HERCULES-2 Project

Fuel Flexible, Near Zero Emissions, Adaptive Performance Marine Engine

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Compendium of scientific papers published by the Consortium

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Work Package Leader Responsible: Nikolaos P. Kyrtatos (NTUA)

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1 Summary

Work Package 11 of the HERCULES-2 Project covers the Dissemination Activities of the Project. The objectives are the communication of the results to the scientific community and the general public. The contents of Deliverable 11.3 focus on the scientific publications of the HERCULES-2 Project from the beginning to the end of the Project (Months 1-42).

2 Scientific Publications

The scientific publications are based on the partners' work that has been conducted in the context of the HERCULES-2 Project and are part of the Dissemination activities. These publications refer to important achievements of the Project and have been presented in Congresses, Conferences and Meetings worldwide. To date 47 publications have been made. They aim to publishing the Foreground Knowledge, to advancing the state if knowledge in the field and also to obtaining recognition of the Partners. It must be noted that using results obtained in the Project, several additional scientific papers are in preparation and will be published after month 42 of the project.

Due to the Partners' common interest in obtaining valid intellectual property protection, a Consortium Agreement with reference to the procedure of Publications was signed by all Partners. According to the Consortium Agreement, each paper should prior to publication be circulated for approval to all Partners. In any case of the other Parties considered that the protection of their Knowledge would be adversely affected, it could object to the publication within a period of 15 days from receipt of the proposed publication.

A list of the publications as they appear in the publicity section of the HERCULES-2 website is presented below:

Table of HERCULES-2 Scientific Publications

#	Title	WP	Conference/ journal	Date Approved	Authors
1	Adaptive power-split control design for marine hybrid diesel powertrain	5	ASME Journal of Dynamic Systems, Measurement and Control	11/5/2016	S. Samokhin, S. Topaloglou, G. Papalambrou, K. Zenger, N. Kyrtatos
2	A Model of a Marine Two-Stroke Diesel Engine with EGR for Low Load Simulation	6	EUROSIM 2016, Oulu, Finland	11/5/2016	X. Llamas, L. Eriksson
3	SCR under pressure - pre-turbocharger NOx abatement for marine 2-stroke diesel engines	7	28th CIMAC, Helsinki, Finland, June 2016	19/5/2016	K. Sandelin, D. Peitz
4	From HERCULES A-B-C to HERCULES-2 : A classic cooperative programme in large engine R&D	10	28th CIMAC, Helsinki, Finland, June 2016	19/5/2016	N. Kyrtatos, G. Stiesch, I. Kallio
5	Investigation of Different Piston Ring Curvatures on Lubricant Transport along Cylinder Liner in Large Two-Stroke Marine Diesel Engines	6	17th Nordic Symposium on Tribology 2016	19/5/2016	H.C. Overgaard, P. Klit, A. Voelund

6	Engine Knock Margin Estimation Using In-Cylinder Pressure Measurements	5	IEEE/ASME Transactions on Mechatronics	14/6/2016	G. Panzani, F. Ostman, C. Onder
7	Parameterizing compact and extensible compressor models using orthogonal distance minimization.	6	ASME Journal Engineering for Gas Turbines and Power	27/6/2016	X. Llamas, L. Eriksson
8	Measuring injection of urea solution into a high pressure hot gas test rig for SCR-applications	8	International Congress of Engine Combustion Processes: Current Problems and Modern Techniques	19/12/2016	M. Höltermann, N. Kawaharada, J. Wichmar, F. Dinkelacker
9	Control-Oriented Compressor Model with Adiabatic Efficiency Extrapolation	6	SAE World Congress and Exhibition 2017	21/12/2016	X. Llamas, L. Eriksson
10	Investigation of Ammonia Synthesis for Large Scale SCR-Applications by Means of a Hot Gas Test Rig	8	8^{th} European Combustion Meeting 2017 in Dubrovnik, Croatia	18/12/2017	M. Höltermann, J. Wichmar, T. Wittenbreder, F. Dinkelacker
11	Analysis of Cylinder Pressure Measurement Accuracy for Internal Combustion Engine Control	5	SAE World Congress 2017, Detroit, Michigan, USA.	27/1/2017	X. Storm, H. Salminen R. Virrankoski, S. Niemi, J. Hyvönen
12	Adaptive and Unconventional Strategies for Engine Knock Control	5	IEEE Transactions on Control System Technology	23/3/2017	D. Selmanaj, S. van Dooren, G. Panzani, J. Rosgren, C. Onder
13	Spray Combustion Chamber: History and Future of a Unique Test Facility	1	28^{th} Conference on Liquid Atomization and Spray Systems ILASS-Europe 2017	3/4/2017	A. Schmid, N. Yamada
14	Design and experiments to investigate spray and impingement characteristics of a common rail type lubrication system	5	28^{th} Conference on Liquid Atomization and Spray Systems ILASS-Europe 2017	20/4/2017	M. Stark, A.de Risi, M. Giangreco, S. Diggelmann
15	Engine knock margin control using in-cylinder pressure data: preliminary results	5	56^{th} IEEE Conference on Decision and Control (CDC2017)	20/4/2017	G. Panzani,D. Selmanaj, O. Gallupi, S. Savaresi, J. Rösgren, C. Onder
16	Model Predictive Control for Hybrid Diesel-Electric Marine Propulsion	5	IFAQ 2017 World Congress	25/4/2017	G. Papalambrou, S. Samokhin, S. Topaloglou, N. Planakis, N. Kyrtatos, K. Zenger
17	Flow in axisymmetric expansion in a catalytic converter	8	12^{th} International Symposium on Particle Image Velocimetry	12/5/2017	E. Gotfredsen, K.E. Meyer
18	Modeling of particulate matter emissions from engine combustion	1	SAE 2017 International Powertrains, Fuels and Lubricants Meeting	18/5/2017	K. Hentelä, O. Kaario, M. Larmi, V. Garaniya, L. Goldsworthy
19	Investigation of the Combined Application of Water-in-Fuel Emulsion and Exhaust Gas Recirculation in a Medium Speed Diesel Engine	7	9th International Conference on Modeling and Diagnostics for Advanced Engine Systems (COMODIA 2017), July 25-28, 2017, Okayama, Japan	6/6/2017	B. von Rotz, P. Kyrtatos, K. Herrmann, K. Boulouchos
20	Feasibility of new liquid fuel blends for medium-speed engines	1	Fuel journal	30/6/2017	K. Sirviö, S. Niemi, S. Heikkilä, M. Hissa, E. Hiltunena
21	Transient Load Share Management of a Diesel Electric Hybrid Powertrain for Ship Propulsion	5	International Journal of Powertrains	28/7/2017	S. Topaloglou, G. Papalambrou, K Bardis, N. Kyrtatos
22	Calibration method for the determination of the FAME and HVO contents in fossil diesel blends using NIR spectroscopy	1	Fuel journal	8/8/2017	L. Sherman, S. Heikkilä, K. Sirviö, S. Niemi, P. Välisuo, A. Niemi
23	An Optical Investigation of Diesel-Pilot and Methane Dual-Fuel Combustion	1	Nordic flame days 2017	4/10/2017	Z. Ahmad , J. Aryal, O. Ranta, O. Kaario, M.Larmi

24	Investigation of the Cylinder Cut-Out for Medium Speed Dual Fuel Engines	6	Heavy-Duty - On- and Off-Highway Engines /MTZ Industrial 1/2018	4/10/2017	J. Konrad, T. Lauer, M. Moser, J. Zhu
25	Influence of the Al content on the aqueous corrosion resistance of binary Fe-Al alloys in H2SO4	3	Proceedings Intermetallics 2017	2/11/2017	J. Peng, F. Moszner, D. Vogel, M. Palm
26	Kinematic viscosity studies for medium-speed CI engine fuel	1	Agronomy Research	16/2/2018	K. Sirviö, R. Help, S. Niemi, S. Heikkilä, E. Hiltunen
27	Properties of local produced animal-fat based biodiesel and its blend with fossil fuel	1	Agronomy Research	16/2/2018	K. Sirviö, S. Heikkilä, R. Help, S. Niemi, E. Hiltunen
28	Crank Shaft Torsional Vibration Analysis on the perspective of Improving the Crank Angle Measurement Accuracy for Closed-loop Combustion Control in ICES	5	SAE World Congress 2018	17/2/2018	X. Storm, H. Salminen, R. Virrankoski, S. Niemi, J. Hyvonen
29	Engine Efficiency Optimization under Consideration of NOX- and Knock-Limits for Medium Speed Dual Fuel Engines in Cylinder Cut-Out Operation	6	SAE World Congress 2018	17/2/2018	J. Konrad, T. Lauer, M. Moser
30	Control-oriented modeling of two-stroke diesel engines with EGR for marine applications	6	SAGE Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment	9/3/2018	X. Llamas, L. Eriksson
31	Predictive Control for a Marine Hybrid Diesel-Electric Plant During Transient Operation	5	5th International Conference on Control, Decision and Information Technologies	13/3/2018	N. Planakis, G. Papalambrou, N. Kyrtatos
32	Combustion Property Analyses with Variable Liquid Marine Fuels in Combustion Research Unit	1	Agronomy Research	17/3/2018	M. Hissa, S. Niemi K. Sirviö
33	Impact of catalyst activity and geometry on diffusion and SCR kinetics under elevated pressures	7	Chemie Ingenieur Technik" WILEY-VCH	30/3/2018	D. Peitz, M. Elsener, O. Kröcher
34	High-pressure pyrolisis and oxidation of ethanol	2	Fuel Journal	15/3/2018	H. Hashemi, J.M. Christensen, P. Glarborg
35	High-pressure oxidation of ethane	2	Combustion & Flame Journal		H. Hashemi, J. Jacobsen, C. Rasmussen, J. Christensen , P. Glarborg, S. Gersen, M. van Essen, H. Levinsky, S. Klippenstein
36	Towards a temperature dependent and probabilistic lifetime concept for nodular ductile cast iron materials undergoing isothermal and thermo-mechanical fatigue	4	Fatigue 2018	11/4/2018	E.G. Trelles, C. Schweizer, S. Eckmann
37	Influence of the Al content and Pre-oxidation on the Aqueous Corrosion Resistance of Binary Fe-Al Alloys in Sulphuric Acid	3	Corrosion Science	8/6/2018	J. Peng, F. Moszner, J. Rechmann, D.Vogel M.Palm, M. Rohwerder
38	Experimental analysis of fuel alternatives for marine propulsion systems	1	ICLASS 2018	13/6/2018	A. Schmid, R. Bombach, T. Yildirim
39	NH_3 sensor measurements in different engine applications	7	SAE INTERNATIONAL POWERTRAINS, FUELS & LUBRICANTS MEETING conference	2/7/2018	T. Murtonen, H. Vesala, P. Koponen, R. Pettinen, T. Kajolinna, O. Antson
40	Skip Firing in Medium Speed Dual Fuel Engines: Detailed Assessment and Engine Performance Optimization in Compliance with IMO Tier III	6	Rostocker Großmotorentagung	18/7/2018	J. Konrad, T. Lauer, M. Moser, E. Lockner, J. Zhu
41	Isothermal Oxidation Behavior of Tribaloy™ T400 and T800	3	NPJ Materials Degradation Journal	21/7/2018	J. Peng, X. Fanga, V. Marx, U. , M. Palm
42	Development of a shear ultrasonic spectroscopy technique for the evaluation of viscoelastic fluid properties: theory and experimental validation.	5	Elsevier Journal Ultrasonics	26/7/2018	M. Schirru, X.Li, M. Cadeddu, R.S. Dwyer-Joyce
43	Transient Simulation of a Large Two-Stroke Marine Diesel Powerplant Operation with a High Pressure SCR Aftertreatment System	6	27th Aachen Colloquium Automobile and Engine Technology 2018	26/7/2018	M. Foteinos, N. Kyrtatos

44	Robustness analysis of the next generation of EGR controllers in marine two-stroke diesel engines	6	International Ship Control Systems Symposium 2018 (iSCSS 2018)	14/8/2018	X. Llamas, L. Eriksson
45	Eindüsung von Harnstoff-Wasser-Lösung mit Zweistoffdüsen für großskalige SCR-Systeme unter Druck	8	16. FAD-Conference "Herausforderung - Abgasnachbehandlung für Dieselmotoren"	25/9/2018	M. Höltermann, P. Roloff, F. Dinkelacker
46	SCR beschichteter Dieselpartikelfilter für schnelllaufende Vier-takt-Dieselmotoren im Marinebereich	8	16. FAD-Conference "Herausforderung - Abgasnachbehandlung für Dieselmotoren"	26/10/2018	M. Kleinhenz, A. Fiedler, A. Döring
47	SCR coated DPF for Marine Engine Applications	8	11th International Congress on Catalysis and Automotive Pollution Control	26/10/2018	M. Kleinhenz, P. Lauer, A. Fiedler, A. Döring

3 Appendix

In the Appendix that follows the first page of all the publications is included.

Adaptive power-split control design for marine hybrid diesel powertrain

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It is known that mechanical wear and tear of components of large marine engines throughout their lifetime can cause the engine dynamics to alter. Since traditional control systems with fixed parameters cannot deal with this issue, the engine performance may degrade. In this work, we introduce adaptive control algorithms capable of adapting the control system in order to preserve the engine performance once its dynamics deviate from the nominal ones. Particularly, direct and indirect model reference adaptation mechanisms are studied. In this work, the case of degraded oxygen sensor is investigated as an example of engine components deterioration throughout its lifetime. The controllers are implemented in Simulink and their performance is evaluated under both nominal and degraded sensor conditions. Specifically, the sensor degradation is imitated by altering its time-delay. In such conditions, adaptive controllers demonstrate a notable improvement in tracking performance compared to the fixed parameters PI controller. Finally, the designed controllers are validated on the hybrid marine engine testbed using dSpace rapid prototyping system.

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1 Introduction

During the last decades, marine diesel engine emission regulations have become increasingly stringent due to stricter environmental requirements imposed by the International Maritime Organization (IMO) [1]. As a result, achievement of near-zero emissions has recently become one of the key targets for marine engine manufacturers [2,3].

Recently, the combination of an internal combustion engine with an electric motor has emerged as a powerful approach for reducing emissions within the automotive industry [4]. A large number of research papers has been devoted to evaluating various aspects of hybrid electric vehicles (HEVs), including components sizing, control systems design and topologies investigations. The control of HEVs is usually categorized into rule- and optimization-based algorithms [5]. Various optimization-based algorithms have been proposed for HEVs control, including model-predictive control [6], optimal control based on Pontryagin's minimum principle [7,8], and genetic algorithms [9]. Typ-

A Model of a Marine Two-Stroke Diesel Engine with EGR for Low Load Simulation

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***Abstract*—A mean value engine model of a two-stroke marine diesel engine with EGR that is capable of simulating during low load operation is developed. In order to be able to perform low load simulations, a compressor model capable of low speed extrapolation is also investigated and parameterized for two different compressors. Moreover, a parameterization procedure to get good parameters for both stationary and dynamic simulations is described and applied. The model is validated for two engine layouts of the same test engine but with different turbocharger units. The simulation results show a good agreement with the different measured signals, including the oxygen content in the scavenging manifold.**

I. Introduction

The marine shipping industry is facing increased demands in the reduction of harmful exhaust gas emissions. Stricter emission limits of Sulphur Oxides (SOx) and Nitrogen Oxides (NOx) are imposed in certain Emission Control Areas (ECAs). The emission values to fulfill in these ECAs are set by the IMO Tier III limits [1] that came into play in January 2016. One of the available technical solutions to achieve the targeted reduction in NOx emissions is Exhaust Gas Recirculation (EGR). An EGR system recirculates a fraction of the exhaust gas into the scavenging manifold, providing burned gases in the combustion chamber that directly decreases the production of NOx during the combustion.

EGR technologies for two-stroke engines are still at the initial phases of its development. In addition, there are not many available vessels with an EGR system installed and thus performing tests is often difficult. Furthermore, testing any new system in marine two-stroke engines is also very costly mainly due to the fuel cost associated with the sizes of such engines. Hence, in order to improve the performance of the EGR control systems, a fast and accurate simulation model is a very valuable tool.

Mean Value Engine Models (MVEMs), are a very common approach for control oriented modeling of internal combustion engines. In particular, EGR systems have been also modeled using this approach. Many interesting research articles about EGR modeling in automotive applications can be found in the literature, some examples are, [2] and [3]. On the other hand, marine two-stroke engines have not been widely studied. Nevertheless, some research papers focused on MVEMs for two-stroke engines are [4], [5] and [6]. In addition, in [7] the modeling of the low load operation of a two-stroke engine without EGR is studied.

