Influence of Turbulent Markstein Number on Flame Front Structure and Burning Rate in Premixed Turbulent Flames

Parsa Tamadonfar and Ömer L. Gülder
University of Toronto, Institute for Aerospace Studies
Toronto, Ontario, Canada

The dominant effects of the equivalence ratio, turbulence intensity, and mean turbulent Markstein number on the flame brush characteristics, instantaneous flame front structures, and burning velocities of premixed turbulent methane, ethane, and propane-air Bunsen flames were investigated in a systematic manner. Particle image velocimetry and Mie scattering techniques were used to measure the turbulence statistics and to visualize the flame front corrugations, respectively. All experiments were performed under a constant bulk flow velocity of 21 m/s. The equivalence ratio range was from 0.7 to 1.35 for methane-air flames, 0.7 to 1.45 for ethane-air flames, and 0.8 to 1.35 for propane-air flames. Two perforated plates located upstream were used to produce different turbulence levels. A series of comprehensive parameters including the characteristic flame height, mean flame brush thickness, mean volume of the turbulent flame region, mean fuel consumption rate, two-dimensional flame front curvature, local flame front angle, two-dimensional flame surface density, wrinkled flame surface area, turbulent burning velocity, mean flamelet consumption velocity, mean turbulent flame stretch factor, mean turbulent Markstein length, and mean turbulent Markstein number were evaluated from the experimental data.

The mean progress variable profiles on the centerline and normal to the centerline of the burner mimicked the behaviour of the complementary error function. These profiles collapsed to a universal curve when normalized. The flame front curvature distributions were Gaussian, and they were symmetrical about the zero flame front curvature. The flame front curvature distributions were not sensitive to the equivalence ratio, total turbulence intensity, different thermo-diffusive characteristics, and the fuel type.

The maximum two-dimensional flame surface density increased with increasing equivalence ratio from lean to stoichiometric mixtures. It decreased slightly with increasing equivalence ratio for rich ethane flames at low turbulence intensity and rich methane flames, whereas it remained unaltered for rich ethane flames at high turbulence intensity and rich propane flames. The maximum two-dimensional flame surface density decreased with increasing total turbulence intensity under constant equivalence ratio, non-dimensional bulk flow velocity, and non-dimensional longitudinal integral length scale. The maximum two-dimensional flame surface density for rich mixtures was higher than the corresponding value for lean/stoichiometric mixtures.

The ratio of the wrinkled to the unwrinkled flame surface area decreased with increasing equivalence ratio for propane flames at high turbulence intensities and methane flames, whereas it did not show any trend with increasing equivalence ratio for propane flames at low turbulence intensities and ethane flames. In general, this ratio increased with increasing total turbulence intensity under constant

Correspondence to: ogulder@utias.utoronto

equivalence ratio, non-dimensional bulk flow velocity, and non-dimensional longitudinal integral length scale. The ratio of the wrinkled to the unwrinkled flame surface area for lean/stoichiometric mixtures was higher than the corresponding value for rich mixtures.

The mean turbulent Markstein number displayed a dependence on the equivalence ratio and turbulence intensity. Results show that the mean turbulent Markstein numbers for lean/stoichiometric and rich mixtures were not equal when the unstrained premixed laminar burning velocity, non-dimensional bulk flow velocity, non-dimensional turbulence intensity, and non-dimensional longitudinal integral length scale were kept constant.