On the Lewis number dependency of the Klimov-Williams criterion

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Abstract

A joint planar imaging of laser-induced OH fluorescence and two-sheet Rayleigh scattering is applied to investigate the local, three-dimensional flame-front structures of turbulent lean hydrogen/air premixed combustion. Both the reaction progress variable and OH mole fraction show parallel iso-contours in flames having Karlovitz numbers, Ka, greater than 10. Also, the measured conditional mean progress variable gradient is much higher than the unstretched laminar value calculated with detailed chemistry. These experimental data indicate clearly that the Klimov-Williams criterion, Ka = 1, under-estimates the boundary separating the lamella-like and non-flamelet regimes for lean hydrogen/air premixed combustion. The under-estimation is attributed to the less-than-unity reactant Lewis number so that the flame residence time relevant to turbulent combustion is less than the unstretched laminar value by almost an order of magnitude.

A new criterion for limiting the lamella-like flame-front structure is proposed to be when turbulent scalar transport overcomes laminar diffusion inside the local flame-fronts, and is given as $\mathrm{Pe} > 1$. The Péclet number, Pe, is defined as the laminar diffusion time over the turbulent scalar transport time. Depending on the reactant Lewis number, Le, being less or greater than unity, the laminar diffusion time is determined by either the fuel mass diffusivity or the thermal diffusivity, evaluated at the inner layer temperature. For lean to stoichiometric hydrocarbon/air premixed flames ($\mathrm{Le} \geq 1$), the boundary of $\mathrm{Pe} = 1$ approximates to $\mathrm{Ka} = 1$, and the value of Ka is based on the unstretched laminar flame. For lean hydrogen/air premixed flames ($\mathrm{Le} < 1$), the condition of $\mathrm{LeKa}^{3/2} \approx 1$ is derived as the regime boundary. The flame characteristic scales in the Ka number are evaluated at the stretched laminar flame having the maximum heat release parameter.