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Uncertainty Quantification on Blending Degree of Ammonia-Hydrogen Combustion

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Historically, combustion has been at the heart of transport and power-generation sectors, owing to its technological maturity, widespread infrastructure, and ability to deliver high efficiency. However, the urgent drive toward decarbonization is motivating a shift from conventional hydrocarbon fuels to carbon-free alternatives. Ammonia emerged as a promising option due to its high hydrogen density, low production and storage cost, and well-established handling infrastructure. Yet its low heating value, slow flame speed, and high nitrogen content can lead to elevated NO_x emissions unless combustor designs are re-engineered to mitigate fuel-nitrogen oxidation [1]. Recent studies showed that blending ammonia with a small fraction of hydrogen can improve flame stability and facilitate ignition, while retaining much of ammonia's carbon-free advantage [2, 3]. At the same time, however, the fuel-blend composition becomes a critical source of uncertainty, and small variations in the ammonia/hydrogen blending ratio may propagate to produce significant variability in emissions and performance. Moreover, high-fidelity simulations of realistic combustor geometries are often too costly for extensive parametric or probabilistic studies.

To assess these problems, in the present work, we employ a chemical reactor network (CRN) model and uncertainty quantification techniques to assess the impact of blend-ratio uncertainty on the performance of an ammonia-hydrogen fueled combustor. By forgoing detailed fluid dynamics in favor of a simple network of perfectly mixed and plug-flow reactors, the CRN approach allows us to retain high-fidelity chemical kinetics while enabling rapid evaluation of a large number of calculations. Mapping how input uncertainty in the NH_3/H_2 blending ratio translates into uncertainty in NO_x emissions and combustion efficiency provides actionable guidance for robust ammonia–hydrogen combustor design.

References

[1] Romano, C., Cerutti, M., Babazzi, G., Miris, L., Lamioni, R., Galletti, C., Mazzotta, L., and Borello, D., “Ammonia blends for gas-turbines: Preliminary test and CFD-CRN modelling,” *Proc. Comb. Inst.*, Vol. 40, No. 1, 2024, pp. 105494.

[2] Pugh, D., Bowen, P., Valera-Medina, A., Giles, A., Runyon, J., and Marsh, R., “Influence of steam addition and elevated ambient conditions on NOx reduction in a staged premixed swirling NH3/H2 flame,” *Proc. Comb. Inst.*, Vol. 37, No. 4, 2019, pp. 5401–5409.

[3] Yamashita, H., Hayakawa, A., Okafor, E. C., Colson, S., Somarathne, K. D. K. A., Tsujimura, T., Ito, S., Uchida, M., Kudo, T., and Kobayashi, H., “Optimum primary equivalence ratio for rich-lean two-stage combustion of non-premixed ammonia/methane/air and ammonia/hydrogen/air flames in a swirling flow,” *Fuel*, Vol. 368, 2024, pp. 131598.