

Regularities of the combustion chemistry of PMMA in the oxidizer flow in microgravity

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At zero gravity, combustion is realized due to the heat and mass transfer in a stationary oxidizer or due to forced convection. Although the basic mechanisms of flame propagation are the same, the relative magnitudes and characteristics of heat and mass transfer, as well as the kinetics of chemical reactions in the flame, may be quite different. The influence of the forced convection rate on the chemical structure of a polymethyl methacrylate (PMMA) flame in an oxidizer flow (O_2+N_2) under microgravity conditions was studied using numerical modeling. ANSYS Fluent software was used to solve a 2D problem of gas flow around a solid body with the full system of Navier–Stokes equations for a multicomponent mixture, taking into account thermal conductivity and thermal radiation and supplemented by the detailed kinetic mechanism. The chemical transformation in the flame was simulated using a kinetic mechanism comprising 45 reactions with the participation of 29 components [1]. The combustion of solid polymer includes preheating the polymer to the pyrolysis temperature, its pyrolysis and interaction of the pyrolysis products with oxygen. On the surface of the PMMA sphere, the pyrolysis reaction leading to the transition of the fuel from the condensed phase to the gas phase has been specified. The reaction rate is given in Arrhenius format as $k=8.3 \times 10^{11} \times \exp(-E/RT)$, where $E=35$ kcal/mol [2]. Surface degradation is assumed to occur slowly; therefore, changes in the geometric dimensions during flame establishment are neglected.

The heat transfer and radiation in both the condensed and gas phases were considered in the modeling. On the PMMA surface, the pyrolysis reaction leading to the transformation of fuel from the condensed phase to the gas phase was specified. The forced convection velocity varied in the range from 3 to 100 cm/s. The thermal and chemical structure of the flame near the surface of PMMA sphere was analyzed at various velocities of the oxidizer flow. With an increase in the velocity from 3 to 10 cm/s, the maximum flame temperature increases from 1700K to 1793–1799K. A further increase in the velocity was shown to result in a significant decrease in the maximum flame temperature to 1310K (at a flow speed 100 cm/s). At the same time the temperature gradient at the surface of the sphere increases that leads to an increase the surface temperature and, consequently, the rate of pyrolysis. Thus, a change in the flow velocity and, therefore, in the heat and mass transfer in the combustion zone leads to a change in the products composition near the surface and the chemical flame structure. Besides, with an increase in the speed of the oncoming flow of the oxidizer, the total heat release in the gas phase increases.

The maximum CO concentration increases as the forced convection rate increases. Analysis of the rates of fuel consumption reactions showed that at a low convection speed ($v_{st}=3$ cm/s), the reaction with the H radical, which has the highest diffusion coefficient, plays a crucial role in MMA oxidation.

References

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