IGNITION AND COMBUSTION OF HYDROCARBON FUEL DROPS

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The classical theory of liquid drop vaporization, ignition, and combustion considers an isolated drop in unconfined ambience. Within this presumption, notable progress in understanding relevant physical and chemical processes has been achieved recently. However, in practice, these processes occur in the presence of neighboring drops or confinement surfaces. The corresponding effects are usually referred to as 'spray' and 'confinement' effects. Spray effects manifest themselves in two-phase reactive flows. In existing computational approaches, chemical reaction rates are determined based on considering gas-phase combustion with fuel drops treated as distributed source terms for fuel vapor. As a matter of fact, spray combustion is a complex combination of diffusion-controlled flames around individual drops, groups of drops, and gas-phase partially premixed flames. The objective of this study is to extend our knowledge on drop vaporization, ignition, and combustion with spray and confinement effects taken into account.

For a spatially uniform and monosize drop suspension in air, an elementary polyhedron cell with faces in the form of equilateral triangles can be constructed around each drop. The length of a polyhedron edge is equal to a half-distance between drops in the suspension. Due to symmetry considerations, mass, momentum, and energy fluxes through the faces should be zero. Therefore, drop behavior in the suspension can be modeled by solving the governing conservation equations for a single drop with symmetry boundary conditions at the polyhedron faces. If the polyhedron is approximated with an elementary sphere, the three-dimensional problem is reduced to one-dimensional formulation with zero-flux boundary conditions at its surface. The error of such an

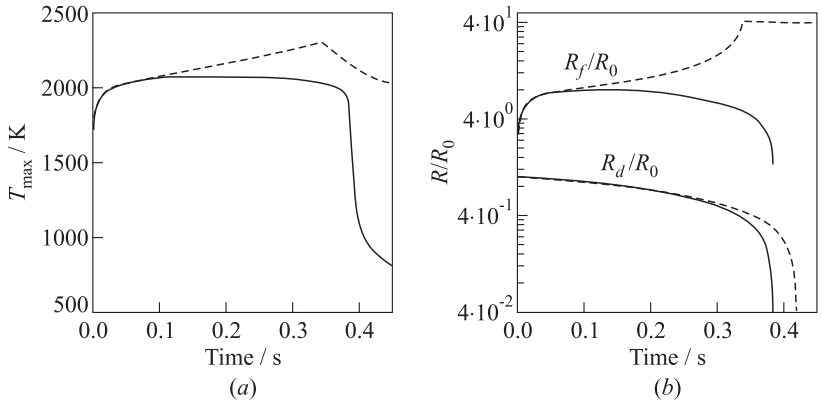

Figure 1 Comparison of flame temperature (a) and dimensionless flame and drop radii, R_f/R_0 and R_d/R_0, histories for the isolated drop (solid curve) and drop in suspension (dashed curve, $\Phi = 1.1$). Fuel: n-heptane, Oxidizer: air, Initial pressure and temperature: 0.1 MPa and 300 K; $R_0 = 0.25$ mm.

approximation depends on the suspension density — mass of dispersed liquid per unit volume.

Numerical solution of the mass, momentum, and energy conservation equations for a hydrocarbon drop within the elementary sphere resulted in several important findings. It has been shown that (1) drops in suspension vaporize slower than do isolated drops, (2) quasistationary d^2-law is, in general, not valid for drops in a suspension, (3) at suspension densities exceeding a certain limiting value, drops vaporize only partly or virtually do not vaporize, (4) drop autoignition delay depends on the suspension density and is heavily affected by the amount of prevaporized fuel, (5) individual drop flame structure and parameters depend on the suspension density, (6) individual drop flame exists within a limited range of suspension densities, and (7) emission indices of pollutants (CO, NOx, soot) depend considerably on the suspension density.

Figure 1 shows the predicted time histories of flame temperatures, T_{max}, as well as dimensionless flame and drop radii, R_f/R_0 and R_d/R_0, respectively, for the isolated drop (solid curves) and drop in suspension

(dashed curves) of similar initial radius R_0. The suspension density in this case is characterized by the equivalence ratio $\Phi = 1.1$ that is the ratio of the actual liquid fuel mass to the corresponding stoichiometric value. The flame temperature for the drop in suspension is considerably higher than that for the isolated drop, in particular at the end of combustion. For the isolated drop, the flame stabilizes at a distance of about $8R_0$, whereas for the drop in suspension the flame spreads towards the edge of the elementary sphere consuming all available oxygen.

Results of calculations have been compared with available experimental data. It is intended to use the results for improved ignition and combustion modeling in two-phase reactive flows.

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