Effect of Pressure on the Threshold between Slow and Fast Flames

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Introduction

A series of experimental studies were made recently on the behavior of turbulent flames in mixtures based on hydrogen and hydrocarbon fuels (see, e.g. [1]). It was found that in tubes containing various configurations of obstacles, a well-defined difference in flame behavior can be observed dividing slow, subsonic flames from fast combustion regimes (choked flames and detonations). It was suggested that the ratio of densities, σ, between reactants and products should exceed a certain minimum value for development of fast flames $\sigma > \sigma^*(\beta, L_T/\delta)$, where $\beta = E_a(T_b - T_u)/T_b^2$, is the Zeldovich number, E_a is the effective activation energy, T_u and T_b are initial and adiabatic flame temperatures, and L_T is the integral scale of turbulence, and δ is laminar flame thickness. Although quite a representative data set was used to analyze the critical conditions in [1], it was no systematic data on the effect of initial pressure on flame acceleration (FA). The initial pressure is an important parameter affecting both, basic properties flames and turbulence. Data on the effect of pressure on FA in a channel with obstacles should help to understanding better the nature of the sharp threshold between cases of subsonic and supersonic flames.

The objective of the present work was to obtain systematic data on the effect of pressure on the critical conditions for strong FA. Experiments were performed using hydrogen-air-steam mixtures at elevated initial temperatures (383K). This system was chosen because of practical applications (nuclear reactor safety) and because of availability of an extensive database for this type of mixtures. Initial pressures were varied from 0.1 to 3 bar in the present tests.

Experimental

The tests were performed in a heated detonation tube with 121 mm id and 8 m in length. Tube was equipped with orifice-plate obstacles spaced by one diameter with blockage ratio (BR) equal to 0.6. To get the most important information on the limits for supersonic flames (FA limits) for the specific system (hydrogen-air-steam), the tests were carried out for the following cases: (1) lean H_2-air mixtures without steam, (2) rich H_2-air mixtures without steam, and (3) stoichiometric H_2-air with variable steam dilution. Hydrogen concentration in dry mixtures changed from 9 to 11% and from 74 to 80%. In stoichiometric H_2-air (ϕ=1) steam content was varied from 46% to 52%. All the mixtures were ignited by means of a spark plug. To ensure ignition of the mixtures near flammability limits, the spark energy varied from 0.5 J to 1 kJ.

Summary of Results

Experimental results obtained with variations of initial pressure showed typical flame regimes similar to those observed in earlier studies at 1 bar: (1) slow flames with global quenching, (2) slow subsonic flames (3) fast supersonic flames (cr<v<cp - flame velocity was less than the sound speed in products, but more than those in reactants). Characteristic velocity was estimated as an average value during the steady-state phase of the flame propagation. It was found that for the same propagation mode characteristic flame velocity increases with initial pressure. Experimental results are summarized in Figs. 1 – 3

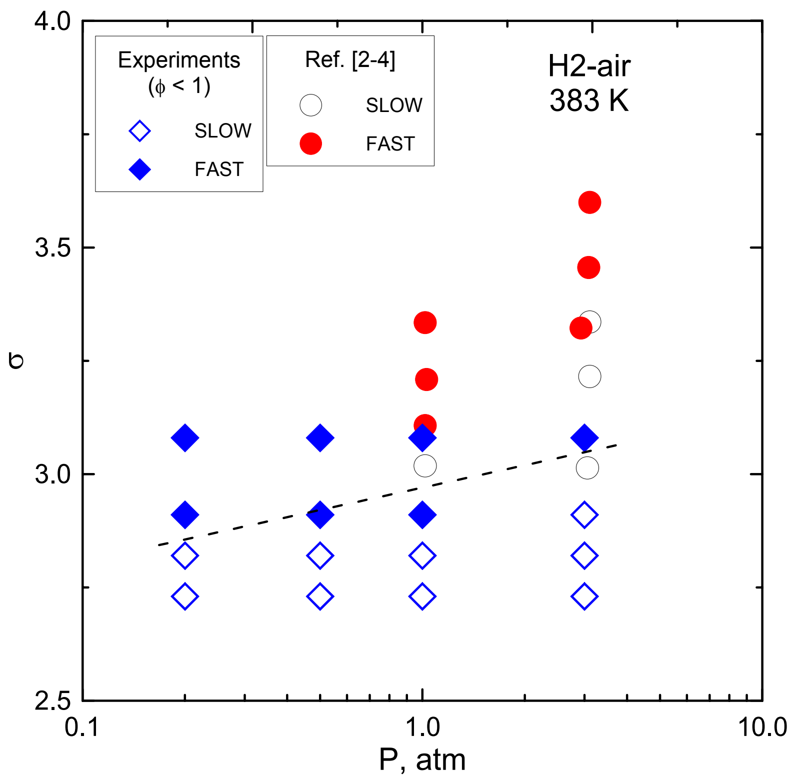

Fig. 1. Effect of initial pressure on the border between slow and fast flames for for lean H_2-air mixtures

