Experimental investigation of detonation limits in smooth and rough-walled tubes using various gaseous mixtures

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1 Introduction

It is of great significance to study the limits of detonation propagation in different sensitive gases for explosion prevention and explosion suppression. Near-limit detonation behavior has been investigated especially in recent years, e.g., [1-8], but these studies are mostly concerned with the near-limit detonation velocity in smooth tubes or thin channels. Recently, Lee proposed the characterization of detonation limits by using rough-walled tubes [9-10]. In this work, the near-limit detonation propagation in rough-walled tubes is investigated focusing on the reaction sensitivity effect of different premixed gases. The sensitivity is defined here as how easy the mixture can be reacted through combustion.

2 Experimental details

A schematic diagram of the experimental setup is shown in Fig. 1. The apparatus consists of 3 brass tubes, each 1.5 meters long. Both driver and test sections have an inner diameter of D = 38.1 mm. In the driver tube, a Shchelkin spiral was placed near the ignitor to promote the detonation formation. The optical fiber was connected to a photodiode and installed to measure the time-of-arrival, which was used to infer the wave speed [11]. The probe spacing in the polycarbonate tube and large-diameter brass tube was 10 cm and 25.4 cm, respectively. In order to introduce the wall roughness of various degrees, different wire diameter spirals were inserted into the test tube. The wire diameters of the spirals were 1.5, 3.0, 5.0 and 6.5 mm, hence, the roughness of d/D were 0.04, 0.08, 0.13 and 0.17, respectively. In all cases, the pitch ratio $\varphi = d/p$ is kept at about 0.5 to provide a meaningful comparison between results obtained from each rough-walled tube, therefore, the pitch was 3, 7, 10, 13 mm, respectively [11].

Stoichiometric $C_2H_2 + 2.5O_2$, $2H_2 + O_2$, $H_2 + N_2O$, $C_3H_8 + 5O_2$, $C_2H_2 + 2.5O_2$ + 70%Ar and $CH_4 + 2O_2$ mixtures were used in the experiments. Before the test, these mixtures were prepared by the partial pressure method. Under the low initial pressure, the more sensitive equimolar $C_2H_2 + O_2$ was used to promote detonation initiation in the driver section [11]. The theoretical Chapman-Jouguet (CJ) detonation velocity under different initial conditions was calculated by using the NASA-CEA program.

