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Publishable summary

The idea of using hydrogen as a spark ignition engine fuel was already proposed decades ago [1]. However, in the past, technical and economical limitations for its production, transportation and utilization have strongly restricted its use. Nowadays, the urgent need to decarbonize the energy sector together with the progress in hydrogen production have led to renewed interest in H_2 powertrain technologies [2].

The fuel-based CO_2, CO and HC emissions from H_2 combustion are zero. However, nitrogen oxide (NO_X) emissions are still an issue that need to be tackled as their formation strongly depends on the in-cylinder mixture and temperature distribution. To achieve the optimal design of internal combustion engines, work on combined experimental and numerical research studies is an effective and powerful strategy.

In the present work package, an integrated numerical and experimental study on a heavy-duty H_2 engine is presented. For this purpose, a single-cylinder engine of the heavy-duty 13 l six-cylinder engine class has been modified to enable operation with H_2. The engine configuration made it possible to employ both a PFI and DI injection strategy for a direct comparison. As mixture homogeneity plays an important role for both engine performance and emissions, the PFI configuration will be used as a near-homogeneous reference for the numerical study. Additionally, this comparison will highlight the potential of DI hydrogen engines regarding the optimization of the mixture homogenization.

Lean-burn operating strategies show benefits in efficiency and emissions when using 100 % H_2. Additionally, stoichiometric operation is limited by knocking and is therefore more suited for passenger car applications, considering the lower boost pressure demand is more advantageous for dynamic operation [12,13].

Concerning numerical simulation, the Extended Coherent Flame Model (ECFM) in both its Reynolds-averaged Navier-Stokes (RANS) [14] and its large eddy simulation (LES) [15] formulation has demonstrated to be a well suited turbulent combustion model to compute spark ignition engines accounting for several complex phenomena: ignition [16], flame propagation [14], auto-ignition [17] and pollutant formation [33]. NO_X formation is modelled based on detailed kinetics using a post-flame model. As a first step, the CFD model is validated in PFI conditions to avoid any possible errors coming from mixing mispredictions on an experimental spark advance sweep and on an equivalence ratio variation. Focus is put on knocking tendencies and NO_X formation. Then, aware of its potentiality and limitations, the CFD model is used to compute DI operating conditions to improve the understanding of in-cylinder phenomena. Using 3D-CFD simulation an alternative injection cap design is also proposed to avoid rich mixture spots that are at the origin of abnormal combustion events.

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