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MODELING OF NON-THERMAL PLASMA IN FLAMMABLE GAS MIXTURES

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Abstract. An idea of using plasma-assisted methods of fuel ignition is based on non-equilibrium generation of chemically active species that speed up the combustion process. It is believed that gain in energy consumed for combustion acceleration by plasmas is due to the non-equilibrium nature of discharge plasma, which allows radicals to be produced in an above-equilibrium amount. Evidently, the size of the effect is strongly dependent on the initial temperature, pressure, and composition of the mixture. Of particular interest is comparison between thermal ignition of a fuel-air mixture and non-thermal plasma initiation of the combustion. Mechanisms of thermal ignition in various fuel-air mixtures have been studied for years, and a number of different mechanisms are known providing an agreement with experiments at various conditions. The problem is – how to conform thermal chemistry approach to essentially non-equilibrium plasma description. The electric discharge produces much above-equilibrium amounts of chemically active species: atoms, radicals and ions. The point is that despite excess concentrations of a number of species, total concentration of these species is far below concentrations of the initial gas mixture. Therefore, rate coefficients for reactions of these discharge produced species with other gas mixture components are well known quantities controlled by the translational temperature, which can be calculated from the energy balance equation taking into account numerous processes initiated by plasma.

A numerical model was developed combining traditional approach of thermal combustion chemistry with advanced description of the plasma kinetics based on solution of electron Boltzmann equation. This approach allows us to describe self-consistently strongly non-equilibrium electric discharge in chemically unstable (ignited) gas. Equations of pseudo-one-dimensional gas dynamics were solved in parallel with a system of thermal chemistry equations, kinetic equations for charged particles (electrons, positive and negative ions), and with the electric circuit equation. The electric circuit comprises power supply, ballast resistor connected in series with the discharge and capacity. Rate coefficients for electron-assisted reactions were calculated from solving the two-term spherical harmonic expansion of the Boltzmann equation. Such an approach allows us to describe influence of thermal chemistry reactions (burning) on the discharge characteristics.

Results of comparison between the discharge and thermal ignition effects for mixtures of hydrogen or ethylene with dry air will be reported. Effects of acceleration of ignition by discharge plasma will be analyzed. In particular, the role of singlet oxygen produced effectively in the discharge in ignition speeding up will be discussed.