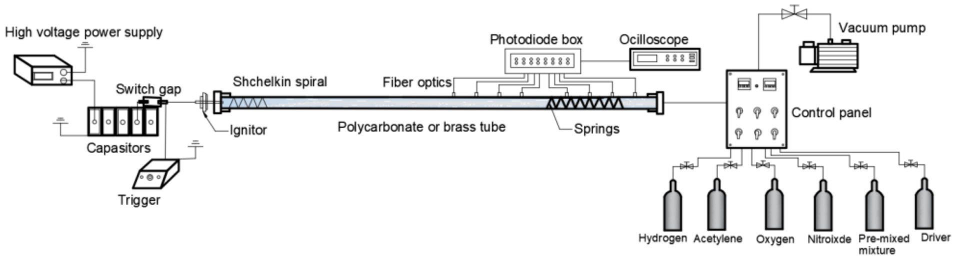
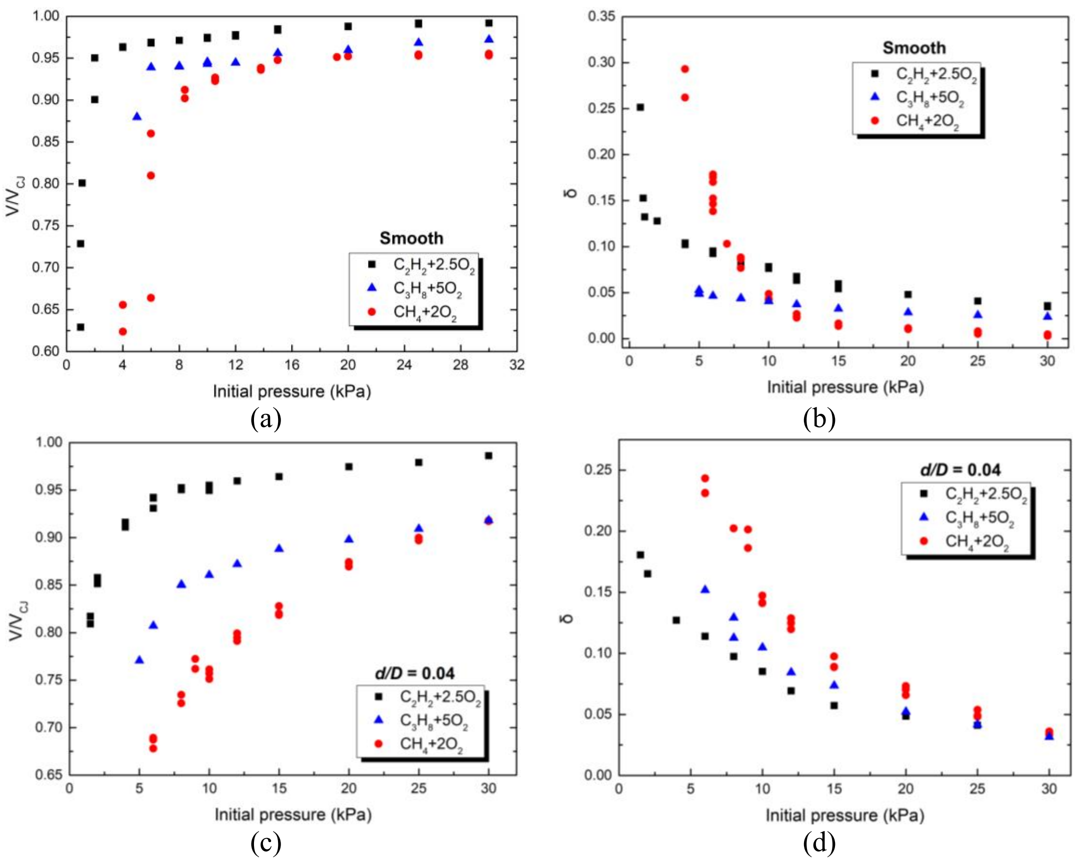
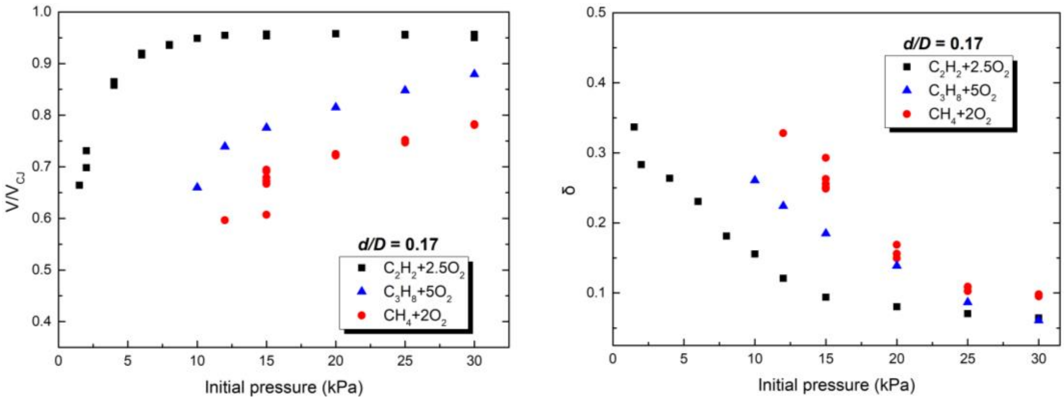


Fig. 1 Sketch of the apparatus [11]

3 Results and discussion

Results obtained using premixed gases with different sensitivities are compared and their influences on detonation limits are assessed. The results of velocity deficits (V/V_{CJ}) and velocity fluctuation ($\delta = |V_l - V_m|/V_m$ where V_l is the local detonation velocity and V_m is the average velocity over the length of propagation of the detonation along the tube) as a function of initial pressure and different wall roughness, obtained using the highly sensitive gas $C_2H_2 + 2.5O_2$, the medium sensitive gas $C_3H_8 + 5O_2$, and low sensitive gas $C_2H_2 + 2.5O_2 + 70\%Ar$ are presented in Figs. 2 (a) - (f).