The work presented here is an extension of the model proposed in [8], which enables the model to simulate low engine loads. The low load operation is very relevant for the EGR control since the Tier III emission limits have to be fulfilled near certain coasts, e.g. harbors, where the vessel is normally operating at low loads. The main new component that needs to be introduced for this low load simulation is the auxiliary electrical blower. Its mission is to ensure that there is enough scavenging pressure at low loads when the turbocharger is not capable to provide it. Moreover, the turbocharger model will be required to simulate at low speeds and pressure ratios. This area is normally not measured in the provided performance maps, so a model that can extrapolate to this area is also required.

The developed model is, as in [8], based on the 4T50ME-X test engine from MAN Diesel & Turbo. The 4T50ME-X is a two-stroke uniflow diesel engine, turbocharged, with variable valve timing and direct injection. Its maximum rated power is $7080\, kW$ at $123\, rpm$. Also, it is equipped with an EGR system and a Cylinder Bypass Valve (CBV).

II. Experimental data

The targeted test engine is constantly being rebuilt to test new components and new control strategies. This implies that it is difficult to find measurement data from the same engine configuration. Most of the measurement data available is from the same layout as the data used in [8]. For layout number 1 the oxygen sensors were not properly calibrated and thus cannot be used for validating the oxygen levels at the manifolds. For the model parameterization 30 different stationary points are extracted from the measurement data. another 24 stationary points are saved for the validation.

Some more data is available from another layout of the engine and will be used for validation of the oxygen level in the scavenging manifold. However, in this layout, number 2, the turbocharger was changed and some sensors where removed. Moreover, there is much less data available, and only 18 stationary points could be extracted for the parameterization and the validation of the model.

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SCR under pressure - pre-turbocharger NOx abatement for marine 2-stroke diesel engines

Topic 07 Exhaust Gas Aftertreatment

Kristoffer Sandelin, Winterthur Gas & Diesel

Daniel Peitz, Winterthur Gas & Diesel

This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country.
The Congress programme centres around the presentation of Technical papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The topics of the 2016 event covered Product Development of gas and diesel engines, Fuel Injection, Turbochargers, Components & Tribology, Controls & Automation, Exhaust Gas Aftertreatment, Basic Research & Advanced Engineering, System Integration & Optimization, Fuels & Lubricants, as well as Users' Aspects for marine and land-based applications.

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HELSINKI | JUNE 6–10, 2016

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From HERCULES A-B-C to HERCULES-2 : A classic cooperative programme in large engine R&D

Topic 08 Basic Research & Advanced Engineering

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GUNNAR STIESCH, MAN DIESEL & TURBO,
ILARI KALLIO, Wärtsilä

This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country.
The Congress programme centres around the presentation of Technical papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The topics of the 2016 event covered Product Development of gas and diesel engines, Fuel Injection, Turbochargers, Components & Tribology, Controls & Automation, Exhaust Gas Aftertreatment, Basic Research & Advanced Engineering, System Integration & Optimization, Fuels & Lubricants, as well as Users' Aspects for marine and land-based applications.

Investigation of Different Piston Ring Curvatures on Lubricant Transport along Cylinder Liner in Large Two-Stroke Marine Diesel Engines.

Hannibal Christian Overgaard*, Peder Klit*
and Anders Vølund†

April 25, 2016

Abstract

A theoretical investigation of the hydrodynamic lubrication of the top compression piston ring in a large two-stroke marine diesel engine is presented. The groove mounted piston ring is driven by the reciprocal motion of the piston. The ring shape follows a circular geometry and the effect of changes in radii is analysed.

A numerical model based on the finite difference method in 1D has been developed for solving Reynold's equation in combination with the load equilibrium equation together with flow continuity between the piston ring surface and liner for analysis of the lubricant transport.

The cyclic variation throughout one stroke is presented for the minimum film thicknesses at different interesting locations of the piston ring surface together with the friction and the pressure distribution history. The before mentioned parameters have been investigated numerically. The numerical results are presented and discussed.

Keywords: lubricant transport, Reynold's equation, piston ring lubrication, finite difference method, perturbation of Reynold's equation, hydrodynamic lubrication, flow continuity, lubricant starvation.

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Engine knock margin estimation using in-cylinder pressure measurements

Giulio Panzani, Fredrik Östman and Christopher Onder

***Abstract*—Engine knock is among the most relevant limiting factors in the improvement of the operation of spark ignited engines. Due to an abnormal combustion inside the cylinder chamber, it can cause performance worsening or even serious mechanical damage. Being the result of complex local chemical phenomena, knock turns out to have a significant random behaviour but the increasing availability of new on-board sensors permits a deeper understanding of its mechanism. The aim of this paper is to exploit in-cylinder pressure sensors to derive a knock estimator, based on the logistic regression technique. Thanks to the proposed approach it is possible to explicitly deal with knock random variability and to define the so-called *margin* (or *distance*) from the knocking condition, which has been recently proven to be an effective concept for innovative knock control strategies. In a model-based estimation fashion, two modelling approaches are compared: one relies on well-known physical mechanisms while the second exploits a principal component analysis to extract relevant pressure information, thus reducing the identification effort and improving the estimation performance.**

***Index Terms*—Engine knock estimation, knock control, in-cylinder pressure sensors, logistic regression, principal component analysis**

I. Introduction and Motivation

THE combustion process in SI engines is normally triggered by the spark, whose timing is accurately defined in order to achieve the desired engine performance. In particular engine operating conditions, a too early spark timing may cause an abrupt unburned mixture (end-gas) self-ignition, due to the high temperature and pressure conditions reached inside the cylinder chamber. This event is usually termed *knock*, recalling the typical metallic sound caused by the shock waves generated by the spontaneous detonation of the air/fuel mixture. Such event limits the improvement of engine performance, being responsible for some undesirable effects: while it can cause serious cylinder damages, less dramatic consequences are powertrain oscillations, a general decrease of engine efficiency and an increase of pollutant emissions [1]. An accurate control of SI timing has thus lately become a crucial issue in the development of advanced combustion control systems.

In the scientific literature specific attention has been paid to the knock event due to its applicative relevance. The air/fuel self ignition is the result of complex local phenomena in the cylinder chamber and as such shows significant experimental random nature. For this reason, the first research efforts have been devoted mainly to knock sensing and detection [2], [3], with the development of techniques and technologies that, flanked with efficient signal processing algorithms, could be able to reliably discriminate knocking from not knocking cycles (and, if possible, to quantify the detonation severity).

Knock control strategies developed consequently: the standard approach, which has been widely adopted in series production, can be classified as event-based where, based on simple [4] or more complex [5] rules, a single measured knock occurrence causes a controller intervention. In order to cope with knock random nature, stochastic knock control strategies have been recently proposed. Their main idea is to compare the statistic knock properties of the current engine operating point (rather than considering each event individually) with a target value and to adapt the control action accordingly. In [6] the feedback statistic is established as a cumulative sum of knocking events over a certain number of cycles, whereas in [7] a likelihood ratio approach is employed. In [8] a nonlinear transformation is used to shape the random distribution of the knock events as a Gaussian variable whose mean and variance are recursively estimated and used as feedback signals for the knock control strategy. The advantage of stochastic approaches is the fact that reckoning with the stochastic knock behaviour leads to better mean engine running conditions and to less cyclic variability. The drawback of the mentioned strategies lays in the fact that the feedback statistic signal is built in real-time, which requires several cycles. Given a single engine cycle, out of the current operating point history, no statement about the expected knock rate is possible.

The control strategy proposed by Lezius et al. in [9] approaches the problem differently. It is based on the evidence that cycles with a higher peak pressure are more likely to knock. Engine knock is thus closed-loop regulated tracking a peak pressure reference that is a compromise between engine output torque and engine knock tendency. The distinguishing feature of this approach is the fact that a *margin* (or *distance*) from the knocking condition is defined for any single cycle. In this specific case the cycle peak pressure is used to estimate engine knock and its distance, computed as the error between the measured and the target peak pressure value.

Proper models are required to design such a knock margin estimator. In Lezius' work, the model is implicitly enclosed in the experimental evidence of a more frequent knock occurrence for higher peak pressure cycles. With respect to the real-time stochastic approaches described previously, the additional modelling effort compensates for the advantage of a cycle-to-

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Parameterizing compact and extensible compressor models using orthogonal distance minimization

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A complete and compact control oriented compressor model consisting of a mass flow submodel and an efficiency submodel is described. The final application of the model is a complete two-stroke mean value engine model which requires to simulate the compressor operating at the low flow and low pressure ratio area. The model is based on previous research done for automotive-size compressors and it is shown to be general enough to adapt well to the characteristics of the marine-size compressors. A physics based efficiency model allows, together with the mass flow model, to extrapolate to low pressure ratios. The complexity of the model makes its parameterization a difficult task, hence a method to efficiently estimate the nineteen model parameters is proposed. The method computes analytic model gradients and uses them to minimize the orthogonal distances between the modeled speed lines and the measured points. The results of the parameter estimation are tested against nine different standard marine-size maps showing good agreement with the measured data. Furthermore, the results also show the importance of estimating the parameters of the mass flow and efficiency submodels at the same time to obtain an accurate model. The extrapolation capabilities to low load regions are also tested using low load measurements from an automotive-size compressor. It is shown that the model follows the measured efficiency trend down to low loads.

1 Introduction

The marine propulsion industry is facing new and more strict regulations on the engine exhaust emissions. For example, the Tier III regulations [1] have to be fulfilled for new vessels built from January 2016 on certain emission control areas. For the case of the low speed two-stroke marine engines, industry is developing and testing technologies that have potential in achieving such emission limits. One of these technologies is the Exhaust Gas Recirculation (EGR) that has been widely used in the automotive industry to reduce NO_x formation during combustion and thus exhaust emissions.

Testing is required for the development of the EGR technology. However, performing tests on such big engines is limited mainly due to two reasons. First, there is a lack of available engines to perform such tests, the production numbers are much lower than the automotive case. The second issue is the very high economic cost required to perform tests in those large engines, mainly associated to fuel consumption. Due to these limitations, a reliable and fast dynamic engine model would be a valuable tool for the development of EGR systems and control strategies. A common approach for control oriented engine models is the Mean Value Engine Model (MVEM), which has the particularity that the model is based on average values of the engine cycle. For more information see e.g. [2–4]. Furthermore, [5] contains an overview of the targeted type of two-stroke engine as well as the current modeling status. Such engines contain several components that need to be modeled, and obtaining a reliable control oriented compressor model is one of the first challenges.

A compressor model consists of a mass flow model and an efficiency model, normally more emphasis is found for the mass flow-pressure ratio model in literature. Many different compressor models can be found in literature, in particular many different modeling approaches are investigated for automotive compressors, see e.g. [6,7]. For the much bigger compressors used for turbocharging the low speed two-stroke engines there is less research done. Nevertheless some different models can be found in the literature. In [8] the compressor model is based on the fact that marine engines are loaded following the propeller law, and thus the compressor model has to be accurate only on the projected propeller

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Sitzung: wird vom Editor eingetragen

Messungen zur Eindüsung von wässriger Harnstofflösung in einen Hochdruck-Heißgaskanal für SCR-Anwendungen

Measuring injection of urea solution into a high pressure hot gas test rig for SCR-applications

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Kurzfassung

Die selektive katalytische Reduktion (SCR) ist eine Möglichkeit, Stickoxide (NO_x) in Abgasen zu verringern. Als Reduktionsmittel dient Ammoniak, das durch Einbringung wässriger Harnstofflösung in den Abgasstrang erzeugt wird. Um die SCR-Technik bei Schiffen platzsparend, effizient und betriebssicher einsetzen zu können, müssen die Prozesse der Ammoniaksynthese genauer untersucht werden.
Dazu wurde an der Universität Hannover ein Heißgasprüfstand aufgebaut, mit dem sowohl die Sprayprozesse als auch die chemischen Reaktionen untersucht werden. In dieser Arbeit werden Messungen zur Bestimmung von Tropfengrößen vorgestellt, um den Einfluss des Heißgasdrucks zu beurteilen. Für die Messungen kamen sowohl ein Phasen-Doppler-Anemometer in verschiedenen Messkonfigurationen als auch ein Verfahren zum direkten Tropfen-Imaging zum Einsatz. Die Ergebnisse der einzelnen Messmethoden zeigen, dass sich die Tropfenspektren mit zunehmendem Druck zu größeren Durchmessern verschieben. Quantitativ zeigen die Messungen Abweichungen, die zum Teil auf Phänomene im Versuchsaufbau zurückzuführen sind. Um diese Abweichungen besser beurteilen zu können, ist eine Validierung beider Verfahren geplant.

1. Einleitung

Die internationale Seeschifffahrts-Organisation (International Maritime Organization, IMO) ist für die Definition von Emissionsgrenzwerten für Schiffsmotoren zuständig [1]. Seit Januar 2016 ist die dritte Stufe (Tier III) der Grenzwerte in Kraft getreten, die den Schadstoffausstoß innerhalb von Kontrollzonen regelt. Gegenüber der vorherigen Stufe sind die zulässigen Grenzwerte für Stickoxide (NO_x) in Abhängigkeit der Motordrehzahl auf ca. ein Viertel gesenkt worden [1].
Der selektiven katalytischen Reduktion (SCR) kommt für die Einhaltung der NO_x-Grenzwerte eine Schlüsselrolle zu. Die SCR-Technologie ist sowohl bei Kraftwerksanlagen als auch bei mobilen Anwendungen etabliert. Auch bei Schiffen sind SCR-Systeme bereits anzutreffen, jedoch besteht großer Entwicklungsbedarf, um die Technologie flächendeckend effizient und betriebssicher einsetzen zu können. Ein wesentlicher Punkt ist die Bereitstellung des Reduktionsmittels Ammoniak aus wässriger Harnstofflösung. Dieser Prozess lässt sich aufteilen in das Einsprühen der wässrigen Harnstofflösung sowie in die chemische Umsetzung des Harnstoffs. Um beide Aspekte untersuchen zu können und so die Grundlage für Modellentwicklungen und Validierungen zu schaffen, wurde am ITV der Universität Hannover ein

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Control-Oriented Compressor Model with Adiabatic Efficiency Extrapolation

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ABSTRACT

Downsizing and turbocharging with single or multiple stages has been one of the main solutions to decrease fuel consumption and harmful exhaust emissions, while keeping a sufficient power output. An accurate and reliable control-oriented compressor model can be very helpful during the development phase, as well as for engine calibration, control design, diagnostic purposes or observer design. A complete compressor model consisting of mass flow and efficiency models is developed and motivated. The proposed model is not only able to represent accurately the normal region measured in a compressor map but also it is capable to extrapolate to low compressor speeds. Moreover, the efficiency extrapolation is studied by analyzing the known problem with heat transfer from the hot turbine side, which introduces errors in the measurements done in standard gas stands. Since the parameterization of the model is an important and necessary step in the modeling, a tailored parameterization approach is presented based on Total Least Squares. A standard compressor map is the only data required to parameterize the model. The parameterization is tested with a database of more than 230 compressor maps showing that it can deal well with different compressor sizes and characteristics. Also, general initialization values for the model parameters are provided using the complete database parameterization results. The results show that the model accuracy is good and in general achieves relative errors below one percent. A comparison of the model accuracy for compressor maps with and without heat transfer influence is carried out, showing a similar model accuracy for both cases but better when no heat transfer is present. Furthermore, it is shown that the model is capable to predict the efficiency characteristics at low speed of two compressor maps, measured with near adiabatic conditions.

1 INTRODUCTION

The legislation pressure on the exhaust emission limits drive the automotive industry into researching more advanced technologies. Moreover, the increasing fuel prices, also push the need to develop more and more fuel efficient internal combustion engines (ICE). One of the most popular solutions to achieve these demands is downsizing and turbocharging the ICE. Many examples of boosting systems exist nowadays, e.g. from various turbocharger stages to electrically driven compressors. Introducing more and newer components into a ICE makes the complete system more complex to deal with. First, in terms of system design choices, later due to the complexity that arises from having to control the ICE as efficient as possible. In order to overcome this, having a simulation model to apply model-based control techniques can be very useful to benchmark different system architectures as well as to test different control strategies.

