

Competition between Self-Ignition and Deflagrative Burnout in Hydrogen-Air Mixture Heated by Reflected Shock Wave

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1 Background

Shock tube measurements of ignition delays in hydrogen-oxygen [1,2] and hydrogen-air [3,4] mixtures revealed some unexpected features. It was found that at temperatures $T < 1000\text{--}1100$ K a reaction behind a reflected shock wave starts much earlier than it is predicted by kinetic theory. A discrepancy between estimated and observed values of ignition delays increases with decrease of temperature and reaches several orders of magnitude at $T = 800\text{--}850$ K [4].

High-speed schlieren photography demonstrates that at relatively low temperatures the reaction starts in random sites located in the immediate vicinity of walls [3]. Explanation of this phenomenon can be based on the consideration of non-ideality of shock tube flow due to interaction between reflected shock and boundary layer [4]. Another approach was developed in [2] where it was taken into consideration that adsorption of molecular oxygen by metallic surface leads to the formation of chemically active atomic oxygen on the adsorbing surface. In spite of perturbations near the walls of the shock tube, a core of the volume compressed (and heated) by reflected shock wave remains uniform and its parameters (i.e. pressure and temperature) correspond to that calculated by standard procedure via incident shock Mach number. The purpose of the investigation is to examine conditions under which the described undisturbed region is suitable for study of self-ignition.

2 Preliminary Results

Near-wall burning serves as ignition source for the rest of a fresh mixture behind a reflected shock. Thus, as a first approach one can compare two alternatives, namely self-ignition and deflagrative burnout of the portion of the unburned gas. The calculated ignition delay represents the characteristic time interval t_A for the self-ignition event. The analysis of burning in deflagration regime requires the estimation of laminar flame speed under conditions behind a reflected shock wave.

The calculations of ignition delays and laminar flame speed were performed for the conditions of the experiments reported in [4]. The kinetic scheme includes 21 reactions. The initial conditions were as follows: stoichiometric hydrogen-air mixture at pressure $P = 1\text{--}50$ bar and temperature $T = 700\text{--}1200$ K. It was found that laminar flame velocities S_L were within the interval $5\text{--}50$ m/s and

depended on the initial conditions. Multiplying S_L by expansion ratio gives the conservative estimation of visible flame speed. The duration of deflagrative burnout t_B is the ratio of characteristic length to visible flame speed. The tube radius ($r = 25$ mm in [4]) represents the characteristic length scale when deflagration propagates from periphery to the axis of the tube.

The parameter t_A exhibits strong dependence on temperature. The calculations revealed that the value of t_B just slightly increases with temperature decrease. It was found that typically $t_A < t_B$ at $T > 1100$ and, hence, self-ignition delay will elapse earlier than fresh mixture will be consumed by deflagrative burnout. At lower temperature, i.e. $T < 1000 - 1100$ K, the value of t_B becomes much shorter than the parameter t_A . Therefore deflagration prevails over self-ignition and, hence, both measurements of the self-ignition delays and searching for the adequate kinetic scheme become irrelevant.

3 Concluding Remarks

The analysis of probable competition between the processes of self-ignition and deflagrative burnout was performed for hydrogen-air mixtures heated by reflected shock wave. It was demonstrated that early stage appearance of near-wall burning zones at relatively low temperatures ($T < 1000 - 1100$ K) inevitably violets overall self-ignition. It should be emphasized that the suggested estimations are conservative. The rate of combustion under real conditions can significantly exceed the values typical for laminar flames. This can lead to decrease of t_B parameter and to intensification of the deflagrative burnout of the mixture prepared for measurement of self-ignition delay.

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References

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