High-repetition rate stereoscopic PIV investigation of stratified swirl flame flashback at atmospheric and elevated pressures

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HIGHLIGHTS

• The upstream propagation of stratified methane-air flames during flashback at atmospheric and elevated pressure conditions (3 atm) has been studied.
• Diagnostics include time-resolved PIV and flame luminosity to assess flow/flame interaction, and acetone PLIF to assess equivalence ratio variations.
• Stratification in the mixing tube is evaluated by employing acetone-PLIF for non-reacting flows. The equivalence ratio distribution shows the presence of mean radial stratification, with richer mixtures toward the outside wall of the mixing tube. Stratification increases at higher pressure.
• The pockets of rich and lean mixtures that are associated with stratification lead to an increase in the flame-surface wrinkling.
• Stratification causes an increase in the radial spread of the flame skirt for atmospheric as well as elevated pressures.

ABSTRACT

Boundary layer flashback in lean stratified methane-air swirl flames was investigated at atmospheric and elevated pressure conditions (3 atm). The average axial velocity was kept at 2.5 m/s for all experiments. Non-reacting flow experiments were performed to establish the nature of stratification in the mixing tube. The distribution of equivalence ratio in the plane of visualization was measured by performing planar laser-induced fluorescence (PLIF) imaging of acetone vapor injected through the fuel ports in the swirl vanes. For the non-reacting 1-atm ensemble-averaged measurements, strong stratification is observed in the radial direction, with richer mixtures present near the mixing tube outer wall. The instantaneous PLIF measurements show the presence of fuel-rich structures in the mixing tube at the globally lean conditions ($\phi = 0.63$). For the reacting flow experiments, simultaneous chemiluminescence imaging and three-component PIV are applied to study the physics behind the flame-flow interaction in stratified conditions. During upstream propagation of the flame, a large flame tongue swirls around the center body while propagating upstream. At a certain upstream location, the flame stops moving upstream and swirls around the center body. The radial spread of the stratified flames is found to be larger than that of the fully premixed cases. At elevated pressure the acetone-PLIF images show that pockets of varying local equivalence ratio increases the curvature of the flame. The elevated pressure flashback experiments are conducted at 3 atm at a higher global equivalence ratio ($\phi = 0.85$). The upstream propagation of the flame exhibits similar features of flame-flow interaction as that of atmospheric pressure cases. The high-pressure flame was highly wrinkled due to the presence of turbulence and small scale variation in equivalence ratio. Intermittently, the flame skirt was observed to spread in radial direction.