Effect of the swirl intensities and equivalence ratio on the NH3/CH4 diffusion flame structure and chemical kinetics

Ahmed Adam[1,2,*], Reo Kai[1], Hiroaki Watanabe[1]
*lead presenter: Adam.ahmed.542@s.kyushu-u.ac.jp
1 Kyushu University, Japan
2 Helwan University, Egypt

The power sector continues to evolve to meet rising global energy demands, with chemical fuels remaining the most energy-dense option for thermal energy conversion in gas turbines and internal combustion engines [1]. However, their combustion produces pollutants such as CO_2, CO, and NO_x, contributing to climate change. This has driven interest in carbon-free alternatives like hydrogen and ammonia. These fuels, especially in blends, offer comparable performance to hydrocarbons [2], though challenges remain regarding their storage, transport, and combustion [3].

Ammonia stands out due to its compatibility with existing infrastructure and its role as a hydrogen carrier [3]. Nonetheless, it exhibits poor combustion properties, such as high ignition temperature (~930 K) and low laminar flame speed (~0.072 m/s) [4]. Blending ammonia with hydrogen [2] or hydrocarbons like methane [5] is a common strategy to improve its reactivity.

In industrial and power applications, turbulent flames are prevalent due to their high energy output and stability. Swirling flows are widely used to generate central recirculation zones that increase fuel residence time and enhance combustion. The swirl number is thus a key parameter influencing flame behavior [6].

This study numerically investigates the influence of swirl number and equivalence ratio on flame structure and chemical kinetics, with a focus on NO formation as a key pollutant in ammonia combustion. Four cases are considered: two with a swirl number of 8 and two with 12, each pair examined at equivalence ratios of 0.54 and 0.77. The results are validated against published data from the KAUST research group [6].

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