Applied Thermal Engineering 37 (2012) 344–352

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Validation of a zero-dimensional model for prediction of NO_x and engine performance for electronically controlled marine two-stroke diesel engines

Fabio Scappin [a], Sigurður H. Stefansson [a], Fredrik Haglind [a,*], Anders Andreasen [b], Ulrik Larsen [a]

[a] Technical University of Denmark, Department of Mechanical Engineering, DK-2800 Kgs. Lyngby, Denmark
[b] MAN Diesel & Turbo, Engine Process Research, Process Development, Marine Low Speed Development, Teglholmsgade 41, DK-2450 Copenhagen SV, Denmark

ARTICLE INFO

Article history:
Received 24 May 2011
Accepted 22 November 2011
Available online 30 November 2011

Keywords:
Diesel engine
Modeling
Engine tuning
NO_x
Performance
Optimization
Emissions
Zero-dimensional

ABSTRACT

The aim of this paper is to derive a methodology suitable for energy system analysis for predicting the performance and NO_x emissions of marine low speed diesel engines. The paper describes a zero-dimensional model, evaluating the engine performance by means of an energy balance and a two zone combustion model using ideal gas law equations over a complete crank cycle. The combustion process is divided into intervals, and the product composition and flame temperature are calculated in each interval. The NO_x emissions are predicted using the extended Zeldovich mechanism. The model is validated using experimental data from two MAN B&W engines; one case being data subject to engine parameter changes corresponding to simulating an electronically controlled engine; the second case providing data covering almost all model input and output parameters. The first case of validation suggests that the model can predict specific fuel oil consumption and NO_x emissions within the 95% confidence intervals given by the experimental measurements. The second validation confirms the capability of the model to match measured engine output parameters based on measured engine input parameters with a maximum 5% deviation.

1. Introduction

The development of marine low speed diesel engines with lower emissions is primarily driven by the MARPOL Annex VI regulation [1] adopted by the International Maritime Organization (IMO). MARPOL Annex VI contains regulations on NO_x, SO_x and Particulate Matter emissions. On July 1, 2010 the revised MARPOL Annex VI entered in to force and it contains new limits for NO_x emissions for both new and existing ships as well as reduced SO_x and PM emissions for all ships.

Allowable NO_x emissions are reduced to 14.4 g/kWh for large marine low speed engines ($\leq$130 rpm) installed on ships constructed from January 1, 2011 and onwards, according to the Tier II standard, and to 3.4 g/kWh for engines installed on ships constructed from January 1, 2016 and onwards, according to the Tier III standard in designated emission control areas.

The widely used low speed two-stroke diesel engine can be combined with a waste heat recovery unit and potentially offer uniquely high fuel efficiency and low specific emissions for diesel engine ship propulsion. In designing and optimizing such a combined energy system, the focus is on the interaction among components in the system rather than on component behavior. Furthermore the newly adapted Engine Efficiency Design Index (EEDI), expected to enter into force on January 1, 2013 [2], may impose further constraints on the layout of the engine, auxiliaries, etc. Thus, a fast, yet thermodynamically realistic engine model which can be integrated with an energy system analysis software is highly desired for optimizing engine performance in combination with waste heat recovery for minimal NO_x as well as Green House Gas (GHG) emissions.

The literature offers various modeling methodologies for the internal combustion engine. Scope of the application, accuracy and calculation time demand, are the determining parameters for the modeling approach [3–8]. Zero-dimensional models [9–13] with a few combustion zones are effective tools for providing reasonable estimations of NO_x emissions and/or engine performance with low computational effort. Multi-zone combustion models [14–20] seem to offer more accurate NO_x predictions, a more realistic modeling of the fuel spray, as well as provide the modeling of other emissions such as soot. These advantages come with the cost of increased computing time, possibly without providing additional information essential for energy system analysis.

Analytical models for cycle simulation of four-stroke engines and HCCI engines have been described with some validation

* Corresponding author. Tel.: +45 45 25 41 13; fax: +45 45 93 52 15.
E-mail address: frh@mek.dtu.dk (F. Haglind).

1359-4311/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2011.11.047