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Deep Neural Network-Based Multi-Objective Optimization of Combustion Stability and Emission Trade-Off in Diesel–Propane Dual Direct Injection Combustion

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This study presents a machine learning-based multi-objective optimization framework for diesel–propane dual direct injection combustion, building upon previous experimental and CFD investigations conducted in a rapid compression expansion machine (RCEM). To overcome the limited parametric space of experimental studies, a high-fidelity CFD dataset is generated by extending key operating conditions, including compression ratios (CR = 17, 19, 21, and 23) and independent variations of diesel and propane injection timings. The expanded dataset captures complex nonlinear interactions between fuel reactivity, mixture stratification, and thermodynamic conditions that govern combustion stability and emission formation. Supervised machine learning models (DNN) are trained on the CFD-generated database to predict critical combustion and emission indicators, including ignition delay, peak pressure rise rate, indicated thermal efficiency, and NO_x-related temperature characteristics. The trained surrogate models are subsequently integrated with a multi-objective optimization algorithm to identify optimal operating strategies that balance combustion stability and emission trade-offs. The results reveal that higher compression ratios enhance propane reactivity and reduce ignition delay, while optimal injection phasing strongly depends on the propane energy fraction and mixture preparation characteristics. The proposed framework significantly reduces computational cost compared to brute-force CFD optimization while maintaining high predictive accuracy. This work demonstrates the potential of combining physics-based CFD simulations with machine learning to accelerate the design and control optimization of dual-fuel combustion systems, providing a scalable pathway toward high-efficiency and low-emission operation in advanced compression ignition engines.

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