Numerical Analysis of Rocket Fuels

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Abstract

Rocket engine efficiency depends on the chemical reactions between fuel and oxidizer, as well as the conditions inside the combustion chamber. Engineers favour hydrocarbons paired with liquid oxygen (LOX) because these combinations deliver high energy, ignite dependably, and produce stable flames. However, researchers have conducted few broad comparisons of how the equivalence ratio (ϕ), chamber pressure, and initial fuel temperature influence performance across various hydrocarbons in equilibrium combustion. Such knowledge proves essential for selecting optimal propellants.

This study employs NASA's Chemical Equilibrium Analysis (CEA) program for simulations. The fuels under examination include methane (CH_4), ethane (C_2H_6), pentane (C_5H_{12}), RP-1 ($C_{12}H_{26}$), and JP-10 ($C_{10}H_{16}$), all combined with LOX at 90.19 K. The equivalence ratio (ϕ) is varied from 0.1 to 30 in increments of 0.1 while maintaining constant chamber pressure and fuel temperature to examine the influence of fuel composition and C/H ratio. Further analysis is performed by varying chamber pressure from 1–100 bar in steps of 10 bar and from 100–400 bar in steps of 50 bar, while fuel temperature is varied from 300–1000 K in increments of 50 K.

CEA provides key metrics: combustion temperature, characteristic velocity (C*), thrust coefficient (Cf), specific impulse (Isp), and vacuum Isp. The equivalence ratio strongly governs combustion and propulsion output, whereas C/H ratio shapes exhaust molecular weight and temperatures. Heavier fuels like RP-1 and JP-10 perform better at elevated pressures due to superior energy density and C*, while lighter fuels such as methane and ethane yield higher Isp through lower exhaust mass. These insights support propellant choices for cryogenic rocket engines.

Keywords

Rocket propulsion, Hydrocarbon fuels, Equivalence ratio, Chamber pressure, Numerical analysis.