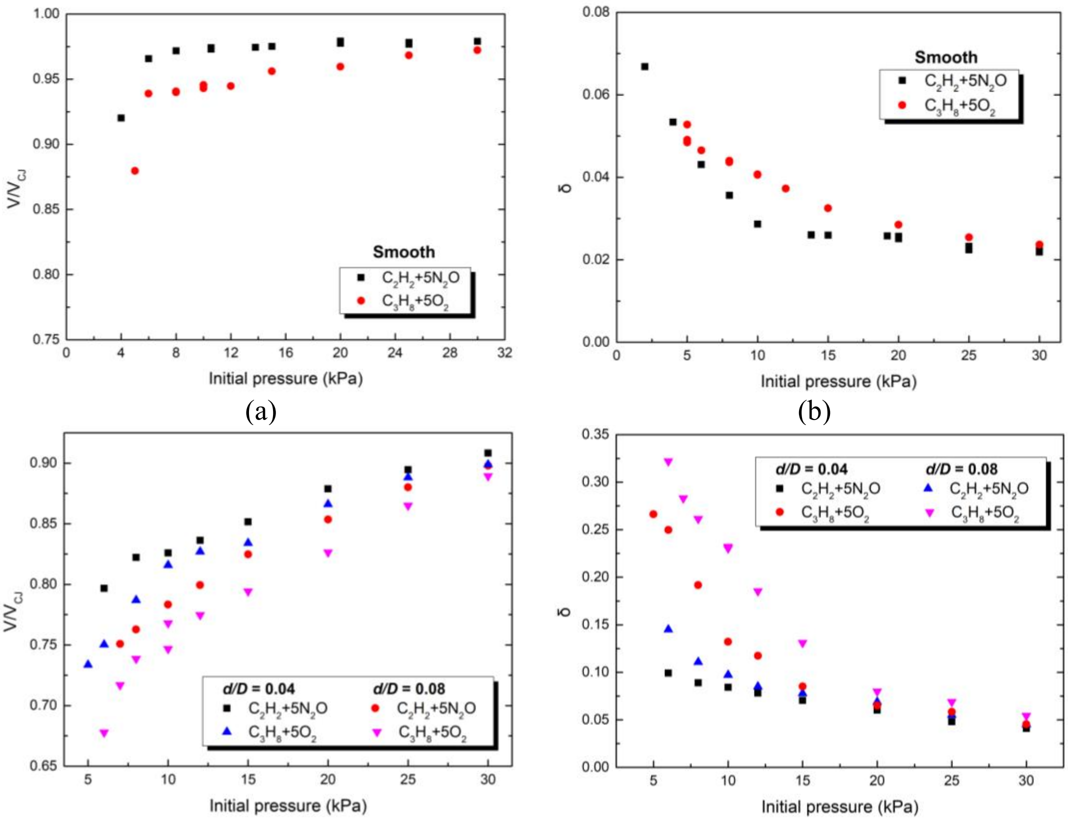




(e) (f)

Fig. 2 Velocity deficits and fluctuation as a function of initial pressure and different wall roughness for different premixed combustible mixtures

In smooth tubes, within the limits, the detonation velocity of premixed gas C_2H_2 + $2.5O_2$ is slightly higher than that of C_3H_8 + $5O_2$, while the detonation velocity of C_3H_8 + $5O_2$ is slightly higher than that of CH_4 + $2O_2$. C_2H_2 + $2.5O_2$ fails when the initial pressure is lower than 0.8 kPa, and it is relatively stable until the limit approaches. For less sensitive mixtures, CH_4 + $2O_2$ and C_3H_8 + $5O_2$ fail at a higher initial pressure of about 4 kPa. Similar trends are also observed in rough tubes. In rough tubes, the velocity fluctuation is much more pronounced, indicating the effect of roughness influences more the detonation propagation and limits for less sensitive mixtures.



(a) (b) (c) (d)

Fig. 3 Detonation velocity deficit and fluctuation for C_2H_2 + $5N_2O$ and C_3H_8 + $5O_2$ mixtures

Figure 3 compares the results obtained using different oxidizers, i.e., $C_2H_2 + 5N_2O$ and $C_3H_8 + 5O_2$. The velocity deficit of $C_2H_2 + 5N_2O$ is slightly smaller than that of $C_3H_8 + 5O_2$, and the velocity fluctuation is smaller than that of $C_3H_8 + 5O_2$, when initial pressure is higher or far from the limits. With the increase of the roughness *d/D*, the velocity fluctuation of detonation propagation appears to be larger for $C_3H_8 + 5O_2$, which is less sensitive to reaction.

