DDT in Hydrogen-Oxygen Mixtures in Smooth Tubes

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Introduction

Many practical applications involve handling of extremely sensitive gaseous combustibles in volumes or tubes with characteristic sizes, which exceed considerably typical chemical length scales of the mixture, such as detonation cell size. If these mixtures are ignited the combustion process should easily end up with the transition from deflagration to detonation (DDT). In these cases an important problem to be solved is where can the onset of detonation occur, rather than can it be expected or not. This problem is related to creation of conditions that are necessary for the onset of detonation during flame propagation.

It has been shown by many investigators that a flame should reach high, generally supersonic speed, to create conditions necessary for the onset of detonations. The process of flame acceleration is affected significantly by obstructions along the flame passage. In many situations with dense obstructions, the growth of the flame surface can be the leading factor affecting the rate of flame acceleration. Different physical mechanisms are expected to play their roles in smooth tubes or channels. Thus processes of flame acceleration and DDT in smooth tubes filed with highly sensitive mixtures differ significantly from DDT in obstructed tubes at nearly critical conditions. Present study addresses the situation with highly sensitive mixture and smooth tubes. The objective of this work was investigation of DDT process for stoichiometric hydrogen-oxygen mixture. Run-up distances for the onset of detonations were studied in the series of tests as a function of initial pressure.

Experimental

Experiments were performed in a smooth detonation tube of 105-mm id and 24-m length. Relatively large length of the tube provided conditions when end-wall reflections and global pre-compression cannot influence DDT processes. Stoichiometric H_2-O_2 mixture at initial pressures from 0.2 to 8 atm was used in the tests. Detonation cell sizes of these mixtures vary from 8.5 mm (0.2 atm) to 0.17 mm (8 atm) [1, 2]. This means that

DDT can easily occur in 105-mm tube.

A glow plug was used for ignition to avoid possible direct initiation of detonations by a spark plug. Piezoelectric and piezoresistive pressure transducers and collimated photodiodes were used to record pressure and light signals. One of the photodiodes was installed in the tube axially to record light signal from combustion continuously. With this gage it was possible to define the time of the onset of detonation by specific inflection of the signal curve.

Summary of Results

It was found that the onset of detonation was well defined in the tests. Visible flame velocities had well pronounced jump at a certain distance from the ignition point. It was found that flame velocities (respective to fixed observer) reached values from about 800 m/s to 1000 m/s just before the transition to detonation for all the pressures used in the tests. At the transition location, the detonation speed was considerably overdriven (up to 4000 m/s) dropping then to the Chapman-Jouguet (CJ) values, which were from 2760 to 2960 m/s depending on the initial pressure. Detonation speeds and overpressures approached CJ values in about 1 m from the transition location. Retonation waves were observed in most of the tests.

The distance from ignition point to the transition location r_D was found to decrease with initial pressure (see Fig. 1). The dependence of this run-up-distance on initial pressure was found to be close to inverse proportionality: $r_D \sim p^{-1.17}$. This is a stronger function on initial pressure than it was found for hydrocarbons [3-5], where the negative pressure exponent ranged from 0.4 to 0.8. For the highest initial pressures the run-up distances were as small as one tube diameter.

The laminar burning velocities [6] of the mixtures tested vary from 7 to 12 m/s with increase of initial pressure. The ratio of densities between reactants and products is almost the same for all the mixtures, from 8 to 9. This means that initial flame speed was basically independent of the pressure. The flame speed just before the onset of detonation was found to be similar for all the pressures tested (from 800 to 1000 m/s). In this situation, the difference in the run-up distances should be related to ability of a flame to accelerate from initial speed of about 90 m/s to the speed of about 900 m/s, which was probably the critical one to create conditions for the onset of detonations.

