A Unified Model to Evaluate the Effect of Strain Rate on Extinction of Premixed and Diffusion Flames

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Abstract

Objectives of this work include, first, developing and justification of the flame extinction model for large eddy simulations of under-resolved turbulent diffusion flames and, second, formulating a unified model to evaluate the effects of the strain rate on extinction of both premixed and diffusion flames. The model is based on the perfectly stirred reactor (PSR) concept, in which the residence time is coupled with the local strain rate [1], and the radiative losses from the reaction zone are taken into account. In evaluating radiative losses, the reaction zone is assumed to be optically thin. The effective absorption coefficient is obtained using the mean Planck values for the major combustion products (CO_2, H_2O, CO and soot) having concentrations estimated in the Burke-Shumann limit. The single-step global reaction of incomplete fuel oxidation is considered, with the prescribed yields of soot and carbon monoxide. A possible way to calibrate the kinetic parameters is that by fitting measured values of flame temperature and strain rate at blow-off. By comparing the simulation results with experimental data available for methane-air and heptane-air flames and with the published predictions made by the activation energy asymptotics for the ethylene-air flame, it is demonstrated that the PSR model is capable of evaluating flammability bounds of the diffusion flame, including high-strain blow-off and low-strain quenching (Fig. 1).

Due to joint consideration of finite reaction rate and inherent radiative losses from the reaction zone, the model acquires capability of predicting the fundamental flammability limit, beyond which the flame cannot exist at any (low or high) strain rate. It is this limit, which determines extinction in LOC tests in premixed combustion and LOI tests in diffusion flames. This approach is based on competition of finite-rate chemical heat release and heat losses from the reaction zone, and it does not rely on the critical flame temperature assumption.

For the flames diluted by inert gases (nitrogen, carbon dioxide, water vapor, or argon), minimum extinguishing concentrations predicted by the non-adiabatic PSR model are shown to agree with the measured values. Critical values of the unified extinction criterion, the Damköhler number, are evaluated and found to be similar at both high- and low-strain extinction limits [2].

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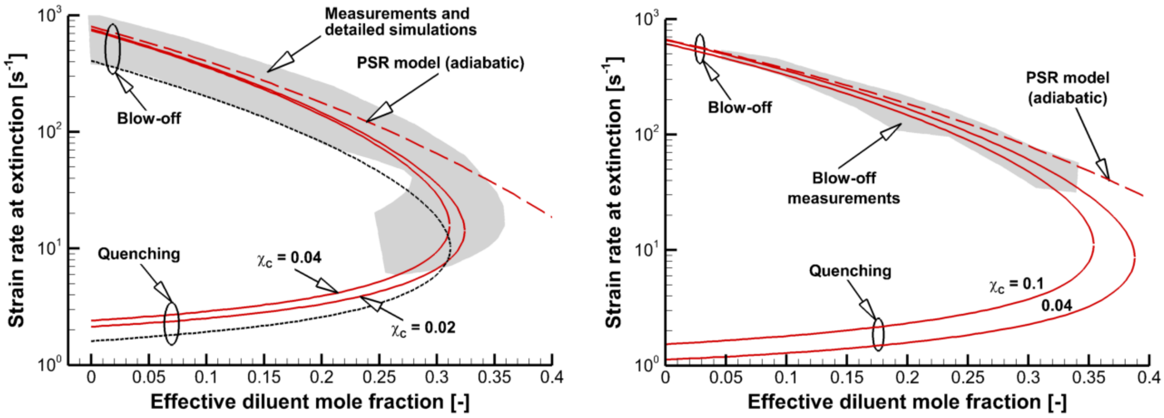

a) b)

Figure 1. Flammability maps (critical strain rates vs effective diluent mole fraction): a) – methane (dotted line is obtained with kinetic parameters from Ref. [1]); b) – heptane. Diluent is nitrogen. Solid lines are predicted by the PSR model [2]. χ_C is the prescribed soot yield in the global reaction.

References

[1] Snegirev A.Yu., Tsoy A.S. (2015) Treatment of local extinction in CFD fire modeling. Proc. Combust. Inst. 35: 2519.

[2] Snegirev A.Yu. (2015) Combust. Flame (submitted).