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TITLE

Experimental and Numerical Investigation of the CO_2 Reduction Potential of a Dual-Diluted Spark-Ignition Engine Concept for Plug-In Hybrid Electric Vehicle Application.

SUMMARY

Despite the legislative targets set by governments promoting the full electrification of new light-duty vehicles by 2035, the deployment of a wide portfolio of sustainable powertrain solutions represents the only approach to achieve carbon neutrality of the on-road transport sector within 2050. Among them, the contribution of a new generation of environmentally friendly hybridized Internal Combustion Engines (ICEs) remains crucial to overcome the limits of pure electric vehicles and to move toward more sustainable mobility.

In this context, the work presented in this doctoral thesis, carried out within the PHOENICE (PHev towards zerO EmissioNs & ultimate ICE efficiency) H2020 project, focuses on the development and optimization of a highly efficient Direct Injection (DI) Spark-Ignition (SI) engine for passenger car applications. By combining a dual dilution combustion concept with an innovative in-cylinder charge motion system (i.e., the SWUMBLE™), a 48V electrified turbocharger, an aggressive cycle Millerization and a high compression ratio, the PHOENICE engine targets a 10% reduction in fuel consumption of a C-SUV-class plug-in hybrid (P0/P4) over the WLTC driving cycle in charge-sustaining conditions. Additionally, to meet forthcoming EU7 emission standards under real-world driving conditions, the engine is paired with an advanced aftertreatment system that integrates an electrically heated

Three-Way Catalyst (TWC), a Gasoline Particulate Filter (GPF), and a Selective Catalytic Reduction (SCR) device.

The development and optimization of such a complex engine concept relied on the synergistic use of numerical simulations and experimental investigations. Initially, 3D-CFD analyses were leveraged to optimize the SWUMBLE™ intake duct geometry. Subsequently, 1D-CFD simulations were exploited to identify the best turbocharger design and conduct a preliminary virtual calibration of key engine parameters. This approach provided essential insights into the potential of the dual dilution combustion system to enhance thermal efficiency and paved the way for the subsequent investigation at the engine test bench.

Experimental testing confirmed the combined benefits of the technologies implemented in the PHOENICE prototype. The high compression ratio proved effective at low loads, while the cycle Millerization delivered benefits across the map by reducing knock and pumping losses. Lean combustion combined with EGR further improved BTE thanks to substantial reductions in heat losses. Overall, BTE improvements exceeded 10% over a wide region of the map compared to the baseline engine. From the pollutant emissions perspective, extremely low engine-out levels were observed for CO and NOx, and sub-10nm particulate.

The test campaign also explored the fuel economy potential of E85, a renewable ethanol-based fuel, which led to an additional 16% efficiency gain in the low-end torque region due to its superior knock resistance and enhanced evaporative cooling effect. The impact of E85 on particulate emissions was also assessed, revealing significantly lower sub-10 nm particle formation, a key aspect for future regulations. Transient tests on an engine-in-the-loop setup enabled further calibration refinement and assessment of the aftertreatment effectiveness on both regulatory and real-world profiles. The engine was finally integrated into a vehicle demonstrator to achieve a

Technology Readiness Level (TRL) of 7 and certify the project targets through roller bench testing.

From a global perspective, this dissertation, as well as the whole PHOENICE project, demonstrates that advanced combustion systems, innovative turbocharging solutions and renewable fuels can significantly enhance the efficiency and environmental performance of future hybrid powertrains, providing a viable pathway towards sustainable mobility in the medium-to-long term.