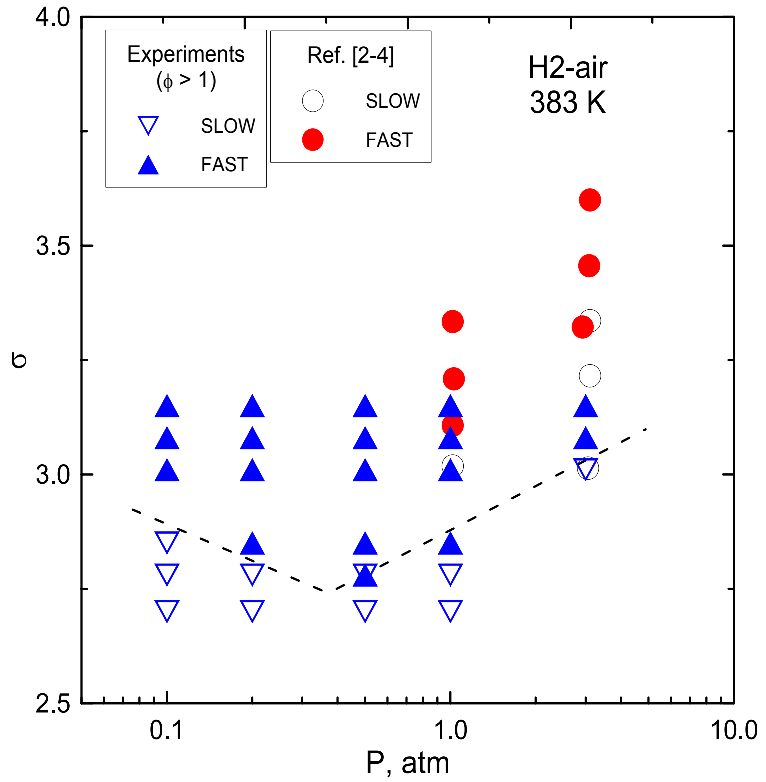

Fig. 2. Effect of initial pressure on the border between slow and fast flames for rich H_2-air mixtures

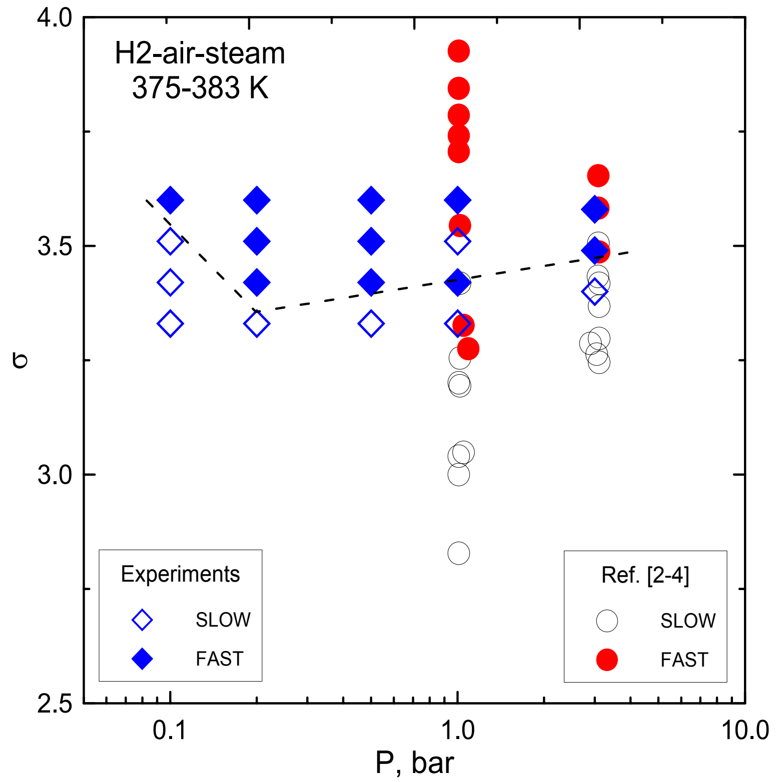

Fig. 3. Effect of initial pressure on the border between slow and fast flames for stoichiometric H_2-air mixtures diluted with steam

At lowest pressures of about 0.1 bar the scale ratio L_T/δ was smaller than the critical value of 100, and according to [1] the limited tube size affected the critical conditions. With higher initial pressures the critical expansion ratio was found to be almost constant or to have a slight increase with pressure. The results of these tests provide new data for analysis of the critical conditions for FA. Their impact on the correlations described in [1] is discussed in this paper.

References

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