In model-based control, a model that is capable to capture the main dynamic characteristics of the system is required. At the same time, this model has to be computationally low demanding. Mean value engine models (MVEM) fulfill these two requirements, and have been successfully applied to many different types of combustion engines, see e.g. [1, 2, 3]. A control-oriented compressor model is required as a part of the complete MVEM. This family of compressor models has also received significant attention in the automotive research literature, see among many others [4, 5, 6, 7, 8, 9].

In the research literature, the compressor efficiency modeling has received less attention than the mass flow modeling. One reason for that could be the known problem with heat transfer from the hot turbine gases in the gas stand, which introduces errors in the compressor efficiency measurements. This issue has a greater effect at low compressor speeds, as it is pointed out in [10, 11, 12, 13, 14] among many others. The fact that normal compressor maps are only measured down to $35\% - 40\%$ of the maximum rotational speed adds even more uncertainty to what is the true value of the compressor efficiency in this area. This in turn makes the validation of the efficiency extrapolation a difficult task.

The main objective of this investigation is to continue the work carried out in [15] for centrifugal compressors used in marine propulsion. The focus here is to apply the modeling approach together with an updated estimation procedure to automotive compressors. Hence, the general applicability of the model and parameterization method to any compressor size is demonstrated. At the same time an investigation of how the heat transfer affects the compressor efficiency is done. This motivates some changes in the efficiency model compared to

Investigation of Ammonia Synthesis for Large Scale SCR-Applications by Means of a Hot Gas Test Rig

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Abstract
Selective catalytic reduction (SCR) of nitric oxides will play an important role to fulfil actual TIER III emission limits for ships. In order to apply the SCR-technology successfully to marine engines, further research is needed, especially regarding the synthesis of ammonia from aqueous urea solution. Therefore a hot gas test rig was built up at ITV. The test rig offers a broad optical accessibility allowing various measurement techniques to study injection of urea as well as the occurring chemical reactions. The current work focusses on measuring droplet diameters by PDA as well as by a self-developed direct imaging technique.

Introduction

Selective catalytic reduction (SCR) was originally developed for industrial furnaces [1] and has become an established method to reduce nitric oxide emissions of trucks and heavy diesel cars [2]. In January 2016, the next step of emission standards for marine shipping came into operation (Tier III) [3]. Also in this field, SCR will play an important role to fulfil the limits for nitric oxides, as they have decreased to approximately 25% of the former values. Applying the SCR technology to ship engines requires further research and detailed development of such large scale systems. Especially the synthesis of ammonia from aqueous urea solution has to be studied in detail. Therefore, a hot gas test rig was built up at ITV, which is the basis for comprehensive investigations of the urea decomposition. All measurement activities can be divided in the characterisation of the spray process and the investigation of the occurring chemical reactions. The present work presents the hot gas test rig as well as first measurements of droplet spectra by phase-Doppler anemometry (PDA) and direct droplet imaging.

Selective catalytic reduction

SCR is a way to reduce nitric oxides by means of a catalyst and reducing agent, typically ammonia (NH_3). As the reduction is selective, nitric oxides can be removed from gases with excess oxygen. Thus the method is particularly suitable for diesel engines. The Ammonia is provided from aqueous urea solution, which is safer to be stored especially for automotive applications. The urea solution is sprayed into the hot exhaust gas where the water evaporates from the droplets first [2]. The remaining urea is decomposed into ammonia and isocyanic acid (HNCO). HNCO reacts with water and forms ammonia and carbon dioxide.

Thermolysis:
$$(NH_2)_2CO \rightarrow NH_3 + HNCO \quad (1)$$

Hydrolysis:
$$HNCO + H_2O \rightarrow NH_3 + CO_2 \quad (2)$$

The three steps, evaporation, thermolysis and hydrolysis are crucially important and have to be designed in order to have evenly distributed ammonia supply to the catalyst and to prevent unwanted wall interactions which can lead to deposits.

Hot gas test rig

The hot gas test rig consists of tube elements with an inner diameter of approximately 300 mm. It offers the possibility to investigate the whole process chain of ammonia synthesis by a broad optical accessibility. The test rig is unitized in order to achieve maximum flexibility. The sketch of the test rig is shown in Figure 1.

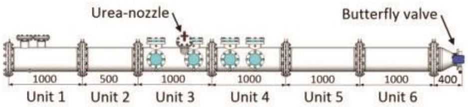

Figure 1: Sketch of unitized hot gas test rig

The first unit contains an oil burner, which provides a hot gas flow up to a temperature of 500°C. The desired operating points, consisting of temperature and gas velocity, are achieved by tuning thermal output of the burner together with secondary air mass flow. Due to this combination, the thermal power output has to cover a range of 1:10, which is achieved without hardware changes in the burner setup. The hot air passes a flow straightener (unit 2) before the actual measurement section start with unit 3. This unit includes the urea nozzle, which currently is a two fluid nozzle. The unit has two measurements planes, which consist of a set of three optical windows. Two windows are facing each other with the third one perpendicular to them. One measurement plane is upstream the nozzle in order to measure the flow field e.g. as boundary condition for numerical simulations. The second plane allows observing the near field of the nozzle. Unit 4 contains two sets of measurement planes as well. This unit can be placed instead of the blind units 5 and 6, which yields further measurement positions shown in Figure 2.

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Analysis of Cylinder Pressure Measurement Accuracy for Internal Combustion Engine Control

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Abstract

With the tightening requirements on engine emission and performance, pressure based combustion controls are becoming common in medium speed large bore reciprocating internal combustion engines. The accuracy of the cylinder pressure data including the raw pressure value at its corresponding crank angle, has a vital impact on engine controllability. For instance, this work shows that a 1-bar pressure offset leads to a 0.7% variation in the total heat release (THR) while the 50% heat release crank angle (CA50) can be shifted by 2 degrees. Similarly, with a single degree error in the crank position, the indicated mean effective pressure (IMEP) gets a 1.5% error. Thus, in this work the typical errors for cylinder pressure measurement are reviewed and analyzed for large bore four stroke marine and power plant production engines.

The main sources of error for pressure measurement are thermal shock and installation defects. Meanwhile, calibration is carried out for ten production pressure transducers to provide a general accuracy result of the pressure transducers that are used in production engines.

The main sources of error for crank angle position monitoring - when done with a flywheel-based inductive system, manufacturing tolerance, installation, and the relative displacement between the pickups and the shaft due to shaft bending, shaft longitudinal movement, torsional vibration and engine block vibration are the main sources of error.

In this paper, those errors are quantified individually through simulation and their impacts on IMEP and CA50 are also presented. At last, cylinder volume deformation and its impact on combustion diagnostics are also estimated. From the result it is concluded that torsional vibration and cylinder volume deformation have the most significant effects for combustion analysis.

Introduction

The cylinder pressure signal provides a valuable source of information for engine monitoring, diagnostics and control because it is a direct feedback from the combustion status [1] [2]. With the toughening requirements on engine emission and performance, pressure-based combustion control systems have been regarded as the potential gain for the future engine, which relies mostly on pressure-extracted information such as IMEP, heat release rate, combustion duration, compression condition etc. In order to guarantee the precision of the extracted parameters, both the pressure and crank angle need to be measured with a high accuracy.

Cylinder pressure transducers have been used in research for decades, however, since recent years they are widely used in production applications due to the decreasing price of piezoelectric pressure transducers. Piezoelectric pressure transducers have various advantages that make them suitable for production applications, such as long lifetime, high natural frequency, and low price. However, there are some sources of error which impact the pressure measurement accuracy [3]:

- The piezoelectric pressure transducer is sensitive to temperature which can cause thermal shock, signal drift and sensitivity variation.
- The installation of the transducer has an effect on the accuracy of the measurement because of the location and mounting method.

On top of obtaining high accuracy cylinder pressure measurement data, there are higher requirements for a precise crank angle or cylinder volume measurement for thermodynamic analysis. There are two different methods to measure the crank angle: a crank angle encoder and a teethed/slotted wheel. Literature claims that the most accurate method to measure cylinder pressure is to use a crank angle encoder as a trigger source to guarantee that each pressure is measured at a predefined crank angle. Although this solution shows high angular accuracy, it cannot be applied in production because of the practical and price restrictions, and reliability reasons. Thus, wheel-based solutions are commonly used in production applications.

Inductive crank angle measurement is one of the most common solutions for production applications because of its reliability, durability and cost effectiveness. However, in practice, this system always produces considerable deviation from the actual crank angle position caused by mechanical and operating sources [4] [5]:

- The manufacturing tolerance of the flywheel and the number of teeth.
- Installation errors: eccentricity, swash, and sensor air gap variations.
- The relative displacement between the pickups and the shaft due to shaft bending, shaft longitudinal movement, and torsional vibration.
- Inductive sensor vibration caused by the engine block vibration because of the component coupling.
- Other sources of error: electromagnetic interference and time delay.

Except for the above-mentioned main sources of error, pressure pegging and TDC offset determination also contribute to errors in a

Adaptive and Unconventional Strategies for Engine Knock Control

Donald Selmanaj, Stijn van Dooren, Giulio Panzani, Jonatan Rosgren and Christopher Onder

***Abstract*—Knock is an undesirable phenomenon affecting gasoline spark-ignition (SI) engines. In order to maximize engine efficiency and output torque while limiting the knock rate, the spark timing should be adequately controlled. This paper focuses on closed-loop knock control strategies. The proposed control strategies, compared to conventional approaches, show an improved performance while remaining simple to use, implement, and tune. First, a deterministic controller which employs a logarithmic increase of the spark timing proves to outperform the conventional strategy in terms of spark timing average and variance. Second, a stochastic adaptive strategy that is meant to assist the deterministic controller is introduced. Due to this extension, the average and the variance of the spark timing are improved while preserving the easy tuning and the fast reaction times of the deterministic strategy. Throughout the paper, all the knock controllers are compared with a conventional deterministic strategy and with a recently proposed stochastic one. The advantages of the proposed approaches are confirmed both by simulation and by experimental data collected at a test bench.**

***Index Terms*—knock control, SI engines, engine knock.**

I. Introduction

The phenomenon of knock is a major limitation for SI engines. Knock has its name from the audible noise that results from autoignitions in the unburned part of the gas. It causes undesired pressure oscillations in the combustion chamber. In order to avoid knock, the engine has to be run in a sub-optimal way with respect to efficiency. In addition to limiting the compression ratio and lowering the levels of pressure and temperature, preventing knock requires the spark timing to be delayed [1]. Closed-loop knock control systems acting on spark timing are thus crucial in order to maximize the engine efficiency while limiting the knock rate.

Knock sensing is a key component for knock control systems. On the one hand, considerable research efforts have been dedicated to the problem of knock detection [2]–[5] by processing different types of measurements to produce knock metrics [6]–[15]. On the other hand, knock control strategies have received less attention. The most trivial strategy consists of rapidly retarding the spark timing if a knock event is observed, and slowly advancing the timing during non-knocking cycles [16]. This strategy is referred to in literature as the conventional knock control strategy and is widely used in industrial applications. The conventional strategy is easy to implement and tune, but it results in late average and a high variance of the spark timing.

More advanced methods are based on the concept of margin (or distance) from the knocking condition. Instead of acting on knock events, these approaches relate the knock intensity to measurement data obtained during non-knocking cycles. The most evident measurement related to knocking is the cycle peak pressure [17]; cycles with higher peak pressures are more likely to result in knock. The authors model the relation between knock intensity and peak pressure and control the latter at a reference value that is a compromise between engine torque output and knock tendency. Exploiting the same philosophy, in [18], the authors build a gray-box model of the knock margin that proves to effectively describe the knock rate in various engine operating conditions, outperforming more traditional physics-based approaches. While both approaches are effective, they require a considerable modeling effort and do not consider engine aging, which also can change the relation between measurement data and knock intensity.

The majority of the scientific literature is based on the control of the statistical properties of the knock phenomenon. These methods are referred to as "stochastic" knock controllers. Instead of controlling a knock margin or acting on knock events, these methods control the statistical properties of a knock intensity metric. One possibility consists of quantifying the knock intensity through engine casing acceleration to build a knock energy indicator controlled via a proportional integral (PI) controller acting on the spark timing [19]. The method requires the estimation of the mean and the variance of the acceleration signal energy which slows the controller action. Similar approaches based on the statistical properties of knock intensity [20] and combustion stability [21], aim at improving controller responses by adding fast control actions.

An alternative approach consists of modeling and controlling the statistical properties of knock events based on the comparison of the knock intensity metric with a calibrated threshold [16]. This approach neglects the knock intensity information and uncouples the latter from the control action intensity, but it simplifies the modeling of the knock phenomenon as knock events can be modeled by simple statistical (e.g., binomial) distributions whose characteristics are functions of the spark timing. Based on this philosophy a controller that monitors the cumulative summation of knock events and compares it with the desired knock rate is proposed

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Spray Combustion Chamber: History and Future of a Unique Test Facility

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Abstract
Large marine two-stroke diesel engines are still the most used propulsion system for large merchant ships. With steadily increasing transport demands, rising operational costs and increasing environmental restrictions, the global marine shipping industry finds itself facing the challenge to future-proof its fleet. In order to comply with international maritime organizations emission standards (TIER II and TIER III), highly sophisticated and flexible combustion systems are necessary. Spray and combustion research substantially contribute so that such systems can be developed and continuously improved. A highly valuable tool to investigate sprays of large marine diesel injectors, under engine relevant conditions is the Spray Combustion Chamber (SCC). This paper reviews the history of the SCC, shows todays possibilities and looks towards the near future of research in large marine two-stroke engines. The SCC was built during the first Hercules project (I.P.-HERCULES, WP5, [1]). The initial setup allowed for fundamental investigations with highly flexible thermodynamic conditions. In the following projects (Hercules beta [2], Hercules C [3]) the SCC was continuously improved and extended, while various influences on spray and combustion have been experimentally assessed. The initial SCC design focused on maximal optical access and the application of a wide span of optical techniques. With single hole nozzles, reference data for the optimisation of spray and combustion simulations has been generated, different fuel types and fuel qualities have been investigated and effects of the in-nozzle flow on spray morphology have been identified. A sound set of results could be achieved and was published in several (internal and public) reports. Even though basic spray research at WinGD is not over, its focus will be set more on cavitation and in-nozzle flow, which is done with external partners [4], [5]. Future research in the SCC will focus on the investigation of more engine related questions, as for example the application of a fuel flexible injection system, as it is currently developed in the HERCULES-2 project [6]. This system could not have been tested properly on the old setup, as the injector position and therefore exposure of the spray to the swirl were not fully congruent to real engine applications. Of course the new setup also has some drawbacks, e.g. the optical access of the nozzle tip is only possible via one side, so line-of-sight methods are currently only possible at selected positions in the centre of the chamber. To illuminate the spray, the installation of a new setup was necessary, consisting of a high speed, high energy laser (100 kHz, 100 W) and special optics.

Keywords
Large marine diesel engines, spray, combustion, high pressure high temperature conditions, heavy fuel oil, residual fuel

Introduction

Due to their high thermal efficiency and reliability, Diesel engines are still relied upon extensively for seaborne freight transport. With steadily increasing transport demands, rising operational costs and increasing environmental restrictions, the global marine shipping industry finds itself facing the challenge to *future-proof* its fleet. Ship owners and operators will need oil alternatives in order to stay economically competitive while complying with environmental regulations. Today's injection systems already allow for a variety of oil based fuels: From light fuel oils down to residual fuels of very high viscosity and density, can all be injected with the same components. Nevertheless, to allow the end user for even higher fuel flexibility, an injection system is needed, to inject fuels with for example very poor self-ignition or very low lubricity.

To develop such an injection system, WinGD can access highly sophisticated tools. From state of the art injection- and component test rigs up to full scale test engines (e.g. RTX-6, located in Oberwinterthur, Switzerland). One important step before the test engine is the Spray Combustion Chamber, the SCC.

The past

Before the SCC was built, no experimental data regarding spray and combustion of large marine diesel engines was readily available. Especially for common rail type engines – also for large marine diesel engines a cornerstone – the injection pattern could only be estimated based on up-scaled results from (much!) smaller experiments. This

Design and experiments to investigate spray and impingement characteristics of a common rail type lubrication system

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Abstract

This paper reports on the establishment of a testing facility to investigate spray and impingement characteristics of a recently developed, fully adaptive lubrication system for large two stroke marine diesel engines. The reported part of this research relates to development steps towards the new lubrication system as well as the implementation of a dedicated testing facility and the establishment of validation approaches in order to corroborate technology developments in this context.

