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Modeling of particulate matter emissions from engine combustion

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ABSTRACT

In the present study, a new approach for modelling emissions of coke particles or cenospheres from large diesel engines using HFO (Heavy fuel oil) was studied. The used model is based on a multicomponent droplet mass transfer and properties model that uses a continuous thermodynamics approach to model the complex composition of the HFO fuel and the resulting evaporation behavior of the fuel droplets. Cenospheres are modelled as the residue left in the fuel droplets towards the end of the simulation. The mass-transfer and fuel properties models were implemented into a cylinder section model based on the Wärtsilä W20 engine in the CFD-code Star CD v.4.24. Different submodels and corresponding parameters were tuned to match experimental data of cylinder pressures available from Wärtsilä for the studied cases. The results obtained from the present model were compared to experimental results found in the literature. The performance of the model was found to be promising although conclusive validation of the model would require more detailed experimental results about cenosphere emissions from the specific case studied here. According to the results obtained from this model the emissions of cenospheres are a function of both operating conditions and fuel properties. While the droplet evaporation and properties models were in this study used to model cenosphere emissions, the approach could also be used to study the combustion behavior of HFO in a broader sense.

INTRODUCTION

Despite ever tightening restrictions on emissions and emerging alternative fuels, Heavy Fuel Oil (HFO) will still remain an important fuel for the foreseeable future, especially within the maritime transport industry[1], [2]. While the market share of HFO might decrease over time, from about 80 % in 2010 due to the emergence of alternative fuels, Lloyds Register Marine still forecasts the share of HFO in the marine fuel market in 2030 to be between 47 % and 66 % [1]. With the increase in fuel demand this means that the total consumption of HFO is actually likely to increase in the near future.

This continuing prevalence of HFO as a transport fuel coupled with tightening environmental regulations means that there will be a demand for emissions abatement solutions for HFO combustion processes [2]. Additionally optimization of HFO combustion process is also useful for minimizing the challenges presented by using heavy fuels in large diesel engines. One challenge presented by using heavy fuel in an engine is the different behaviour with regards to emissions of particulate matter(PM) compared to operation with lighter fuels. PM emissions modelling in diesel combustion processes is generally focused on modelling soot particles formed in gas phase reactions between fuel molecules. Although this may give an accurate estimate when modelling emissions from operation with light distillate fuels, in combustion of HFO other mechanisms of PM formation are prevalent and gas phase soot presents only a fraction of total PM. The larger amount of impurities in HFO leads to larger emissions of ash and sulphates. In addition to this, the poorly evaporating heavy molecules present in HFO can lead to the formation of carbonaceous residue directly from the fuel droplets. While the ash emissions are easily estimated from the ash content in the fuel, predicting the emissions of the carbonaceous particles formed from the fuel droplets, commonly referred to as cenospheres, is more complicated.

According to Ikegami et al. [3] the combustion process of a HFO droplet consists of two distinct phases, a liquid droplet phase and a solid coke particle phase. First