Michael I. Foteinos[1]
Laboratory of Marine Engineering,
National Technical University of Athens,
P.O. Box 64501, Zografou Campus,
Athens 15704, Greece
e-mail: m.foteinos@lme.ntua.gr

Stavros K. Konstantinidis
Laboratory of Marine Engineering,
National Technical University of Athens,
P.O. Box 64501, Zografou Campus,
Athens 15704, Greece
e-mail: skonstantinidis@lme.ntua.gr

Nikolaos P. Kyrtatos
Laboratory of Marine Engineering,
National Technical University of Athens,
P.O. Box 64501, Zografou Campus,
Athens 15704, Greece
e-mail: nkyrt@lme.ntua.gr

Kræn Vodder Busk
MAN Energy Solutions,
Teglholmsgade 41,
Copenhagen 2450, Denmark
e-mail: kraenv.busk@man-es.com

Simulation of the Transient Thermal Response of a High Pressure Selective Catalytic Reduction Aftertreatment System for a Tier III Two-Stroke Marine Diesel Engine

The IMO tier III legislation, applicable to vessels with a keel laying date from Jan. 1, 2016, has compelled engine builders to apply new technologies for NO_x abatement. One of the most promising technologies for tier III compliance is the selective catalytic reduction (SCR) of nitrogen oxides (NO_x). Despite that SCR technology has been applied in powerplants and heavy duty truck engines for years, there are challenges that stem from its applications in large two-stroke marine diesel engines. In this paper, an SCR model applicable to large two-stroke marine diesel engines is introduced. The goal of the model is to predict the thermal response of a marine SCR aftertreatment system when the engine undergoes transient loading. The model has been developed and validated using testbed measured data from a large two-stroke marine diesel engine. The output of the model is the SCR outlet temperature. It is shown that the model can accurately predict the transient inertial response of the SCR during engine acceleration, deceleration, and low load operation. [DOI: 10.1115/1.4042131]

1 Introduction

Ships with a keel laying date from Jan. 1, 2016, have to comply with the IMO tier III NO_x emission limits when sailing within the NO_x emission controlled areas [1]. These areas currently include the North American coast, parts of Canada, and the Caribbean Sea. As of Jan. 1, 2021 the North Sea and the Baltic Sea will also be designated as NO_x emission controlled areas [2]. A 75% reduction of NO_x emissions from tier II is required in order to comply with the new regulations. One promising solution for tier III compliance is the selective catalytic reduction (SCR). Although SCR has been long used in powerplants and in heavy duty truck engines, there are challenges in the application of SCR in marine two-stroke diesel engines using heavy fuel oil.

The SCR inlet temperature should ideally be around 330 and 350 °C when the engine is operated on heavy fuel oil with a high sulfur content. If the exhaust temperature drops below 300 °C, ammonium bisulfate (ABS) may be formed on the catalyst surface and clog the reactor. In four stroke engine applications, the exhaust gas temperature after the turbine is adequately high for SCR operation. On the other hand, in two stroke diesel engines, the exhaust gas temperature after the turbine lies between 230 and 260 °C due to the high thermal efficiency of these engines and the mixing of exhaust gas with fresh air during scavenging. By placing the reactor before the turbine (high pressure SCR), it is possible to obtain SCR inlet temperatures about 50–200 °C higher than the ones obtained if the reactor is placed on the low pressure side of the turbine (low pressure SCR) [3].

By placing the SCR on the high pressure side of the turbine, the coupling between the engine and the turbocharger is affected due to the large thermal inertia of the SCR reactor. This might lead to temperature oscillations especially during low load operation [4].

Due to these challenges, extensive testing is required for the development of SCR technology. However, the performance of tests in large marine diesel engines is limited due to the high cost required for such tests. Therefore, it would be valuable to be able to simulate the SCR thermal response during the design process. This paper presents an SCR model for simulating the transient thermal behavior of a marine SCR unit. The output of the model is the outlet temperature of the SCR unit. The model was developed to be connected with an engine model in order to simulate the complete engine-SCR system during transient engine operation.

1.1 Literature. A large number of publications deal with SCR modeling in medium and heavy-duty four-stroke applications. In such applications, the reactor size is small, and hence, the influence of the reactor thermal inertia on the transient thermal behavior of the SCR is not of high importance. As a result, most publications focus on chemical modeling and the prediction of NO, NO_2, and NH_3 concentrations at SCR outlet rather than the SCR thermal behavior. Such models can be found in Refs. [5–9]. A control-oriented model investigating the temperature dynamics of SCR, diesel oxidation catalyst (DOC), and diesel particulate filter (DPF) in a medium duty engine is presented in Ref. [10]. The thermal inertia of a DOC for a medium-duty engine during load transients is investigated in Ref. [11]. The ash impact on DPF backpressure is examined using experimental and modeling approaches in Ref. [12].

Publications on SCR models for large two-stroke engines are much fewer. Experimental results from a large two stroke marine diesel equipped with a high pressure SCR system can be found in Ref. [13]. The effect of reactor thermal inertia in engine-SCR operation and the appearance of temperature oscillations is discussed in Ref. [4] using a SCR thermal model which is, however, not presented in the paper. A simplified approach on an SCR heating model can be found in Ref. [14]. The importance of the reactor

[1]Corresponding author.

Manuscript received March 19, 2018; final manuscript received November 13, 2018; published online January 10, 2019. Assoc. Editor: David L.S. Hung.