The major objective of this development yields an optimization of lubricant utilization and at the same time a significant reduction of lubricant fraction in the exhaust gas. A requisite to obtain the desired level of flexibility calls for a revised approach in injecting the lubricant. Common lubrication system concepts make use of a constant volume pump which is connected to a non-return valve type lubricant injector. The amount of injected lubricant is adjusted on basis of engine load and fuel property dependent feed rate settings, which leads to the injection of lubricant as a function of the amount of engine cycles between single lube oil injections. The desired flexibility of the new lubrication approach foresees a cycle based adjustment of the injected amount of lubricant as well as the injection pressure in order to provide the possibility to shape the injection spray pattern. Concept studies nominate the application of a common rail system with integrated needle lift type injectors and adjustable injection pressure as compliant with the requisite to inject the lubricant with a high level of flexibility.

This paper hence encompasses design and development aspects of the new lubrication system but most of all highlights steps in developing a validation concept in order to compare common lubrication systems with the new type of lubrication system.

Investigating on mentioned injection characteristics calls for the establishment of a sound testing environment. Therefore a system was designed to provide testing conditions which are similar to the boundary conditions that are found in a real engine. The test cell design features a cylinder liner segment between two lubrication quill positions in order to simulate the lubricant spray and impingement on a simulated segment of a cylinder liner under engine like conditions over the full engine load range.

Initial results of the test cell provide an insight regarding relevant information on the injection spray characteristics over the full engine load range as well as the possibility to compare common lubrication system performance with the new common rail lubrication system.

Keywords

Injection system development and validation, computational injection spray simulation, experimental spray investigation

Introduction

Detailed investigations related to lubricant flow optimizations and transportation mechanisms clearly demonstrate the importance of an appropriate lubricant injection. [1-4] A characterization of relevant contributors to the total lubricant balance of a large two stroke marine diesel engine was performed to address the optimization potential of single components of the tribosystem. Optimizations of piston ring pack geometries showed superior functionality in terms of considerably reducing the amount of lubricant in the exhaust gas. Another, yet equal important aspect which must be taken into consideration when looking at further reducing lubricant consumption of such an engine type, relates to a detailed investigation regarding the application of the lubricant by means of a properly designed lubrication system. Design aspects of such a recent development focus on controlling lubricant spray characteristics over the complete engine load range and related variations of boundary conditions. Thus, investigations in the context of this paper, focus on developing an evaluation approach to support lubricant spray simulation tool

Engine knock margin control using in-cylinder pressure data: preliminary results

Giulio Panzani[1], Donald Selmanaj[2], Olga Galluppi[1], Sergio Savaresi[1], Jonatan Rösgren[3] and Christopher H. Onder[4]

***Abstract*— Knock is an undesired phenomenon occurring in spark ignited engines and is controlled acting on the spark timing. This paper presents a closed-loop architecture that addresses the knock control problem in a standard model-based design framework. An engine knock margin estimate is feedback controlled through a PI controller and its target value is computed on the desired knock probability. A black-box modelling approach is used to identify the dynamics between the spark timing and the knock margin and a traditional model-based controller synthesis is performed. Experimental results at the test bench show that, compared to a conventional strategy, the proposed approach allows for a better compromise between the controller speed and the variability of the spark timing. Moreover, another advantage w.r.t the conventional strategies is that closed-loop performances prove to be constant for different reference probabilities, leading to a more regular engine behaviour.**

I. Introduction

Knock is a limiting phenomenon in spark ignited engines; it is the autoignition of the end gas in the combustion chamber which generates large pressure oscillations [1] causing potential engine damages and performance decreases. However, in order to maximize the engine efficiency, in particular on low speed and high torque operation, the engine needs to run close to the knocking condition: thus a closed loop knock margin regulation, acting on the spark timing, is a crucial component.

The scientific literature has dedicated considerable effort to the problem of knock sensing and knock control. While the detection of knock events is a relatively easy task [2]–[5], the control part is more challenging. Due to the stochastic behaviour of engine knock and its binary nature (*i.e* an engine cycle knocks or not), the use of classical standard control strategies is limited and not-trivial. Strategies proposed in literature can be divided in two groups: those controlling properties of knock, derived by knock occurrence and others controlling a knock-related (usually model-based) metrics.

Among the strategies controlling the stochastic properties of knock events, the most simple one is referred to in literature as the conventional strategy. It consists of rapidly retarding the spark timing if a knock event is observed, and slowly advancing the timing during non-knocking cycles [6]. Due to its easy implementation and tuning, the conventional knock controller is widely used in industrial applications. However, it results in a late average (*i.e.*, low efficiency) and a high variance of the spark timing. More advanced methods monitor the cumulative summation of knock events and compare it with the desired knock rate [7], [8]. Instead of acting at each knock event, those controllers retard the spark timing when the difference between the observed and the desired knock rate exceeds a positive threshold and advances the spark timing when the difference falls below a negative threshold. The methods proposed in [7] and [8] use fixed amplitudes of the retarding and the advancing actions. A further improvement can be made by relating the action intensity to the discrepancy between the observed and the desired knock rate: the likelihood ratio is an indicator of this discrepancy and is employed in [9]. The so-called likelihood-based approach shows satisfactory results on both simulation end experimental data [10]. Although effective, advanced stochastic knock controllers rely on non-standard tuning procedures, have a delayed transitory response and present a sub-optimal trade-off between the controller speed and the steady-state variability of the spark timing.

Due to the difficulty of modelling the combustion inside a cylinder chamber, methods based on the control of a knock-related metrics are less developed. The most trivial knock metric is the cycle peak pressure [11]. Cycles with higher peak pressures are more likely to result in knock, thus the maximum pressure can be controlled at a reference value that is a compromise between the engine torque output and the knock tendency. Another possibility consists in quantifying the knock intensity through the engine casing acceleration to build a knock energy indicator controlled via a proportional integral (PI) controller [12]. However, the estimation of the mean and the variance of the energy indicator slows the controller action.

The knock control strategy proposed in this paper is based on the estimation approach introduced in [13], where the authors build a gray-box model of the knock margin that proves to effectively extract important information from the cylinder pressure traces and describes the knock behaviour in various engine operating conditions, outperforming more traditional physics-based approaches. The estimator provides, for each engine cycle, the knock margin (*i.e.* the distance from knocking conditions) and an estimate of the expected

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Model Predictive Control for Hybrid Diesel-Electric Marine Propulsion ⋆

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Abstract: In this work, the problem of energy management strategies in hybrid diesel-electric marine propulsion systems is investigated with the implementation of two types of Model Predictive Controllers. The system behavior is described by models based on system identification as well as on first-principles. These models were used for the design of linear and adaptive predictive controllers respectively. The controllers were successfully tested at HIPPO-1 testbed, at the Laboratory of Marine Engineering, evaluating diverse strategies for disturbance rejection, system stability, and operation of the plant within desirable limits.

Keywords: hybrid marine engine, predictive control, λ control, transient operation

1. INTRODUCTION

Strict emission regulations imposed by legislation authorities (e.g. International Maritime Organization-IMO) make marine engine manufacturers to look for new opportunities for emissions reduction. One promising technology for emissions reduction and fuel efficiency enhancement is hybridization, i.e. usage and coordination of more than one energy sources used for propulsion.

This research work tackles the problem of energy management strategies (EMS) in hybrid diesel-electric marine propulsion systems, without any battery storage capacity. Such a system decides in real time the amount of power delivered at each time constant by the energy sources present in the experimental marine power train. Objectives are to investigate a) the interaction between the power sources and b) the feasibility of the hybrid configuration to achieve reduced exhaust emissions and improved fuel consumption during transient loading operation. This could lead to diesel engine downsizing as is the case in the ”modern” point of view in marine propulsion.

Usually, the engine control units contain a certain amount of single closed-loops, with many look up tables in order to achieve closed-loop control of the multi-parametric and strongly non-linear engine behavior, Ripaccioli et al. [2009]. Today, a more sophisticated and complicated control method is needed: one that continuously decides the operation point of the plant, while enforcing the operating constraints and optimizing the energy consumption, in terms of fuel and electric energy consumption.

Several strategies for power management have been applied so far, including dynamic programming, stochastic dynamic programming, equivalent fuel consumption minimization and model predictive control (MPC). Of the many advanced control design methodologies, MPC seems to be the most capable to handle multi-variable processes, satisfy constraints, deal with long time delays and utilize plant response disturbance knowledge. MPC has been used in a broad range of applications, such as diesel engine control, del Re et al. [2009], Ortner and del Re [2007], Adachi et al. [2009], Hybrid Electric Vehicles, Ripaccioli et al. [2009], etc.

Usually the objective of the EMS is to minimize fuel consumption. In the work presented here, the control problem is recast in an alternate way so as to track λ reference while ensuring that certain constraints, like NOx and fuel consumption are met.

2. SYSTEM DESCRIPTION AND MODELING

2.1 Experimental Facility

The hybrid propulsion powertrain HIPPO-1 test bed at Laboratory of Marine Engineering, NTUA (LME) (seen in Fig. 1) consists of an internal combustion engine (ICE) in parallel connection to an electric machine (EM). As such, the rotational speeds of ICE and EM are identical, whereas the supplied torques add together. The desired

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Flow in axisymmetric expansion in a catalytic converter

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ABSTRACT

The flow in an axisymmetric expansion (circular diffusor) is used in many different engineering applications, such as heat exchangers, catalytic converters and filters. These applications require a relatively uniform flow at the inlet. To minimise the pressure loss, an ideal solution would be to use a quite long expansion, but this is often not possible due to space restrictions. Therefore a short expansion combined with e.g. guide vanes is often used. The present study will use a Selective Catalytic Reduction (SCR) system for large marine diesel engines as a case. The catalyst is designed for a specific local flow rate and a non-uniform inflow to the catalyst will severely reduce the efficiency of the process. Since each ship will have a unique design the flow system, it is desirable to be able to design the system using Computational Fluid Dynamics (CFD). However, CFD fails to predict flow separation in many cases and cannot be used as the only design tool [1]. Typically CFD has to be validated against experimental data from representative designs under varying conditions to find trustworthy turbulence modelling, sufficient grid resolution and suitable boundary conditions. Here Particle Image Velocimetry (PIV) is a unique method that resolve the entire cross flow. This type of flow is expected to have a fluctuating 'jet'-like structure from the smaller inlet pipe into the larger converter. The fluctuations of the jet are difficult, if not impossible, to capture with standard time averaged models, and more expensive methods like Large Eddy Simulation (LES) could be needed. Here PIV has an advantage compared with other measurement methods, because it captures instantaneous flow fields that are relevant for the catalyst efficiency and thus also for CFD validation.

The aim of the present study is to investigate flow phenomena in sudden pipe expansions similar to design used for catalytic converters with different upstream conditions and flow conditioning devices like guide vanes. This is done to provide a set of data that can be used to validate the use of CFD to such flows.

For the present study, a down-scaled model of the catalytic converter is constructed, see figure 1. The experiments are performed at laboratory conditions, with lower pressure, temperature and velocity than the full-scale catalytic converter. The Reynolds number based on the velocity in the inlet pipe and the diameter of the converter is Re = 200000. A preliminary study shows that this Reynolds number is high enough to ensure very small dependence of the Reynolds number. The inlet pipe has a diameter of D = 0.1 m. The catalytic container has a diameter of 2.8D and a length of 8D. The diffusor connecting the pipe and the converter container is expanding abruptly within a length of 0.5D. The inlet section has a length of 20D to give almost fully developed flow conditions before the expansion. Several inlet conditions will be investigated, including a straight pipe, one 90° bend and two out-of-plane bends. A catalyst dummy will also be mounted and tested. For the catalyst dummy different model factors will be tested to insure the corrected pressure resistance. The distanced from the expansion to the dummy will also be varied and tested. Then different guide vane configurations will be mounted to investigate the flow uniformity at the catalyst converter. The investigation is done with Stereoscopic Particle Image Velocimetry (PIV). The measuring plane, a cross plane through the converter pipe, will be transverse along the flow direction (z-axis at figure 1). The cross plane is created with a 200 mJ Nd:YAG double cavity laser. Two 16 MPixel cameras are placed in forward and backward scatter, respectively. Glycerine droplets with a diameter of about 2 µm, are used as tracer particles.

Example results are shown in Figure 2, where the cross plane is placed 5D downstream of the expansion. Here the mean velocity field of 500 snapshots from the empty converter with a straight inlet shows that the flow consist of a fast 'jet' in the middle and negative velocity at the walls. A snapshot been selected to represent a very common flow structure corresponding to the first mode found from a snapshot proper orthogonal decomposition (POD) analysis [2]. The white line indicate the change from positive to negative velocity. In the snapshot, the 'jet' has spread along a line through the center and is in contact with two opposite walls. At the rest of the walls, a recirculation zone is seen. As seen in Figure 2, the wall region is well resolved except at the bottom where velocity vectors are missing due to optical reflections.

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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

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Investigation of the Combined Application of Water-in-Fuel Emulsion and Exhaust Gas Recirculation in a Medium Speed Diesel Engine

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Key Words: Marine Diesel Engine, EGR, Water-In-Fuel Emulsion

ABSTRACT

Medium speed diesel engines are utilized as prime movers or auxiliary generators in the maritime transportation sector as well as for stationary power generation. To regulate the environmental footprint, strict emission legislations are effective and further regulations are under evaluation. Therefore, continuous overall improvement of engine performance and R&D on low emission technologies, with respect to NO_x as well as PM emission reduction, are of high importance.

A well-established method for NO_x reduction in diesel engines is the use of cooled exhaust gas recirculation (EGR), which reduces flame temperature resulting in lower NO_x formation. The adoption of EGR leads to increased soot emissions due to the lower flame temperature and reduced oxygen availability, both of which hamper soot oxidation. The application of water-in-fuel emulsions (WFE) has been shown to improve the NO_x vs. soot tradeoff.

A medium speed marine diesel engine equipped with 2-stage turbocharging, Miller valve timing as well as common rail injection is utilized for the experiments where EGR and WFE have been applied simultaneously. The emulsion is produced by a custom-designed on-line emulsifier upstream the high-pressure pump.

The investigations presented include the influence of EGR rate, rail pressure and injection timing on the engine operation with and without WFE. The study shows the analysis of combustion characteristics, emission measurements, performance indicators as well as engine energy flows for the simultaneous application of the emission reduction technologies EGR and WFE.

The findings extend the understanding and knowledge regarding engine operation and performance of the combined application of EGR and WFE with focus on large engines in order to achieve a significant NO_x emission reduction with minimal penalties in soot emissions and fuel consumption.

INTRODUCTION

In recent years, strict emission legislations for diesel engines were brought into force and further regulations are under evaluation. NO_x is a major pollutant occurring in diesel combustion and its emissions are limited [1]. Hence, additional NO_x reduction technologies need to be developed and adopted.

The use of cooled Exhaust Gas Recirculation (EGR) which reduces the flame temperature, resulting in lower NO_x formation, is a well-established method to reduce NO_x in diesel engines [2,3]. Due to the known tradeoff relationship between the emission of NO_x and soot [5,6], the reduction of NO_x by utilizing EGR yields to increased soot emissions, as the lower flame temperature and reduced oxygen availability both of which hamper soot oxidation [2,4-6].

In order to overcome the disadvantage of increased soot emissions when lowering NO_x via EGR, water-in-fuel emulsion (WFE) application has shown to be a promising technology to simultaneously reduce soot

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ARTICLE

Feasibility of new liquid fuel blends for medium-speed engines

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The compression-ignition (CI) engines are very reliable stand-alone prime movers, also showing the highest fuel conversion efficiency of all thermal prime movers within an output range of approx. 100 kW to 100 MW. Most of the engines still burn conventional liquid petroleum based fuels but the fossil reserves are declining. The share of gaseous and renewable liquid fuels increases rapidly since the greenhouse gas (GHG) emissions shall be strongly reduced in the near future. Several renewable and sustainable liquid fuel alternatives are therefore needed for different CI engine applications to reduce GHG emissions and to ensure proper primary energy sources for the engines. The main aim of the current study was to determine all the most important properties of five fuel blends to create fundamental knowledge about their suitability for, in particular, medium-speed CI engines. The share of renewables within these five blends varied from 20 vol-% to 100 vol-%. Rapeseed methyl ester (RME) was blended with renewable naphtha in a ratio of 80 vol-% of RME and 20 vol-% of naphtha. This fuel blend was 100% renewable and it has not been studied before. Moreover, naphtha was blended with low-sulfur light fuel oil (LFO) in a ratio of 20 vol-% naphtha and 80 vol-% LFO. RME was also blended with LFO, kerosene and circulation economy based marine gas oil (MGO) in a ratio of 20-vol% of RME and 80 vol-% of the fossil share. The investigated and compared properties were the cetane number, distillation, density, viscosity, cold properties and lubricity. According to the results, all the studied blends may be operable in medium-speed engines when the target of 27% of renewable share of the total energy consumption set by the European Commission.

