

Parametric Analysis of Lean Turbulent Premixed Hydrogen Flames

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Abstract

Hydrogen is increasingly recognised as a clean and sustainable energy carrier due to its high energy density and near-zero greenhouse gas emissions. In this context, the study of hydrogen combustion is crucial for both its practical implementation and safety. Hydrogen combustion exhibits complex behaviour, such as thermodiffusive instabilities. In this regard, the present work aims to investigate the effect of high pressure and temperature on thermodiffusive instabilities using large-scale two-dimensional and three-dimensional Direct Numerical Simulations (DNS). A large-scale 3D DNS of turbulent lean premixed hydrogen/air combustion is performed at ambient conditions (1 bar, 298 K). This simulation is then compared with another at elevated pressure and temperature (20 bar, 700 K), representative of typical gas turbine conditions. Both cases employ the same slot burner geometry with a coflow of burnt gases, maintaining constant jet Reynolds (11,200) and Karlovitz (90) numbers. The results show that the high pressure case appears characterized by faster reaction rate, higher turbulent flame speed and a broader flame brush with more pronounced wrinkling. Additionally, the joint probability density function (jPDF) of several quantities is computed to observe the magnitude of their fluctuations compared to the conditional means in 2D unstable laminar flames and 1D laminar unstretched flamelet trends. Larger fluctuations in the jPDFs under gas turbine conditions indicate stronger thermodiffusive instabilities and turbulence effects. Moreover, the turbulent flame speed analysis shows that the turbulent consumption speed increases relative to the laminar burning velocity due to the interaction between turbulence and thermodiffusive instabilities, enhanced at high pressure. The stretch factor is greater than unity for both gas turbine and ambient conditions, with the gas turbine case showing higher values, indicating a greater impact of pressure on the turbulence-thermodiffusive instabilities interaction.