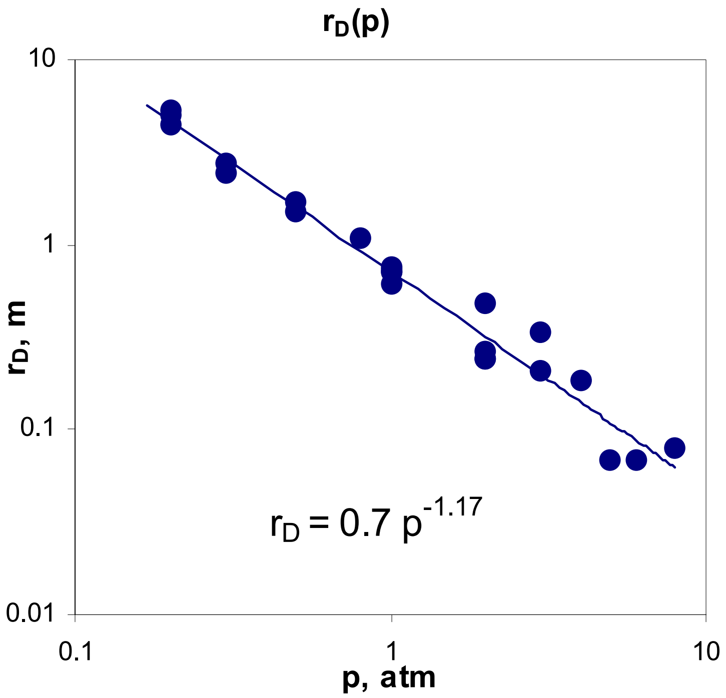

Figure 1. Run-up distance to DDT versus initial pressure

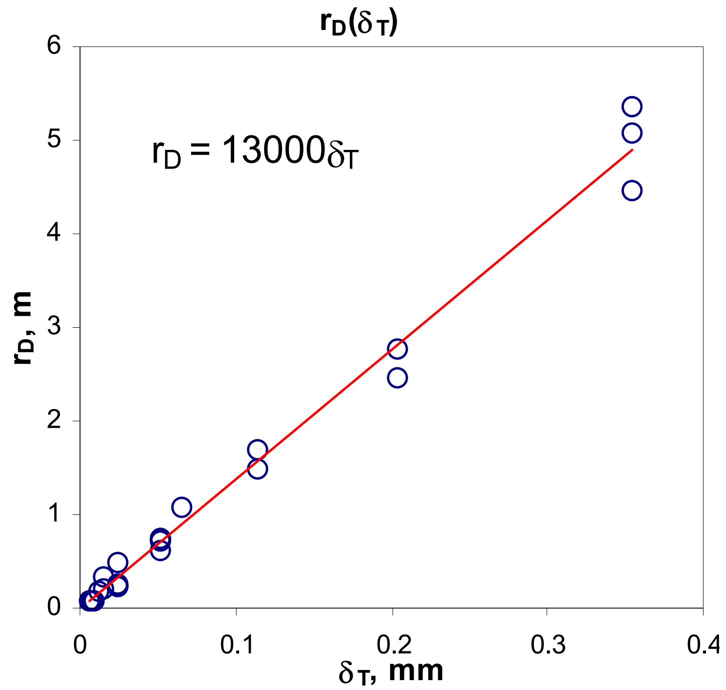

Figure 2. Run-up distance to DDT versus laminar flame thickness

Generally, flame acceleration from weak ignition should be influenced by the ratio of integral length scale of turbulence L to laminar flame thickness δ: L/δ_T. Moreover, for the present set of initial conditions, all other parameters, which can play a role, appear to be of similar for the mixture tested. This makes the scale ratio, L/δ_T, the only parameter, which can be used to explain the dependence of the run-up distances on the initial pressure. Since all the tests were made in the same tube the run-up distances can be correlated with laminar flame thickness, δ. Such a correlation is presented in Fig. 2. The run-up distance appears to be proportional to the thermal thickness of laminar flame with a good accuracy. It should be noted that correlation presented in Fig. 2 should be considered as a qualitative one, because it is based on the tests in a single tube.

This somewhat unusual correlation results from the specific features of the system studied. The detonation cell sizes were very small compared to the tube diameter. This means that it was practically no scale limitations on the possibility of the onset of detonation. Although not all details of the DDT process could be resolved in the present experiments, the results suggest that a certain minimum flame speed was necessary for DDT to occur. The run-up distances thus were just given by a distance necessary for the flame to reach this speed.

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