Introduction

The use of diesel or compression-ignition (CI) engines in heavy-duty transportation, off-road machines, power generation and shipment has spread all over the world. The engine technology is at a high level. The CI engines are very reliable stand-alone prime movers and they show the highest fuel conversion efficiency of all thermal prime movers within an output range of approx. 100 kW to 100 MW. Most of the engines still burn conventional liquid petroleum based fuels. In the mentioned applications, liquid fossil fuels will, most probably, also dominate for the next few decades.

Nevertheless, the share of gaseous and renewable liquid fuels increases rapidly since the greenhouse gas (GHG) emissions shall be strongly reduced in the near future. Renewable, alternative fuels could relieve the biased usage of fossil fuels. The energy efficiency and sustainability must be continuously improved since it further promotes the reduction of GHG emissions. (1) The 2030 EU climate & energy framework sets three key targets. The first one is to cut GHG emissions at least 40% from the level that was current in 1990. The second target is to have at least 27% share for renewables in energy consumption by 2030 and the third one is to reach at least a 27% improvement in the energy efficiency. (2)

The pollutant exhaust emissions of CI engines are already strictly limited. The most stringent standards concern the on-road engines but even the off-road and power plant engine legislation is very tight. Recently, the emissions limits of marine engines have also become stricter, first the limits of oxides of nitrogen, but now even the sulphur and particulate matter limits. For the EU inland waterways, the pollutant emissions must already be strongly reduced, also including the particulate number emissions. The development of the emissions legislation, thus, tightly guides the engine development and simultaneously directs the transfer from fossil fuels to more sustainable alternative fuels.

On the other hand, the fuels must be cost-effective. Many countries and regions prefer local fuels to increase the self-sufficiency of the energy generation. The production of renewable electricity, e.g. wind or solar power, increases globally, but for a large part it is highly intermittent. The role of conventional energy production is to keep the electricity grids in balance. Engine-driven power plants suit extremely well to this task since the plants can be started, loaded and stopped very quickly. Gas engines are one favorable option but the availability of gaseous fuels is still limited.

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Transient Load Share Management of a Diesel Electric Hybrid Powertrain for Ship Propulsion

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Abstract:

In this paper, a transient load share methodology for a hybrid diesel electric marine propulsion system is presented. Aim of the system is the performance enhancement and reduction of gaseous emissions during low-load transient operation. The controlled variable is λ while the manipulated variable is the torque from the electric motor regulated by a frequency inverter.

The model for the λ behavior is based on experimental identification while λ values in feedback loop come from an actual and a virtual sensor, the later based on first principles modeling. A nominal model is used for the synthesis of a robust H_∞ controller for the controlled variable regulation.

Calibration method for the determination of the FAME and HVO contents in fossil diesel blends using NIR spectroscopy

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Abstract

According to the European standard EN590 for automotive diesel fuel, no additional labeling is required for the diesel fuel additives, such as bio fuels, including the biodiesel (FAME) blended up to 7 % (V/V) and renewable diesel (HVO) with undefined blending ratio. However, the information about the bio fuels' content in diesel fuel blends is an important aspect of the fuels analysis. This work presents a calibration method development for quantification of FAME and HVO contents in diesel fuel blends within the analytical range of 0 – 10 % (V/V) and 0 – 20 % (V/V) respectively using near-infrared spectroscopy. The development of the calibration method is based on partial least squares (PLS) regression method for multivariable data analysis and construction of the calibration models. The constructed PLS models obtained prediction results for all diesel fuel blends with root mean square error of prediction (RMSEP) values of 2.66 % (V/V) for the renewable diesel content quantification and 0.18 % (V/V) for quantification of the biodiesel content, concluding that the calibration method is suitable for practical laboratory applications.

Keywords: Diesel fuel blends, Biodiesel, Renewable diesel, Near-infrared spectroscopy, Partial least squares regression

1. Introduction

The European standard EN 590 for automotive fuels, concerning diesels, states that the use of the diesel fuel additives is allowed for automotive diesel fuel. [1] Such additives may include the fuels developed from alternative to fossil feedstock, renewable feedstock, such as fats and oils. Nowadays, the major diesel fuel additives derived from renewable biological sources are biodiesels and renewable diesels. These fuels have different compositions and properties, due to the different processes of fuels' production, even if the used feedstock is the same. [2]

Biodiesels are defined as fatty acid methyl ester (FAME) fuels. Biodiesels production process is based on the transesterification reaction, where organic feedstock, such as animal fat or vegetable oils, reacts with alcohols in the presence of a catalyst to produce fatty acid alkyl esters. Today, the dominant renewable feedstock for biodiesel production in Europe is rapeseed oil, from which rapeseed methyl ester (RME) fuel is derived. The other sources used for biodiesel production include, e.g., soybean, sunflower and palm oils, as well as animal fat, algae and others. [3] According to the EN 590 standard, current automotive fuel diesel "may contain up to 7 % (V/V) of FAME complying

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Abbreviations used in this article: AFME – Animal fat methyl ester; CNUM – Number of PLS components; DFO – Diesel fuel oil; FAME – Fatty acid methyl ester; HVO – Hydrotreated vegetable oil; NIR – Near-infrared; PLS – Partial least squares; PRESS – Prediction residual sum of squares; R^2 – Coefficient of determination; RME – Rapeseed methyl ester; RMSECV – Root mean squared error of cross validation; RMSEP – Root mean square error of prediction; SNV – Standard normal variate

An Optical Investigation of Diesel-Pilot and Methane Dual-Fuel Combustion

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Abstract –The study investigated dual fuel combustion, where late-cycle diesel-pilot injection ignites the premixed methane-air mixture at light load in a single cylinder heavy-duty diesel engine, modified for optical access. The high-speed natural luminosity technique was employed to visualize the combustion processes at varying methane lambda values and different pilot ratios. Several methane lambda values were tested and to obtain different lambda values, methane quantity was varied while keeping other parameters the same. Methane was injected into the cylinder through intake manifold along with the air. In addition, three different pilot ratios were tested, obtained by varying the diesel-pilot amount. The results show that the flame front propagation becomes more prominent at methane lambda values closer to stoichiometric condition and evidence of flame front propagation could be seen in NL-images. In terms of the pilot ratio, it is observed that an increase in the pilot amount causes a rapid combustion and improves flame front propagation. The trends of ignition delay in dual fuel combustion for conducted tests were also analysed.

1. Introduction

In recent decades, the research and investments in technological advancement in the field of internal combustion engines have mainly been driven by the need for emissions reduction. Dual fuel (DF) combustion in diesel engines consuming methane as a primary fuel, ignited by a small amount of diesel-pilot seems to have potential to reduce emissions and comply with new stringent emission legislations. Methane is the major component of natural gas, typically constituting more than 90% of it and considered a cleaner fuel compared to conventional diesel due to the theoretical reduction of CO_2 resulting from its higher H/C ratio. At lean mixture conditions, highly premixed combustion of methane reduces NOx emission, as the combustion temperature is low. Methane can be applied as a primary fuel source in a conventional diesel engine with a high compression ratio resulting in diesel like efficiency.

A DF engine uses two fuels, typically of different reactivity. In the diesel-methane DF engine, methane as a low reactivity fuel is ignited by a high reactivity, compression-ignited diesel-pilot. The fundamental concept of DF combustion is illustrated in Fig. 1, where liquid diesel-pilot is injected directly into a combustion chamber where it evaporates, mixes with air and ignites by compression. The premixed low reactivity fuel, the methane-air mixture then, burns in the vicinity of diesel-pilot combustion and premixed flame fronts due to methane combustion, propagates throughout the combustion chamber igniting the unburned premixed methane-air mixture and produces a power output. The DF engine can be operated on either DF combustion mode or typical diesel only injection mode [1]. In literature, the term DF may refer to different types of combustion concepts. In the gas-diesel combustion mode, the gas is injected directly into the combustion chamber and burns as it is injected in the same manner as the liquid diesel [1]. Based on the factors of injection timing, the gas lambda value and stratification levels of the in-cylinder mixture at the end of the compression stroke, the DF combustion can be regarded as e.g. PCCI [2] and RCCI [3][4] combustion concepts.

Investigation of the Cylinder Cut-Out for Medium Speed Dual Fuel Engines

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O–CO 05

Influence of the Al content on the aqueous corrosion resistance of binary Fe-Al alloys in H_2SO_4

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Introduction

Fe-Al-based alloys attract much attention for high temperature structural applications because of their outstanding physical and chemical properties. They exhibit a lower density of 5.7-6.7 g/cm^3 compared to other iron-base materials such as cast iron and stainless steels, superior high-temperature corrosion resistance, good wear resistance and low material costs [1, 2]. In addition, the equipment for their production and processing is readily available in industry [2]. Due to the practical and scientific importance, the aqueous corrosion behavior of Fe-Al-based alloys should be understood. A number of studies on the aqueous corrosion behavior of binary Fe-Al alloys have been reported so far, but they mainly focused on binary Fe-Al alloys with a limited variation in the Al content, e.g., (in at. %) Fe-28Al [3], Fe-40Al [4, 5], Fe-(8, 10, 22)Al [6] or Fe-Al alloys with additional alloying elements. A systematic investigation on the Influence of the Al content on the aqueous corrosion resistance of binary Fe-Al alloys is still needed. Therefore the aqueous corrosion behavior of binary Fe-Al alloys with Al contents up to 40 at. % was investigated in the present work.

Materials and Methods

A series of binary Fe-Al alloys with 5, 10, 15, 25, 30 and 40 at.% of Al were prepared by induction melting under argon atmosphere. H_2SO_4 with a pH of 1.6 was selected as the electrolyte. The three electrode-method [7] was employed for the electrochemical experiments. The Ag/AgCl reference electrode (3M KCl) was adopted. The open circuit potentials (OCPs) and potentiodynamic polarization curves were determined at 25 and 97 °C, respectively. Post mortem examination of the microstructures of the corroded samples were performed by scanning electron microscopy (SEM). A second series of the binary Fe-Al alloys was pre-oxidized before performing the electrochemical measurements.

Results and Discussion

All the potentials values obtained in the present work were converted into the value against a saturated calomel electrode (SCE).

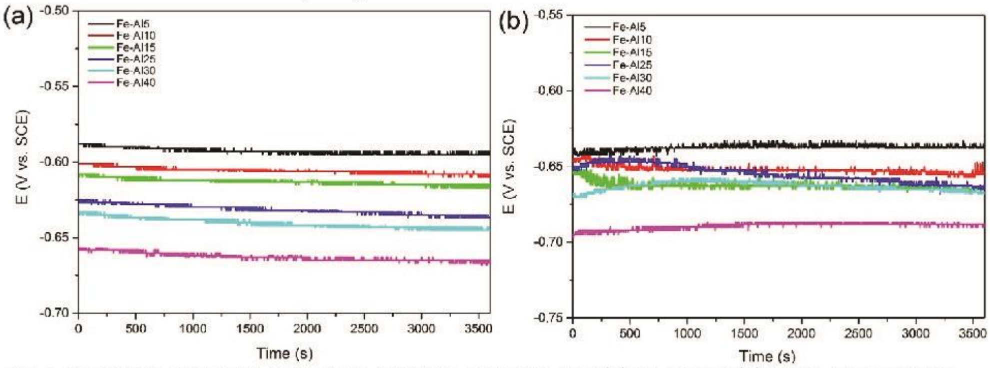

Fig. 1 The OCPs of binary Fe-Al alloys in H_2SO_4 of a pH 1.6 at (a) 25 °C and (b) 97 °C, respectively.

Fig. 1 shows the OCPs of the binary Fe-Al alloys in H_2SO_4 of a pH 1.6 measured for 3600 s at 25 °C and 97 °C, respectively. At both temperatures, the OCPs of the Fe-Al alloys decreased continuously

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Kinematic viscosity studies for medium-speed CI engine fuel blends

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Abstract. Engine-driven power plants, run by diesel fuel or gas, will be needed for peaking power to keep the electricity grids stable when the production of renewable electricity, e.g. utilizing wind or solar power, is increased.
The choice of the alternative, renewable fuels for engine-driven power plants and marine applications is at the moment quite narrow. The amount of renewables of all liquid fuels is at present less than 2%. Biodiesels, FAMEs, have been studied for long time and apparently, despite of the problems they may have, they are still in the great interest. One important increment to the category of alternatives is fuels that are produced from e.g. oil wastes, i.e., recycled fuels. They are not renewable, but recycling of potential energy raw materials is still one step forward in increasing the suitable and more sustainable options.
To utilize the blends in medium-speed engines for power production, accurate knowledge of the physical and chemical properties of fuel blends is very important for the optimization of engine performance. The determination of the fuel kinematic viscosity is needed to create proper fuel atomization. The injection viscosity affects directly the combustion efficiency and the engine power. Consequently, this study focused on measuring kinematic viscosity curves for seven fuel blends, as well as the neat fuels used for blending. The temperature range was 10-90°C. The fuels used for blending were rapeseed methyl ester, animal-fat based methyl ester, hydro-treated vegetable oil, light fuel oil and marine gas oil produced from recycled lubricating oils.

Key words: Kinematic viscosity, alternative fuels, fuel blends, medium-speed engine, B20.

INTRODUCTION

In future energy systems, an increasing amount of renewable energy production, e.g. wind or solar power, will be installed. Due to the intermittent electricity production of those new plants, more emphasis should be put on peaking power to keep the electricity grids stable all the time. Hydro power is the best way to adjust the electricity supply so that the frequency and voltage of the electricity grid remain at a required level. Hydro power is not, though, obtainable everywhere.

Engine-driven power plants, run by liquid fuel or gas, will also be needed for peaking and regulation power generation. They are particularly suitable for this purpose because the plants can be started, loaded and stopped very quickly. They can also be feasible to ensure energy security in rural areas. To increase the share of renewable energy, new liquid and gaseous fuels produced from biomass, residues or waste should, however, be found for engine-driven power plants. These alternative fuels are also needed for marine applications. Together with energy production, in marine industry, the need for cleaner fuels is the most prompt. In 2012, marine sector

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Properties of local produced animal-fat based biodiesel and its blend with fossil fuel

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Abstract. In the near future, more emphasis must be put on reducing greenhouse gas (GHG) emissions in road transportation, house heating, agricultural activities, marine transport etc. This study concentrated on the use of alternative fuels in engine-driven applications of non-road machineries and decentralized energy production. Today, the engines are mainly designed for crude oil derived fuels and liquid renewable fuels are blended with crude oil based fuels to fulfill the requirements of renewable energy usage. Due to the environmental reasons on one hand and to the agricultural needs, on the other hand, different blends of bio- and fossil fuels are becoming more popular. In Europe, the maximum FAME content in diesel fuel is 7 vol% according to the EN 590:2013 but higher percentages are also available and targeted around the world. For example in the United States, the 20% blend fraction is becoming more common. For these reasons, B20 fuels were chosen to be investigated in this study. Special emphasis was put on improving blending issues since fuel blending may cause some operating risks. The main aim was to research widely the properties of animal-fat based methyl ester (AFME) and B20 fuel blend produced from it. AFME is a waste based fuel and produced in Ostrobothnia region, Finland. The aim was to find out in which engine applications the fuels are feasible and investigate if the fuels fit in the quality of automotive fuel Standards. According to the results, AFME is a feasible option to increase self-sufficient energy production in Ostrobothnia.

