



A three-dimensional study on premixed flame propagation in narrow channels

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In numerical studies of quasi-2D problems, such as laminar flame propagation through a slit, the quasi-2D assumption is commonly applied to simplify the problem. However, the impact of the third dimension (in the thickness between walls) can be significant due to strong curvature. The intrinsic Darrieus-Landau instability, the Saffman-Taylor instability, and the thermodiffusive instability lead to curved flame fronts in both the transverse and normal directions and radically change the global flame speed. This study investigates the interaction of these instabilities and their impact on premixed flames freely propagating in narrow channels. Two lean fuel-air mixtures are considered: one with unity Lewis number $Le = 1$ and another with $Le = 0.5$. A single-step Arrhenius-type reaction is used for combustion modeling. Joulin Sivashinsky's model [1], termed as 2D+ model, is implemented to capture the confinement effect due to walls. By comparing 3D Direct Numerical Simulations (DNS) and 2D simulations at unity Le , we find that the 2D+ model accurately reproduces confinement effects for channel width h up to $3.6\delta_T$ (δ_T : thermal flame thickness) as a stable symmetric flame front is established between walls, extending the validity of Darcy's law [2].

However, for larger h , interactions between flame curvatures in two directions result in a higher flame surface increment and consumption speed, as the symmetric flame front between walls destabilizes to an asymmetric shape. Besides, for 3D cases with $Le = 0.5$, positive curvature regions on the flame front primarily contribute to the global reaction due to the Lewis effect. Statistical studies on flame dynamics between walls in 3D cases are also conducted, and results show that both the flame surface increment and the Lewis effect on curvature (if $Le = 0.5$) are approximately consistent. 2D simulations for the thickness between walls can predict the acceleration from flame dynamics between walls in the 3D domain for both mixtures.

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References

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