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Jet Ignition as an Enabling Technology for Stable, Highly Dilute Hydrogen Combustion in Off-Road and Heavy Duty Engines

With a trend towards a zero-carbon dioxide (CO₂) tailpipe future, driven by legislation and societal factors, engine manufacturers globally are investigating the use of alternative fuels that can minimize or eliminate tailpipe CO₂. Hydrogen (H₂) has re-emerged as a viable alternative fuel for combustion engines, aided by its relative flexibility to operating condition resulting from a wide flammability range, and the diversity of H₂ production sources. An increasing share of H₂ production is accomplished through the use of renewable energy, providing improved well-to-tank / cradle to grave and total life-cycle CO₂ budgets.

H₂ as a combustion fuel is exceptionally prone to abnormal combustion, e.g. pre-ignition. The relatively fast laminar burning velocity and wide flammability range enables the use of high levels of dilution, which can partially mitigate the pre-ignition issue as combustion temperatures decrease with increasing levels of dilution. However, the long flame travel distance and asymmetrical flame propagation present in large bore spark ignited engines can limit the effectiveness of this mitigation strategy.

Auxiliary-fueled pre-chamber (APC) jet ignition in gaseous-fueled and gasoline engines has proven successful in extending the dilution limit and reducing the likelihood of abnormal combustion. The APC combustor distributes ignition energy throughout the main combustion chamber through high velocity jets containing radical species. These distributed ignition events promote rapid, symmetrical burning of pre-mixed fuel and air. Liebherr and MAHLE are working together on APC jet ignition with H₂-fueled engines. The current study details the application of APC to a spark ignited H₂-fueled variant of a Liebherr off-road engine.

Results are presented that detail APC-enabled stable combustion at dilution ratios significantly extended beyond the limits of the base engine. This dilution limit extension offers the potential for increasing compression ratio. APC jet ignition therefore represents a viable pathway for highly efficient H₂ combustion, while achieving a higher power density compared to conventional spark ignited combustion.