Key words: Biofuel, blending, FAME, AFME, diesel fuel, B20

INTRODUCTION

In the near future, more emphasis must be put on reducing greenhouse gas (GHG) emissions in road transportation, house heating, agricultural activities, etc. There is an increasing demand to put alternative fuels into operation for engine usage to replace the conventional fossil fuels. Alternative fuel has to be technologically feasible, economic, ecologically beneficial and easily accessible. For diesel engines, biodiesel, produced from vegetable, animal or waste oils, is one of the alternative fuel sources. Today, the engines are mainly designed for crude oil derived fuels and liquid renewable fuels are blended with crude oil based fuels to fulfill the requirements of

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Crank Shaft Torsional Vibration Analysis on the perspective of Improving the Crank Angle Measurement Accuracy for Closed-loop Combustion Control in ICES

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Abstract

Crank shaft torsional vibration has impact on the crank angle measurement accuracy in large-bore Internal Combustion Engines (ICE). In large bore engine, the torsional vibration angular displacement can be up to 1 degree, which in turn can cause a fault of 2 bar in Indicated Mean Effective Pressure (IMEP) and a fault of 0.6 degrees in the Crank Angle of 50% burned (CA50). IMEP and CA50 are critical feedback parameters for closed-loop combustion control, therefore to compensate torsional vibration effect in real-time engine control system can not only provide higher accuracy crank angle data but especially improve the combustion analysis and closed-loop control accuracy. Thus, in this work, a torsional vibration dynamic model is established to improve the accuracy of the crank angle measurement. A lumped parameter model of torsional vibration is established for a Wärtsilä engine, the numerical computing method is determined, harmonic analysis is applied, the Transfer Matrix Method (TMM) result is verified with flexible Multibody Simulation (MBS) calculation and the accuracy of the torsional vibration model is estimated. For the trial of online crank angle correcting, the computation time of this model was found to be around 300 to 400 times heavier as IMEP calculation. A direct IMEP correcting model based on a linear dependence of cylinder number with an accuracy of ±0.1 bar compared with the reference was proposed.

Based on all those results, it is concluded that the TMM method can calculate the angular displacement from torsional vibration with high accuracy and correct the crank angle measurement from cylinder-wise and crank angle wise, and the torsional vibration calculation resolution needs to be considered based on performance and calculation capacity.

Introduction

For a dynamic running engine, torsional vibration is one of the greatest threats for crankshaft over loading [1, 2, 3, 4]. Research about the torsional vibration have been developed since the 1950s [1, 4]. The applications of using torsional response for engine combustion diagnosis have been mostly relying on the flywheel speed measurement for engine misfiring detection [5, 6, 7, 8], cylinder pressure reconstruction [9, 10], engine roughness criteria development [11], and IMEP and HRR estimation [12]. Additional work have been published about the torsional vibration analysis, for example: practical methods to reduce torsional vibration [13, 14, 15], system nonlinear dynamics [16], model simplifications [17, 18] and coupled torsional, longitudinal and bending vibrations [19, 20, 21], and transient torsional vibration response [22]. However, regarding online crank angle correction, so far according to the author's knowledge, there is not much work done. Therefore in this work a preliminary study of the online crank angle correction is done.

Torsional vibration is caused by the periodic and uneven excitation torque in each crank pin, and it leads to different angular velocities or displacements from this oscillating torque in the shaft. Out of many excitation torques acting on the crank-rod system, the tangential component of the piston force is the excitation force for crankshaft torsional vibration [1, 16, 23]. Moreover, torsional vibration is the most significant error contributor for crank angle measurement system [24]: torsional vibration of a 10 cylinder V-engine can have up to 0.4 degrees error in crank angle measurement. Therefore, a further research about the torsional vibration phenomena and its feasibility of correcting the crank angle measurement error online is carried out in this work.

Crankshaft modelling is the base of crankshaft torsional vibration analysis. Practically, there are three most basic shaft models used for torsional vibration analyses: simple mass-

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Engine Efficiency Optimization under Consideration of NO_X- and Knock-Limits for Medium Speed Dual Fuel Engines in Cylinder Cut-Out Operation

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Abstract

As a consequence of the global warming, more strict maritime emission regulations are globally in force or will become applicable in the near future (e.g. NO_X and SO_X emission control areas). The tough competition puts economic pressure on the maritime transport industry. Therefore, the demand for efficient and mostly environmental neutral propulsion systems that meet the environmental legislations and minimize the cargo costs are immense. Medium speed dual fuel engines are in accordance with the strict maritime emissions legislation IMO Tier III. They do not require any exhaust gas aftertreatment, are economically competitive, and allow fuel flexibility. These engines deliver the highest efficiency in high load operation. A valuable approach to improve the efficiency and reduce the environmental impact in low and part load is represented by the electronic cylinder cut-out. Thereby, the natural gas admission is deactivated and the valves are kept activated. It is investigated with the help of a developed 1D GT-Power simulation model of a medium speed dual fuel engine. The predictive model is adjusted to a measured engine map (test bench data) by an optimization workflow that is set up in Optimus. The cylinder cut-out is analyzed with special emphasis on efficiency, NO emissions, and methane slip. Different static cut-out scenarios are simulated and assessed for constant relative air/fuel ratios and varying load. An optimization workflow is developed and set up in Optimus. The selected evolutionary algorithm changes the number of cut-out cylinders and the relative air fuel ratio to optimize the engine efficiency under consideration of IMO Tier III NO_X emission regulations and the knock onset. The optimization is conducted for discrete engine operation points in a load range from 10% to 50%. The optimization predicts a significant increase of the brake efficiency and reduced methane slip at low and part load operation. This depends on an increased turbocharger efficiency, reduced pumping work, richer combustion, and higher indicated mean effective pressures of the fired cylinders that leads to an improved combustion (shifted from diffusion to premix) and engine efficiency without exceeding the NO_X - and knock-limits.

Introduction

In maritime business the internal combustion engine will maintain its important role in a long term [1]. Efficiency, reliability, and energy density, combined with the global availability of liquid fuel, are some of their major advantages. The economic aspects are of great importance but next to them the maritime industry has to consider and fulfil the strict IMO Tier III emission regulations of airborne oxides of sulphur (SO_X) and oxides of nitrogen (NO_X). A growing number of SO_X Emission Control Areas (SECA) has been in force since 2006. Furthermore, the fuel's sulphur content is limited to 0.1% in the SECA and will be worldwide limited to 0.5% from 2020 [2]. NO_X Emission Control Areas (NECA) are already established in North America and will follow in the Baltic and North Sea after January 1, 2021 [3, 4]. Globally, further ECA are currently under discussion, e.g., Mexico, the Mediterranean Sea, and the Black Sea, and some of them will probably become in force in the near future [5, 6].

The tough competition puts economic pressure on the maritime transport industry. Therefore, the demand for efficient and mostly environmentally neutral propulsion systems that meet the emission legislations and minimize the cargo costs is immense. A good match of these entire requirements is represented by the dual fuel engine. Fuel flexibility, combined with high efficiency and the possibility of fulfilling all environmental demands without exhaust gas aftertreatment, makes this kind of engine highly interesting for the maritime industry.

Medium speed dual fuel engines are designed to deliver the highest efficiency and the most economic performance in high load operation [7]. However, in maritime transportation of passengers and goods, economic and punctual operation is the most important. To achieve planned arrival times and to avoid anchoring, low and part load operation can be necessary. Furthermore, low and part load operation is also applied for maneuvering, nautical station keeping, dynamic positioning, as well as auxiliary energy supply.

Medium speed engines typically operate with rotational speed in the range from 300 rpm to 1000 rpm and do not have throttling valves [8]. On the one hand, this has the positive effect of reduced pumping losses, yet, on the other hand, the desirable restriction of the air flow in low load is not possible. This leads to a very lean fuel air mixture in low load [9]. Due to the increased energy demand to ignite the lean mixture, the share of pilot fuel has to be elevated and a shift from mostly premixed to distinct diffusion combustion is a consequence. This results in high combustion temperatures and enhanced formation of NO_X [10]. If the mixture is too lean, ignition is not possible and misfiring emerges [9].

A valuable approach to improve the efficiency, reduce the environmental impact in low and part load, and prevent misfiring is represented by the cylinder cut-out. The cut-out of one or more

Control-oriented modeling of two-stroke diesel engines with EGR for marine applications

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Abstract

Large marine two-stroke diesel engines are widely used as propulsion systems for shipping worldwide and are facing stricter NO_x emission limits. Exhaust gas recirculation (EGR) is introduced to these engines to reduce the produced combustion NO_x to the allowed levels. Since the current number of engines built with EGR is low and engine testing is very expensive, a powerful alternative for developing EGR controllers for such engines is to use control-oriented simulation models. Unfortunately, the same reasons that motivate the use of simulation models also hinder the capacity to obtain sufficient measurement data at different operating points for developing the models. A Mean Value Engine Model (MVEM) of a large two-stroke diesel with EGR that can be simulated faster than real time is presented and validated. An analytic model for the cylinder pressure that captures the effects of changes in the fuel control inputs is also developed and validated with cylinder pressure measurements. A parameterization procedure that deals with the low number of measurement data available is proposed. After the parameterization, the model is shown to capture the stationary operation of the real engine well. The transient prediction capability of the model is also considered satisfactory which is important if the model is to be used for EGR controller development during transients. Furthermore, the experience gathered while developing the model about essential signals to be measured is summarized, which can be very helpful for future applications of the model. Finally, models for the ship propeller and resistance are also investigated, showing good agreement with the measured ship sailing signals during maneuvers. These models give a complete vessel model and make it possible to simulate various maneuvering scenarios, giving different loading profiles that can be used to investigate the performance of EGR and other controllers during transients.

Keywords

Mean Value Engine Model, Dynamic Simulation, Parameterization, Exhaust Gas Recirculation, Ship Propulsion

1 Introduction

Over the last year, maritime transport growth slowed down. However, shipping is still growing, and for the first time the estimated world seaborne trade volume surpassed 10 billion tons.[1] The required technical development to achieve an overall clean and efficient transportation in our society has to involve the marine sector as well. The regulations that have driven the automotive industry started several decades ago, while the regulations affecting marine diesels began at the beginning of the last decade. Hence, the process of reducing the environmental impact of the shipping industry is ongoing. The International Maritime Organization has developed the stricter Tier III emission limits[2] on NO_x, for new vessels built after January 2016.

Low-speed two-stroke diesel engines usually propel the largest vessels, e.g., tankers, bulk carriers, and container ships. These low-speed engines have high fuel efficiency, however, they are also responsible for large amounts of pollutant emissions, like NO_x and SO_x. The large reduction in NO_x emissions enforced by the Tier III compared to the previous Tier II regulations cannot be fulfilled by only improving the combustion of these engines. Thus, new technologies are being developed in order to attain the emission reductions while still keeping a good specific fuel oil consumption (SFOC), which is a good indication of CO_2 emissions. The two most common technical solutions are Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation, (EGR). SCR is an after-treatment technology

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Predictive Control for a Marine Hybrid Diesel-Electric Plant During Transient Operation*

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***Abstract*— We investigate the implementation of model predictive control to the power split problem of a hybrid diesel-electric marine power plant during transient loading. The modeling procedure, the controller design and the experimental validation of the proposed control scheme are covered. System behavior is described by models based on system identification from experimentally obtained data. These models were used to design predictive controllers that cope with physical and operating constraints of the hybrid power train. Experiments were conducted at HIPPO-1 testbed, at the Laboratory of Marine Engineering. Based on the experimental results it can be concluded that predictive control can be utilized as an efficient energy management strategy in marine power plants for disturbance rejection, and operation of the plant within operator's desirable limits.**

I. INTRODUCTION

Modern marine power systems must cope with tight emission standards. Especially during maneuvering or loading operations within port range, diesel engines of the ship face adverse operating conditions due to the continuously transient loading profile of their power supply system, leading to higher fuel consumption and higher emission pollutants formation. Hybridization is one promising technology for emissions reduction and fuel efficiency enhancement and it is getting considerable acceptance amongst marine engine manufacturers.

Although hybrid crafts have been used for military purposes for many decades, only recently hybridization has been considered for use in commercial applications, such as passenger ferries, tugs, offshore support vessels (OSV), inland ferries, yachts, etc. Various hybrid configurations are reviewed in [11]. In such hybrid installations, the main area of interest is their control strategy, i.e. the decision for the power split between the power train components.

To ensure optimal operation, advanced control strategies are required to estimate the amount of energy to be produced by each component of the power system to cope with the transient demand. Usually, the engine control unit contains a certain number of single closed-loops, with many look-up tables and local limiters in order to achieve closed-loop control of the multi-parametric and strongly non-linear engine behavior [16].

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Power management in hybrid marine power plants decides how much power shall be produced by the internal combustion engine and how much should be supplied by the electric motor so as to achieve the total power demand at the driving shaft of the propeller or waterjet. Marine propulsion plants have slow dynamics, due to their size; as a result, transients last longer compared to automotive engines. Rapid load acceptance of diesel engines leads to higher fuel consumption, and consequently production of more CO_2 as well as higher NOx concentration and smoke formation.

Several strategies for the power management of hybrid power trains have been applied, including dynamic programming, stochastic dynamic programming, equivalent fuel consumption minimization and model predictive control (MPC). Dynamic programming generally provides the optimal solution for an optimization problem over a certain driving cycle [6]. However, in marine environment the operation profile for vessels cannot be known a priori and there is no driving cycle for such power plants. As a consequence, the optimization should be short termed, depending on the knowledge of the present state of the power plant. Recently, strategies including a Machine-Learning (ML) framework were introduced [10], in an effort to address the issue of calculation in real time.

Among the advanced control design methodologies, MPC is capable to handle at the same time multi-variable processes, satisfy constraints, deal with long time delays and utilize knowledge for plant disturbance response. MPC has been used in a broad range of applications, such as diesel engine control [7], [8], spark ignition engine control [15], [14], Hybrid Electric Vehicles [16], [17], Plug-in Hybrid Electric Vehicles (PHEV) [9], etc. In [12] a multilevel predictive control approach is used for the energy calculation and optimal power split control of an OSV during maneuvering under the presence of environmental disturbance.

This work focuses on power split strategies during transient operation of a marine power plant with the use of MPC. This is achieved by tracking λ (air to fuel ratio) reference while ensuring that certain constraints, like NOx and fuel consumption are met.

The paper is organized as follows: in Section II the experimental setup is presented and the identification process is explained. In Section III the control system is formulated and analyzed. The experimental results are presented in Section IV. Section V contains the concluding remarks.

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Combustion Property Analyses with Variable Liquid Marine Fuels in Combustion Research Unit

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Abstract. The quality of ignition and combustion of four marine and power plant fuels were studied in a Combustion Research Unit, CRU. The fuels were low-sulphur Light Fuel Oil (LFO, baseline), Marine Gas Oil (MGO), kerosene and renewable wood based naphtha. To meet climate change requirements and sustainability goals, combustion systems needs to be able to operate with a variety of renewable and 'net-zero-carbon' fuels. Due to the variations in the chemical and physical properties of the fuels, they generally cannot simply be dropped into existing systems. The aim of this research project was to understand how changes in fuel composition affect engine operation. The focus was on how various attributes of the fuels impact on the combustion process – especially ignition delay and in-cylinder combustion. The goal of the research project was to allow broad fuel flexibility without any or only minor changes to engine hardware. The results showed that the ignition delay decreased expectedly with all fuels when the in-cylinder pressure and temperature increased. The differences in the maximum heat release rates between fuels decreased in high-pressure conditions. MGO had the shortest ignition delay under both pressure and temperature conditions. Based on the CRU results MGO and kerosene are suitable to use in compression-ignited engines like the reference fuel LFO. In contrast renewable naphtha had a long ignition delay. If naphtha is used in a CI engine, the engine must be started and stopped with, e.g. LFO or MGO.

Key words: Diesel engines, alternative fuels, ignition delay, heat release rate

INTRODUCTION

In compression ignition (CI) engines the combustion process starts when liquid fuel is injected as one or more jets into the cylinder fulfilled with hot high-pressured air near the top dead centre (TDC) position of the piston. The ignition delay (ID) is a period when injected fuel entrains to cylinder, atomizes and mixes with existing air. Chemical reactions start slowly and ignition occurs after the ID. Good atomization provides rapid air-fuel mixing decreasing the ID. The ignition of air-fuel mixture prepared during the ID causes a rapid pressure rise that is called as rapid uncontrolled or premixed combustion. Controlled combustion follows and is the part where preparation of fresh air-fuel mixture determines the rate of combustion. Combustion continues until all the fuel or air is utilized. This last phase is called as final combustion.

Due to variations in the chemical and physical properties of the fuels, they generally can not simply be dropped into existing systems. The aim of this research project was to understand how changes in fuel composition affect engine operation. The fuel properties

Impact of catalyst activity and geometry on diffusion and SCR kinetics under elevated pressures

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Abstract

In marine diesel engine applications, selective catalytic reduction upstream of the turbocharger may become the preferred technology when dealing with high sulfur fuels and low exhaust gas temperatures. The target nitrogen oxide reductions in combination with minimum ammonia slip and reduced gas diffusion rates under elevated pressures require understanding of the impact of catalyst geometry on the SCR kinetics. The extent, trends and sources for this observation are elucidated in this work by systematic testing of catalysts having equal geometry and/or intrinsic activity.

