Development of a Phenomenological Combustion Model for Large Bore Dual Fuel Engines

Abstract

Nowadays, the industry of large-bore engines is facing a period of great innovation. From one side, the need to reduce greenhouse gas emissions is driving all the engine manufacturers to consider sustainable fuels such as bio- and e-fuels (e.g., biomethane, ammonia, hydrogen). On the other side, market demands are becoming increasingly challenging, as multiple conflicting requirements of fuel flexibility and efficient engine operation, investment and operational costs reduction have to be considered simultaneously. To effectively address these market needs, the costs and development times of new products must be reduced. In this context, the exploitation of simulation codes is assuming increasing importance throughout the early stage of the development and calibration processes. More in detail, focusing on the field of large bore dual fuel engines, the exploitation of reliable and fast-running 0D/1D simulation codes has the great potential to partially substitute expensive and highly time-consuming testing activities devoted to the engine concepts definition and calibrations. However, a considerable difficulty when dealing with 0D/1D numerical simulation is represented by the accurate simulation of the combustion process.

Therefore, the aim of the herein study is to develop a phenomenological combustion model for large bore dual fuel engines and assess the predictive capabilities of the proposed model when exploited for system-level simulations. The developed model combines a multi-packet approach for tracking the evolution and the autoignition of the pilot fuel with a two-zone modeling approach to simulate the premixed air-gas mixture flame propagation. The specific properties of the fuels involved in the combustion process and their mutual interaction were considered by developing and implementing a refined ignition delay model and optimizing specific laminar and turbulent flame speed correlations for high-pressure and lean air-gas mixtures. To evaluate the turbulence flow properties, a 0D turbulence model was integrated and correlated against 3D-CFD simulation results.

Moreover, two additional sub-models were considered in this activity. Specifically, a multi-zone Nitrogen Oxides (NOx) model was developed and integrated into the combustion model to evaluate the NOx emissions during the engine operation and consider them in virtual calibration activities. Similarly, a knock model was additionally included in the proposed numerical tool. The knock model was developed considering the cycle-by-cycle variation of the engine and intended to predict the knock likelihood associated with a simulated engine operating condition.

The phenomenological combustion model was developed and correlated based on the data related to a Wärtsilä single-cylinder research engine (310 mm bore), from which an extensive experimental dataset was available. Subsequently, the model was validated on a multi-cylinder Wärtsilä engine (460 mm bore). The results of the proposed dual fuel combustion models were evaluated for both the case studies and compared against experimental measurements available from the Wärtsilä laboratories measurements. The capabilities of the proposed model to reproduce the main observed trends are presented and discussed, as well as the main limitation and critical conditions for the developed combustion model.