# Abstract


Current off-road diesel engines have to meet many different concerns, including engine performance, low emissions, low fuel consumption and low total cost of ownership. In particular, the growing attention of the governments worldwide to the pollution effects by transportation sector on the human health and on the environment has pushed to approve more stringent emission legislation norms, extending the emission compliance tests to critical map areas of the engine such as low-end-torque and rated power, not only in standard conditions but also under extreme ambient conditions like high altitude and/or cold/hot ambient. To meet those requirements, different technologies are being developed for off-road compression ignition engines and the adoption of the exhaust after-treatment systems (EASs) has become essential. In particular, diesel engines require a mix of various after treatment devices to execute the selective abatement of diverse emission species such as Nitrogen Oxides ($NO_x$), unburned Hydrocarbons (HC), Particulate Matter (PM) and carbon monoxide (CO). Besides, the pollutants reduction must be guaranteed for the entire useful life of the engine and this implies further constraints in the design of the EASs.

In this context, the modelling activity and thus the virtual calibration plays a key-role in the assessment of engine and after-treatment systems performances reducing the number of time-consuming and costly experimental campaigns and thus the time-to-market of the engine.

In this research work, robust methodologies were developed with the aim to predict the EASs conversion efficiency for the future generation of compression ignition engines and to create a development setting that facilitates the shifting of major engine development tasks away from the pricey real to the low-cost virtual internal combustion engine (ICE) and EAS testing. For this purpose the exhaust after-treatment system of the KDI 3404 TCR engine, developed and manufactured by Lombardini-Kohler engines was considered. The engine is equipped with a dedicated EAS composed of a Diesel Oxidation Catalyst (DOC), a coated Diesel Particulate Filter (cDPF) and a Selective Catalytic Reduction system (SCR).

In the first chapter, a concise review of the phenomena involved in the mentioned reactors and the principal equations adopted in the simulations to reproduce those phenomena are described.
In the second chapter, 1D-CFD numerical models of the selected DOC, cDPF and SCR systems are presented. The components were largely characterized using first Synthetic Gas Bench (SGB) tests, minimizing the interaction of each reaction on the others by dosing specific chemical species in the inlet batch, and then at the real test bench for models validation purpose.
In the third chapter, the deployment of the created models on Hardware in the loop simulator (HiL) is shown. Once the models are validated, they are incorporated into a Matlab-Simulink® based architecture containing all the Inputs/Outputs links to the real Engine Control Unit (ECU). The results for diesel engine and EAS performances and emissions align with both transient and steady-state measurements. Finally, to explain the advantages and the opportunities of the virtual calibration integrated within the standard engine development process, some applications of the HiL system are presented.