Introduction

Selective catalytic reduction (SCR) has proven to be an effective and cost efficient method for nitrogen oxides (NO_x) removal from combustion generated exhaust gas. The importance of NO_x abatement is imminent due to the noxious nature of these emissions which is claimed to cause more than 38,000 premature deaths globally on an annual base just because of excess NO_x emissions from on-road diesel applications.[1]
In many of the densely populated coastal areas, however, contributions of passenger car NO_x emission are smaller than the amount of NO_x emitted from marine transportation.[2-4] In order to improve this situation, the International Marine Organization's (IMO) Tier III regulation for emission control areas (ECA) is pushing for a 76.4% NO_x reduction compared to the previous Tier II level, thereby fostering the introduction of SCR also for marine applications.[5] The US adopted this regulation since January 1st 2016 for an ECA of 200 nautical miles off their coastlines and around their territories in the Caribbean Sea. While the impact of this unique ECA is limited so far, the introduction of a Baltic Sea and English Channel ECA for NO_x in 2021 is expected to finally lead to a strong global increase of vessels equipped with SCR systems due to the global trade pattern of merchant vessels.

The fuel sulfur content for marine vessels is regulated to 0.1% in ECA's, outside the global limit is still at 3.5%, though a reduction to 0.5% is scheduled for 2020. However, if a sulfur oxide removal system is installed in the exhaust duct, fuel sulfur contents of 3.5% and possibly even higher may still be used as long as the effective SO_x emissions are equivalent to the prescribed sulfur content fuel.[5] The resulting concentrations of SO_3 and H_2SO_4 in the exhaust can impose challenges for the SCR process due to the formation of ammonium bisulfate (ABS) deposits on the catalyst surface.[6] As marine engines are heavily optimized for highest fuel efficiency,[7] the exhaust gas temperatures at which the SCR needs to operate are low compared to other diesel engine applications.
One solution to cope with both, potential issues due to ABS deposits and low exhaust gas

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Full Length Article

High-pressure pyrolysis and oxidation of ethanol

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ABSTRACT

The pyrolysis and oxidation of ethanol has been investigated at temperatures of 600–900 K, a pressure of 50 bar and residence times of 4.3–6.8 s in a laminar flow reactor. The experiments, conducted with mixtures highly diluted in nitrogen, covered fuel-air equivalence ratios (Φ) of 0.1, 1.0, 43, and ∞. Ethanol pyrolysis was observed at temperatures above 850 K. The onset temperature of ethanol oxidation occurred at 700–725 K over a wide range of stoichiometries. A considerable yield of aldehydes was detected at intermediate temperatures. A detailed chemical kinetic model was developed and evaluated against the present data as well as ignition delay times and flame speed measurements from literature. The model predicted the onset of fuel conversion and the composition of products from the flow reactor experiments fairly well. It also predicted well ignition delays above 900 K whereas it overpredicted reported flame speeds slightly. The results of sensitivity analyses revealed the importance of the reaction between ethanol and the hydroperoxyl radical for ignition at high pressure and intermediate temperatures. An accurate determination of the rate coefficients for this reaction is important to improve the reliability of modeling predictions.

1. Introduction

In recent years, ethanol has attracted both scientific and commercial attention as an additive to conventional liquid fuels or even as a alternative neat fuel. Gasoline doped with ethanol is widely used in spark-ignited (SI) engines [1]. Ethanol addition to gasoline promotes the overall octane number of the fuel while it potentially reduces the emission of particulate matter [2,3] and CO [4]. Ethanol addition to diesel fuels has also been studied [5,6] and a positive effect on fuel economy was found [5].

The relatively high energy density of ethanol makes it attractive also as a neat fuel. Using ethanol-based fuels produced from bio-sources can reduce the pressure on fossil fuels resources and reduce CO_2 release to the atmosphere. However, a widespread usage of ethanol as a fuel may increase the emission of aldehydes [1,4,7], which can cause health risks.

Compared to studies of hydrocarbon oxidation, research in the oxidation chemistry of oxygenated fuels is more recent, motivated by their importance in engines. In addition to the interest due to its role as a fuel or fuel additive, the reaction mechanism of ethanol is a crucial part in models for heavier alcohols often found in complicated biofuels [1]. Due to its relevance, e.g., for homogeneous-charge compression-ignition (HCCI) engines [8], ethanol ignition has been studied at high pressure and intermediate temperatures in flow reactors, rapid compression machines (RCM), and, to some extent, in shock tubes.

Data from high-pressure turbulent flow reactors are available for ethanol pyrolysis (950 K, 3–12 atm) [9] and ethanol oxidation (523–903 K, 12.5 atm) [10]. Ignition delay times at intermediate temperatures are mostly obtained in rapid compression machines (RCM),but the relatively short ignition delays of ethanol make it possible to conduct such experiments also in shock tubes. Ignition delay data from RCM have been reported by Lee et al. [11] (750–1000 K, 20–40 atm), Mittal et al. [12] (825–985 K, 10–50 bar), Lee et al. [13] (700–1300 K, 67–80 bar), and Barraza-Botet et al. [14] (880–1150 K, 3–10 atm), while shock tube ignition delays are available from Noorani et al. [15] (1070–1760 K, 2–12 atm), Heufer and Olivier [16] (800–1400 K, ⩽40 bar), and Cancino et al. [17] (650–1220 K, 10–50 bar). Some of these studies cover partly the pressure and temperatures of the current study, but ignition delay times provide only an overall characteristic of combustion. Additional insight into the combustion chemistry can be obtained by measuring more detailed characteristics such as species profiles.

A number of chemical kinetic models for ethanol oxidation has been published over the years [10,12,13,18–25], but only some of them have been applied at elevated pressure. Marinov [21] conducted the first comprehensive modeling study of ethanol oxidation, estimating a number of rate constants by analogy to known reactions. Whereas most of the data used for validation were obtained at low pressures and high

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High-pressure oxidation of ethane

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Reaction kinetics

ABSTRACT

Ethane oxidation at intermediate temperatures and high pressures has been investigated in both a laminar flow reactor and a rapid compression machine (RCM). The flow-reactor measurements at 600–900 K and 20–100 bar showed an onset temperature for oxidation of ethane between 700 and 825 K, depending on pressure, stoichiometry, and residence time. Measured ignition delay times in the RCM at pressures of 10–80 bar and temperatures of 900–1025 K decreased with increasing pressure and/or temperature. A detailed chemical kinetic model was developed with particular attention to the peroxide chemistry. Rate constants for reactions on the $C_2H_5O_2$ potential energy surface were adopted from the recent theoretical work of Klippenstein. In the present work, the internal H-abstraction in CH_3CH_2OO to form CH_2CH_2OOH was treated in detail. Modeling predictions were in good agreement with data from the present work as well as results at elevated pressure from literature. The experimental results and the modeling predictions do not support occurrence of NTC behavior in ethane oxidation. Even at the high-pressure conditions of the present work where the $C_2H_5 + O_2$ reaction yields ethylperoxyl rather than $C_2H_4 + HO_2$, the chain branching sequence $CH_3CH_2OO \longrightarrow CH_2CH_2OOH \xrightarrow{+O_2} OOCH_2CH_2OOH \rightarrow$ *branching* is not competitive, because the internal H-atom transfer in CH_3CH_2OO to CH_2CH_2OOH is too slow compared to thermal dissociation to C_2H_4 and HO_2.

1. Introduction

Investigation of ethane oxidation at high pressure and intermediate temperature is important from both fundamental and practical perspectives. From a practical point of view, ethane is the major non-methane component in natural gas, which is used in gas turbines and gas engines for power generation and transportation; variations in ethane fraction in natural gas may result in significant changes in the ignition properties of the fuel [1]. In addition, the use of ethane as an engine fuel is growing, in the first instance for ships transporting feedstock ethane. Knowledge of ethane oxidation is important for evaluating the potential of knock in the engines using these fuels, as well as for the development of HCCI engines [2] and assessing possible spontaneous ignition in lean-premixed gas turbines [3]. From a fundamental perspective, the oxidation of C_2H_6 plays an important role in the hierarchical structure of the reaction mechanisms of hydrocarbon fuels. To develop and verify these chemical kinetic models for hydrocarbon oxidation, measurements of the combustion characteristics at high pressure are essential.

While hydrocarbon ignition even at high temperatures relies on intermediate-temperature chemistry, this range of temperature, particularly at high pressure, has only been sparsely studied. Species concentrations have been reported from reactor experiments. Hunter et al. [4] studied ethane oxidation at temperatures of 915–966 K and pressures up to 10 atm in a flow reactor. A jet-stirred reactor was used by Dagaut et al. [5] to study ethane oxidation at temperatures of 800–1200 K and pressures of 1–10 atm. Tranter and co-authors [6–8] studied the pyrolysis and oxidation of ethane behind a reflected shock at pressures between 40 and 1000 bar over temperatures of 1000–1500 K by measuring major stable products using gas chromatography (GC).

A number of studies report the measurement of autoignition delay times for ethane [9–18]. Beerer and McDonell [17] evaluated the ignition delay of ethane and other lower alkanes in a flow reactor in the ranges of 785–935 K and of 7–15 atm. Shock tube studies

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Towards a temperature dependent and probabilistic lifetime concept for nodular ductile cast iron materials undergoing isothermal and thermo-mechanical fatigue

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Abstract. In this investigation, the fatigue behaviour of a ductile cast iron with high content of silicon and molybdenum, was experimentally characterized by performing isothermal low cycle fatigue (LCF) tests as well as out-of-phase thermomechanical fatigue (OPTMF) tests within the temperature range RT – 500 °C. The studied material shows an embrittlement at temperatures nearby 400 °C. A possible explanation for the observed lifetime reduction is intergranular embrittlement (IE). A mechanism based lifetime model is proposed for assessing the lifetime. The model is based on the assumption that the crack advance per cycle is correlated with the cyclic crack tip opening displacement (ΔCTOD) attributed to the crack tip blunting caused by accumulation of plastic and creep deformations ahead of the crack tip. Intergranular embrittlement is accounted for by introducing a temperature and strain rate dependent prefactor in the crack growth law, which only acts in a certain temperature range. The model is calibrated for a GJS material and successfully applied to predict the lifetime of this material when undergoing isothermal and non-isothermal mechanical loadings. A probabilistic interpretation of the scatter of the investigated material is presented in conjunction with the random nature of the initial defect size distribution.

1 Introduction

Nodular ductile cast iron materials (DCI) provide a good performance at high temperatures, especially DCI materials with high content of silicon and molybdenum. Due to their good mechanical properties, castability and cost efficient production processes, the use of these materials for fabricating components undergoing thermomechanical fatigue (i.e. cylinder heads, turbochargers, motor housings) is widely spread. In order to guarantee the safety of these components the damage mechanisms involved in the crack initiation and propagation regimes must be carefully investigated and integrated into lifetime concepts.

For non-isothermal conditions, the time and temperature dependent damage parameter D_{TMF} [1] was successfully applied for describing the fatigue damage of numerous high temperature resistant alloys. This parameter accounts for the temperature dependent material properties, the cyclic stresses and plastic strains, fatigue crack closure as well as for creep accelerated fatigue crack growth. The lifetime assessment is performed by assuming that the crack growth per cycle is proportional to the crack tip opening displacement.

However, this model formulation does not account for IE damage. The presence of IE damage is related to a shorter fatigue lifetime and the modelling of DCI materials suffering from IE damage demands a new formulation.

The IE damage mechanism was studied by several authors [2-6]. Nevertheless there is no clear explanation for this phenomenon. It is known to be dependent on microstructural features, such as the graphite size and the eutectic cell wall size, where greater sizes should promote intergranular fracture [2]. Based on tensile testing, it was also studied in [3] how increasing the percentage of silicon, changes the fracture mechanism from a mix of dimpled and intergranular fracture to cleavage and intergranular fracture. This change of fracture mechanism is thought to be related with the presence of MgO particles in the eutectic cell wall region serving as crack initiation sites [4]. Another investigation [5] concludes that MgO inclusions serve as crack initiation sites and the amount of phosphorus segregation on the grain boundaries dictates the fracture mode within the IE temperature of ferritic DCIs. In the same study the amount of segregated phosphor is connected to the solidification cooling rates where slower cooling rates should enhance phosphorus segregation. The kinematics of the process seem to be unclear, however all authors observed a drop in the ductility of the material at the IE temperature for the conducted tensile tests. [6] observed that the ductility drop derived from the IE damage is also dependent on the strain rate of the performed tensile tests. In this work the IE damage was modelled based on tensile tests performed at different temperatures and strain rates including the effect of strain rate on the IE damage process. [6] and [7] investigated the strain rate

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Influence of Al Content and Pre-oxidation on the Aqueous Corrosion Resistance of Binary Fe-Al Alloys in Sulphuric Acid

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Abstract: The influence of Al content and pre-oxidation on the corrosion behavior of binary Fe-Al alloys in 0.0126 M H_2SO_4 was investigated. The minimum Al content for forming a passive film on binary Fe-Al at 25 °C is 15 at.%. Alloys with 25 at.% Al or more show a good and similar corrosion resistance. X-ray photoemission spectroscopy measurements show the passive film on Fe-25Al is enriched in Al and consists of an outer layer of mixed Al and Fe hydroxides and an inner layer of Al oxide. The oxide layer generated at 1000 °C effectively protected against aqueous corrosion in H_2SO_4.

Keywords: Fe-Al alloys; Aqueous corrosion resistance; Pre-oxidation; Sulphuric acid

1. Introduction

Fe-Al-based alloys attract much attention for high temperature structural applications because of their outstanding properties. They exhibit a lower density of 5.7-6.7 g/cm^3 compared to other iron-based materials such as cast iron and stainless steels, superior high-temperature corrosion resistance, good wear resistance and low material costs [1-3]. In addition, the equipment for their production and processing is readily available in industry [2]. Fe-Al-based alloys are mainly developed for high-temperature structural applications [4, 5]. However, due to their lower costs, they are also considered as a potential alternative for replacing conventional stainless steels at low temperatures. Applications that have been looked at in detail are pipes and tubes for sea water desalination [6], Cr- and Ni-free parts used in food industry [7], high-performance brake materials for trucks [8] and as catalysts [9]. For such applications, understanding of the aqueous corrosion behavior is of great importance.

A number of studies on the aqueous corrosion behavior of binary Fe-Al alloys have been reported so far, but they mainly focused on binary Fe-Al alloys with a limited variation of the Al content [10-26] or Fe-Al alloys with additional alloying elements [11, 27-45]. Moreover, these investigations were carried out in a variety of electrolytes. Only two investigations were carried out using H_2SO_4 of low molarity. Masahashi et al. [46] investigated Fe-Al alloys with a wider range of Al content (5, 10, 15, 25 and 30 at.%). However, only the mass changes of the samples after immersion in 5×10^{-3} M H_2SO_4 at 40-100 °C up to 3 h were determined and corroded samples were inspected by scanning electron microscopy (SEM) and evaluated by X-ray photoelectron spectroscopy (XPS). The passivation behavior was not studied. A more extensive study was carried out by Chiang et al. [47] who investigated the passivation behavior of six Fe-Al alloys with Al contents between 3.4 to 41.7 at.% at 25 °C. However, no post

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Experimental Analysis of Fuel Alternatives for Marine Propulsion Systems

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Abstract

Work Package 1 of the European Union's HERCULES-2 project [1] has the objective to develop an injection system allowing for fuel flexible engine operation. Such an injection system must cover the spectrum from classic fuels – residuals from the petrochemical industry – to the far end marked by liquid fuels like ethanol and/or methanol. The Spray Combustion Chamber [2] – a device developed and improved during earlier HERCULES-projects – was chosen to investigate the spray and combustion morphology of two fuel alternatives. As a reference Light Fuel Oil was applied and investigated with a new injector type which allows for variable flow area. Spray penetration of the alternative fuels shows strong differences, compared to classic fuels. The reason for this is expected in the lower viscosity and reduced compressibility of the alcohols, which both influence in-nozzle flow and hence spray tip penetration. The thermodynamic analysis shows a trend towards a good portion of pre-mixed combustion. This is a consequence of the pilot injection, which might still need some improvement on the exact timing, in combination with the swirl velocity. But the rate of heat release looks promising and for the engine tests following this year, a sound knowledge basis could be generated. For the first time CH_2O-LIF was applied for the demanding conditions, present in the combustion chamber of large marine diesel engines. First signals could be recorded, but unfortunately the signal to noise ratio was far from useable. Further investigations are therefore necessary. The injector design proved a good repeatability and a stable spray pattern.