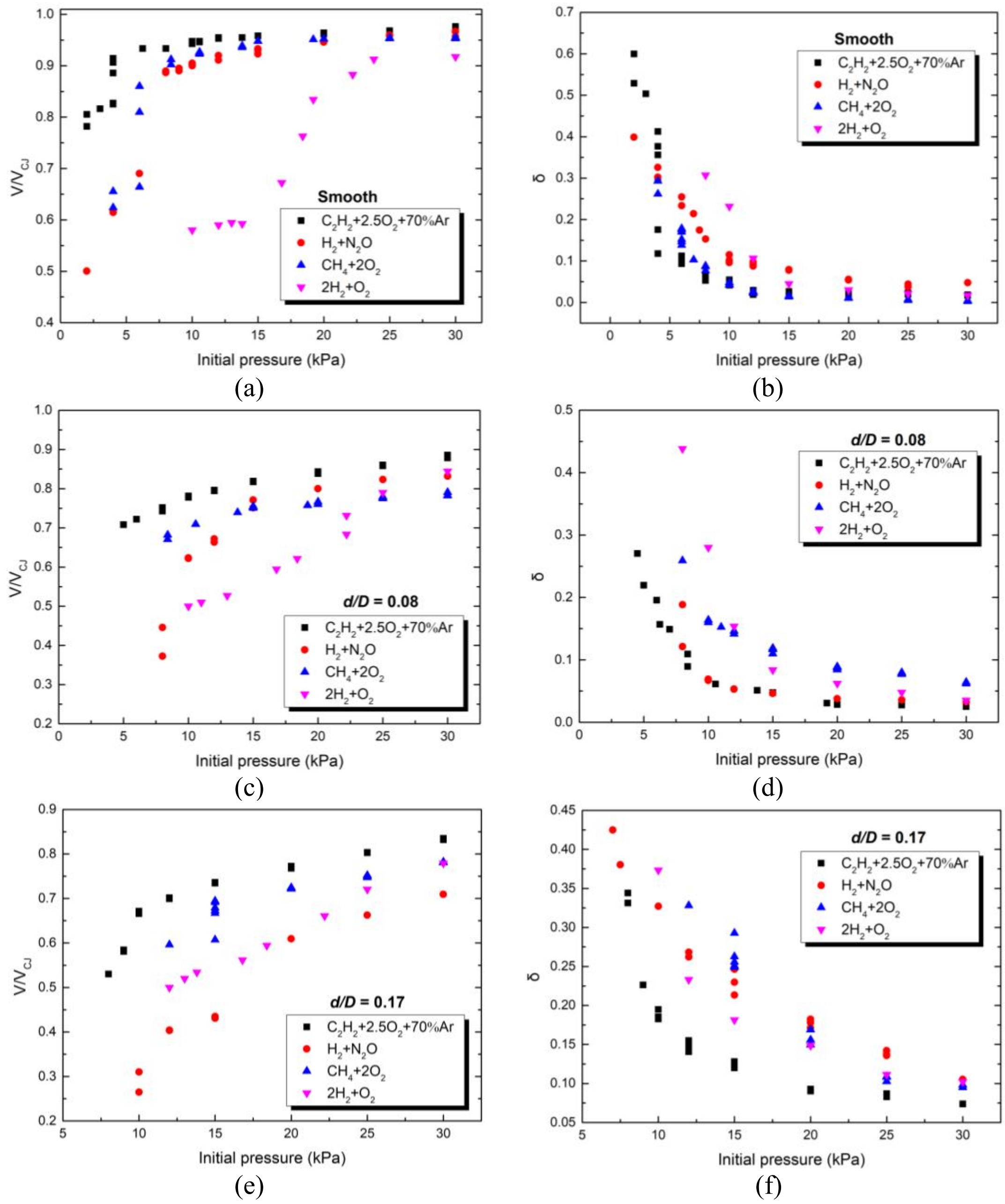


Fig. 4 Effect of low-sensitivity gases on detonation velocity and fluctuation

Finally, results for $C_2H_2 + 2.5O_2 + 70\%Ar$, $CH_4 + 2O_2$, $H_2 + N_2O$ and $2H_2 + O_2$ are given in Fig. 4. These mixtures cover a wide range of reaction sensitivity. For the argon-diluted $C_2H_2 + 2.5O_2$ mixture, the propagation is relatively stable with the limits. Its limit however occurs at a relatively smaller velocity deficit value. For CH_4 + $2O_2$ and H_2 + N_2O, they tend to support the detonation propagation with larger velocity deficits but are accompanied by increasingly larger velocity fluctuation when the limits are approached. Under the influence of the roughness, the velocity deficits while the detonation maintains its propagation increases while the fluctuations obviously are more significant even away from the limits due to the boundary effects.

There appear some peculiarities in the results in H_2 mixtures. Although H_2 mixtures have a high reaction sensitivity, the detonation dynamics is relatively stable (with regular cellular patterns) as compared to CH_4 + $2O_2$ or other hydrocarbon mixtures at low initial pressures. The sustenance of low-velocity detonations, i.e., with large velocity deficits as well as large velocity fluctuations observed for H_2 mixtures near the limits are rather unexpected. It thus suggests that there is a competing effect between the inherent detonation instability within the detonation structure and the chemical reaction sensitivity of the H_2 mixtures.

4 Concluding remarks

This study aims to classify the detonability or limits of various mixtures from the velocity deficit and fluctuation diagrams and correlate these with their reaction sensitivity. The mixtures cover a wide range of reaction sensitivity from C_2H_2 + $2.5O_2$ premixed gas with high reaction sensitivity to C_2H_2 + $2.5O_2$ + 70%Ar with low reaction sensitivity. The results for typical hydrocarbon-O_2 or N_2O mixtures appear to follow what is commonly observed for detonation limits, i.e., quasi-detonation propagation with larger velocity deficits accompanied with larger velocity fluctuations, which correlates well with both the reaction sensitivity and inherent detonation instabilities of these mixtures. Yet, the H_2 mixtures appear to be peculiar from the present study and the possible competition between the reaction sensitivity and the inherent detonation instabilities have to be investigated further in detail.

Acknowledgment

This work is supported by the Civil Aviation Pre-research Project (No.D020304).

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