based mixtures. Intuitively, it is anticipated that large BR will have an adverse effect due to excess momentum losses caused by the blockage and reduction of the “effective” tube diameter. Therefore, this work attempts to determine the optimal value of which detonation transmission is favourably promoted. Another novelty of this work is to introduce a different practical perturbation arrangement designed in an attempt to further promote the detonation transmission for PDE application in aerospace propulsion and power generation.

2. Experimental setup

The experiments were carried out in a modified high-pressure spherical explosion chamber of 20.3 cm in diameter and 5.1 cm in wall thickness. The chamber's body is connected at the top to a 41.8 cm long vertical circular steel tube, of two different test diameters $D = 12.7$ mm and $D = 9.13$ mm. Figure 1 shows the schematic of the experimental setup.

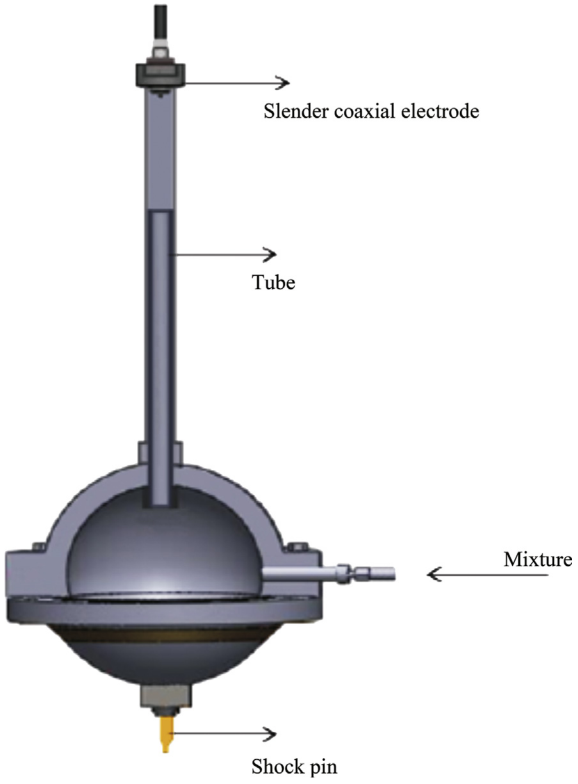

Figure 1 Schematic of the experimental setup.