



Enhancing Reactive Volume Fraction Predictions in Turbulent Combustion Using Kolmogorov-Arnold Networks

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The accurate prediction of turbulence-chemistry interactions presents a key challenge in combustion modeling, particularly in formulating the reactive volume fraction ($\gamma = \tau_c / (\tau_c + \tau_m)$) within Partially Stirred Reactor (PaSR) models. This parameter critically influences reaction rates by determining where reactions effectively occur, yet conventional algebraic formulations rely on simplifications that limit their applicability across combustion regimes. This work introduces Kolmogorov-Arnold Networks (KANs) [1], to develop more robust reactive volume fraction formulations. The KAN methodology leverages recent scientific applications [2], to decompose complex relationships into interpretable functions while incorporating physical constraints into the model architecture. This approach creates a data-driven framework that adaptively transitions between different scaling behaviors based on local combustion conditions and specific flow properties. Performance evaluation focuses on canonical test flames, comparing species prediction accuracy against traditional models and previous machine learning approaches. Unlike black-box neural networks, KANs provide explicit mathematical formulations that offer physical insights into the mechanisms governing reactive volume fraction across different combustion regimes, potentially enhancing both predictive accuracy and computational efficiency of combustion simulations while maintaining physical interpretability.

References

- [1] Liu Z, Wang Y, Vaidya S, Ruehle F, Halverson J, Soljačić M, Hou TY, Tegmark M. KAN: Kolmogorov-Arnold Networks. *International Conference on Learning Representations (ICLR)*. 2025. arXiv:2404.19756.
- [2] Liu Z, Ma P, Wang Y, Matusik W, Tegmark M. KAN 2.0: Kolmogorov-Arnold Networks Meet Science. arXiv:2408.10205. 2024.