Abstract

The increasing environmental impact and health concerns because of rising greenhouse emissions have pushed global institutions to take necessary measures for a more sustainable future. The road transport sector, which is responsible for 11.9% of global greenhouse gas emissions, has been under special focus for decarbonisation. Natural gas, comprised mainly of methane, can play its role to achieve short-term decarbonization of vehicle fleets as it allows for up to 24% reduction in engine-out CO2 emissions due to its low carbon content. Fast-paced development and adoption of untested technologies for natural gas engines is a crucial factor in meeting sustainable goals. Numerical modelling can play a fundamental role by allowing the optimal development of these technologies.

Within this context, the present thesis is a part of the research work carried out at Politecnico Di Torino within the H2020 'GasOn' collaborative project. The objective of the GasOn project was to develop an advanced mono-fuel natural gas engine, able to comply with '2020+' CO2 emissions targets and with the same performance as that of a diesel engine. The present thesis focuses on the development of the 3D CFD numerical model for evaluating the potential of high charge dilution, hydrogen doping, and a direct-injection given its application on natural gas internal combustion engines which can be applied to achieve the targets.

The thesis is divided into seven chapters. In Chapter 1, an overview of the innovative technologies for high-performance natural gas engines is presented followed by the objectives of this work. Chapter 2 details the experimental setup and engines under investigation whereas Chapter 3 discusses the numerical methodology used in the development of numerical models.

Chapter 4 focuses on the impact of EGR dilution on combustion at different engine load conditions. Firstly, the numerical model was calibrated and validated with experiments, at available working points on a single-cylinder engine in PFI mode. The model was then extended to quantify the EGR dilution limits at low, medium, and full load working conditions. The impact of EGR dilution on combustion and peak burning temperatures is discussed in the last section of this chapter.

Chapter 5 focuses on the Impact of hydrogen addition on the EGR dilution tolerance of an engine. For this numerical model was modified to adapt for the change in laminar flame speeds due to hydrogen addition. The model was validated with experiments available for three

hydrogen fuel blends [0%, 15%, 25% by vol] with no EGR conditions. It was then used to evaluate EGR dilution limits with three fuel blends. The impact of hydrogen addition on combustion is also presented in section 5.3 followed by a summary of the results.

Chapter 6 focuses on the impact of direct injection timing on mixture formation and combustion at full load conditions. First, the numerical model developed in chapter 4 was adapted for a centrally mounted injector. The model was calibrated and validated at full load conditions in PFI mode. After that, the impact of early injection, and late injection timings, on mixture formation and combustion were evaluated. 3D CFD model was also used for quantification of late injection on mixture heterogeneity at high engine speeds at full loads. In the last part of this chapter, the impact of injection timing on volumetric efficiency at the low-end torque range is discussed. Chapter 7 summarizes the main conclusion of this work.