Keywords: Marine, alternative, fuels, spray, combustion, experiments

Introduction

Marine industry faces interesting times: The newest LNG-powered, low pressure gas engines are an interesting option for ship owners [3]. Nevertheless, as not for every application an LNG installation is available yet, liquid fuels still play a major role in merchant shipping industry. Large marine two-stroke engines for the propulsion of merchant vessels are nowadays powered with Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO), Marine Gasoil (MGO) or a similar, convenient distillate waste stream fuel. The Global Sulfur Cap in 2020 (GSC2020) [4] or the ongoing discussions about Black Carbon [5] have the potential to change this. With the GSC2020 for example, the Sulphur content of any sea-going fuel will be limited to 0.5%. This probably will give room for alternative fuels. For todays' shipping sector alcohols are interesting only in very special cases, as their availability and price are not competitive enough. Further, they represent a fuel type on the far end of a wide spectrum of possibilities. A fuel injection system which is able to inject everything from residual fuels up to methanol would likely be able to cover most of the possible (liquid) alternatives in the future. But the requirements for such an injection system are enormous: The spectra of viscosity, energy density and lubricity for such a fuel variety are wide along the different dimensions: The kinematic viscosity spans from 1 cSt to over 700 cSt at 50°C, whereas the energy density of the alcohols is half of classic marine fuels. For the alcohols the lubricity is very low, what makes a long and reliable operation of the moving components challenging.

To explore the possibilities and to express the willingness for a drastic change in the propulsion of merchant vessels, a prototype version of such an injection system was developed within the HERCULES-2 project. In the Work Package 1 an injector and adjoining components were designed and manufactured to investigate different fuel types under engine relevant conditions. The core of the new system is a new type of injector with variable flow area. The needle which evolved from the FAST-design [6] allows controlling two different levels of spray orifices. The injector needle has three positions as can be seen in Figure 1:

1. <u>Needle closed:</u>
   When the injector is without electricity spring-operation of the needle closes all orifices against the combustion pressure.
2. <u>Medium opening position:</u>
   For classic fuels with high calorific value, the needle opens the first step, up to half the design lift and allows a lower row of spray orifices to inject fuel.

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NH_3 sensor measurements in different engine applications

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Abstract

In this study the exhaust gas ammonia (NH_3) concentrations from different exhaust sources were measured with ammonia sensor. Aim of the study was to find out if NH_3 sensor has potential to be used for monitoring and control purposes for SCR systems. Measurements were performed in laboratory and field conditions and comparison against Fourier Transform Infrared (FTIR) and Laser Diode Spectrometer (LDS) measurement techniques were carried out.

With heavy-duty vehicle, a comparison between LDS, FTIR and NH_3 sensor was performed on a heavy-duty chassis dynamometer. Measurements were performed on steady speeds and using World Harmonized Vehicle Cycle (WHVC) and Braunschweig test cycles. The urea injection rate for SCR system was varied for generating different ammonia levels on the exhaust gas.

On large cruiser ships the NH_3 measurements with FTIR and NH_3 sensor were performed using heavy fuel oil (HFO) and marine gas oil (MGO) as fuels. Also a long-term trials on two cruiser ships were conducted using heavy fuel oil and low sulphur (S<0.1%) residual fuel.

Results indicate that the NH3 sensor has potential to be used in different applications for monitoring and controlling the SCR system. Measurement results with the sensor were in good correlation with LDS and FTIR techniques and in dynamic measurements the sensor response was very fast.

Introduction

The current NO_x emission limits set by the legislation e.g. in U.S. and Europe, force vehicle and engine manufactures to use emission control systems for limiting NO_x emissions. This is applies to heavy- and light-duty diesel vehicles as well as for the non-road diesel engines and ship engines.

Selective catalytic reduction (SCR) is used for heavy-duty engine applications for controlling the NO_x emissions. Also some light-duty vehicles use the same NO_x reduction strategy. The SCR is based on injecting water-urea solution (AdBlue, hereafter urea) in exhaust gas before a SCR catalyst element. The injected solution decomposes under high temperatures to ammonia (NH_3) which reacts in the catalyst and the nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are reduced to nitrogen (N_2) and water (H_2O). The actual chemical reactions in SCR are more complex and in real operating conditions the reactions can be incomplete.

SCR systems need complicate control system for reducing the nitrogen oxides (NO_x) emissions in the most efficient way and without feeding excess amounts of urea to the exhaust gas. Excessive urea feed causes NH_3 emissions (NH_3 slip) after the catalyst. Therefore the system needs to operate in controlled way under dynamic operating conditions. NH_3 slip is unwanted, since the NH_3 is a precursor of secondary inorganic aerosol [1]. In environment the NH_3 causes acid deposition, coastal eutrophication and productivity of freshwaters, marine waters, and terrestrial ecosystems [2]. In small concentrations the NH_3 is not dangerous to human health but it can be irritating. The occupational health exposure limit for 15 minutes time period is is 50 ppm [3].

Measuring NH_3 from the exhaust gas is mandatory for heavy-duty engine certification in Europe and recommended in U.S. In Europe the allowed average NH_3 concentration during the test cycle is 10 ppm for heavy-duty on-road and non-road mobile machinery (25 ppm for locomotive engines) [4, 5]. In U.S. the EPA has been thought to set 10 ppm limit value for average NH_3 concentration over the test cycle [6]. In Europe the approved NH_3 measurement methods for heavy-duty vehicle engine type approvals are Fourier Transform Infrared (FTIR) and Laser Diode Spectrometer (LDS) and for non-road mobile machinery also Non Dispersive Ultra Violet Resonance Absorption (NDUV) [7,8].

The European heavy-duty engine type-approval procedure includes in-service conformity testing. The first in-use test should be performed at the time of type-approval testing. Portable emissions measurement system (PEMS) is used for the measurement, which is performed on-road according to specified driving pattern. At the moment testing doesn't cover the NH_3 emissions.

As mentioned the chemical reactions of SCR catalyst are complex and sensitive to exhaust gas conditions (temperature, flowrate) and catalyst ageing can cause decreasing efficiency of NO_x reduction. According the European regulations the emission durability requirement for Euro VI heavy-duty vehicles is 500 000 km / 7 years [9]. In U.S. the corresponding requirement for HHDDE category is 435,000 miles / 22,000 hours / 10 years [10]. The U.S. and European legislation also set requirements for on board diagnostics (OBD) system, which needs to detect malfunctioning emission control devices.

The heavy-duty vehicles use NO_x sensors for controlling the SCR system and for the OBD system requirements related to SCR. NO_x sensors are accurate way of controlling SCR and measuring the NO_x emissions before and after SCR catalyst. However, NO_x sensor has cross-sensitivity with NH_3 since NH_3 forms NO inside the sensor. When NH_3 is present in the exhaust gas after the SCR the NO_x

Skip Firing in Medium Speed Dual Fuel Engines: Detailed Assessment and Engine Performance Optimization in Compliance with IMO Tier III

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Abstract

Medium speed dual fuel engines are in accordance with the strict IMO Tier III emission legislation, are economically competitive, do not require any exhaust gas aftertreatment, and allow fuel flexibility. Medium speed engines generally do not have throttling valves to reduce air pumping losses in high load range. Though this leads to a very lean fuel air mixture and an increased fraction of unburned fuel in low load. A valuable approach to reduce this methane slip and increase the efficiency is skip firing.

Skip firing was applied for a medium speed dual fuel engine based on a predictive 1D GT-Power simulation model that is validated against test bench data, raw emissions, and knock onset. Skip firing sequences were simulated, compared, and assessed according to the resulting load depending efficiency, methane slip, and NO emission. Based on the found effects of reduced NO emissions and increased efficiency, an optimization workflow was set up in the commercial optimization software Optimus. The selected evolutionary optimization algorithm varies the skip firing sequence as well as the relative air fuel ratio to optimize the load-specific engine efficiency under consideration of IMO Tier III and knock onset. The optimization is executed for discrete engine operation points in a load range to 64%.

The optimization predicts a significant increase of the brake efficiency and reduced methane slip at low and part load operation. Both depend on an increased turbocharger efficiency, reduced pumping work, richer combustion, and higher indicated mean effective pressures of the fired cylinders. The increased indicated mean effective pressure of the fired cylinders leads to an improved combustion (shifted from diesel to natural gas premix) and engine efficiency without exceeding the IMO Tier III NO_X emissions and knock limits.

Kurzfassung

Mittelschnelllaufende Dual-Fuel Motoren erfüllen die strenge maritime NO_X Emissionsrichtlinie IMO Tier III, sind wirtschaftlich wettbewerbsfähig, benötigen keine Abgasnachbehandlung und ermöglichen Kraftstoffflexibilität. Grundsätzlich besitzen Mittelschnellläufer keine Drosselklappe, um so Pumpverluste im oberen Lastbereich zu reduzieren. Das führt jedoch zu einem sehr mageren Gemisch und einem steigenden Anteil an unverbranntem Kraftstoff im Niederlastbereich. Ein geeigneter Ansatz um diesen Methanschlupf zu reduzieren und den Wirkungsgrad zu erhöhen stellt Skip Firing dar.

Skip Firing erfolgte für mittelschnelllaufende Dual Fuel Motoren, basierend auf einem prädiktiven 1D GT-Power Simulationsmodell, das mittels Prüfstandsdaten, den zugehörigen Rohemissionen sowie Betriebspunkten an der Klopfgrenze abgestimmt wurde. Skip Firing Sequenzen wurden simuliert, verglichen und gemäß dem resultierenden lastabhängigen Wirkungsgrad,

Isothermal Oxidation Behavior of Tribaloy™ T400 and T800

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Abstract: The long-term isothermal oxidation behavior of Tribaloy™ T400 and T800 in synthetic air at 900 °C for up to 1000 hours was investigated. The mass gains of the samples were recorded continuously during the experiments with a thermobalance. Post mortem inspection of the samples was performed and the oxidation mechanism was analyzed. The results show that T800 has a better oxidation resistance than T400. The parabolic rate constant k_p of T800 is $2.4 \cdot 10^{-13}$ $g^2 \cdot cm^{-4} \cdot s^{-1}$, which is about one order of magnitude lower than $1.7 \cdot 10^{-12}$ $g^2 \cdot cm^{-4} \cdot s^{-1}$ for T400. The penetration depth of the oxides in T800 is less than half of that in T400 and steady state oxidation is attained after about 400 h, compared to 600 h for T400. The better oxidation resistance of T800 is related to its higher Cr content whereby protective Cr_2O_3 scales form more readily.

Keywords: Tribaloy; T400; T800; Oxidation resistance; Oxidation mechanism

1. Introduction

Tribaloy™ (a registered trademark of Kennametal Inc.) alloys are a group of Co or Ni-based superalloys that are extensively used as wear-resistant and corrosion-resistant coating materials for applications in which extreme wear is combined with high temperatures and corrosive media, such as industrial turbine applications [1-5]. Tribaloy™ alloys are composed of a large volume fraction of hard intermetallic Laves phase dispersed in a eutectic matrix of Laves phase and a Co- or Ni-based solid solution. These alloys can be used up to 800-1000 °C [6]. The hard Laves phase is a ternary C14 $MgZn_2$-type Laves phase with a melting point of about 1560 °C and compositions between

Development of a shear ultrasonic spectroscopy technique for the evaluation of viscoelastic fluid properties: theory and experimental validation.

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Nomenclature

A_m	Amplitude ultrasonic measurement (V)
A_r	Amplitude ultrasonic reference (V)
η	Shear viscosity (mPas)
k_m	Matching layer wavenumber (1/m)
t_m	Matching layer thickness (m)
z_l	Shear liquid impedance (Rayl)
z_m	Matching layer shear impedance (Rayl)
z_s	Shear solid impedance (Rayl)
ρ_l	Fluid density $(\mathrm{kg/m^3})$
f	Frequency (Hz)
f_0	STFT minimum detectable frequency (Hz)
f_s	Sampling frequency (Hz)
G'	Storage shear modulus (Pa)
G''	Loss shear modulus (Pa)
Im_{zl}	Imaginary part shear acoustic impedance (Rayl)
l	Slip length (nm)
Q	Quality factor
QCM	Quartz Crystal Microbalance
R	Reflection coefficient
Re_{zl}	Real part shear acoustic impedance (Rayl)
δ	Penetration depth (nm)
τ	Relaxation time (s)
W	STFT window size
ω	Rotational frequency (rad/s)

Abstract

In-situ measurement of viscosity advances the field of rheology, and aides the development of sensing systems for condition and performance monitoring of lubricated mechanisms. Many lubricated mechanisms, such as journal bearings or seals, are characterised by three-layer interfaces; an oil separating two solid (usually metallic) bodies. The viscoelastic study of the lubricating oil in layered systems is possible in-situ by means of ultrasonic reflection [1]. General solutions exist for the reflection of longitudinal plane waves from multi-layered solid-fluid systems. Similar solutions can be applied to plane shear waves. The use of a quarter-wavelength intermediate matching layer improves the sensitivity of the ultrasonic measurement and overcomes problems of acoustic mismatch. This opens the possibility of using reflectance methods to measure engineering (metal-oil) bearing applications that are acoustically mismatched. In this paper, a rigorous mathematical model for wave propagation in a three-layer system is solved for the reflection coefficient modulus and validated using a quarter wavelength ultrasonic viscometer. The model was tested against experimental data for two Newtonian reference fluids, water and hexadecane, and for one non-Newtonian reference fluid, squalene plus polyisoprene (SQL+PIP), measured ultrasonically at frequencies between 5 and 15 MHz. The results are in agreement with the expected viscosity values for the reference fluids. Further, the viscosity measurement is not limited to the resonance frequency, but it is performed over a broad band frequency range. This is important to improve

Transient Simulation of a Large Two-Stroke Marine Diesel Powerplant Operation with a High Pressure SCR Aftertreatment System

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Summary

The IMO Tier III legislation concerning nitrogen oxide (NOx) emissions from marine engines has compelled engine designers to apply new technologies for NOx abatement. Selective Catalytic Reduction (SCR) is a promising aftertreatment technology that enables compliance with the new rules. However, due to the large size of these engines the size of the SCR reactor is quite considerable (comparable to the size of the engine). As a result, the large thermal inertia of the SCR system has a detrimental effect on the transient and low load operation of the engine. Since the current number of SCR vessels is low and engine testing is expensive, having a fast and reliable model would be useful in order to study the SCR transient behaviour. In this paper, the transient response of a two-stroke marine diesel engine equipped with a High Pressure SCR system is studied. Each part of the propulsion system is modelled, namely, the main engine, the SCR unit, the propeller and the hull of the ship. The prediction capability of the entire model is validated by comparing model predicted results against on-board measured data available from a sailing vessel. The complete propulsion system model makes it possible to study the performance of the SCR system under various transient loading conditions.

1. Introduction

Emissions produced by large two-stroke marine diesel engines have recently gained attention due to their detrimental environmental effect. The International Maritime Organization (IMO) recently introduced stricter legislation on NO_X emissions, produced by marine diesel engines, also known as the IMO Tier III standard. The IMO Tier III legislation, is applicable to vessels with a keel laying date on or after January 1st 2016, when operating inside Nitrogen Emission Controlled Areas (NECAs) [1]. The North American coast, parts of Canada and the Caribbean Sea are currently designated as NECAs. As of January 1st, 2021 the North Sea and the Baltic Sea will also be designated as NOx ECA [2]. The reduction in NOx emissions required by the Tier III legislation, cannot be met only by in-engine modifications, such as combustion improvement or slide fuel valves. The most prominent technologies for Tier III compliance is Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR), both long used in the automotive and truck industry. EGR is a method that reduces the formation of NOx during the combustion, by recirculating a fraction of exhaust gas back to the scavenge receiver. The heat capacity of the gas entering the engine cylinders increase, due to the large heat capacity of CO_2 contained in the recirculated exhaust gas. Consequently, the maximum temperatures in the cylinder

Robustness analysis of the next generation of EGR controllers in marine two-stroke diesel engines

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Synopsis

Exhaust Gas Recirculation (EGR) has recently been introduced in large marine two-stroke diesel engines to reduce NO_x emissions. During accelerations, controlling the amount of EGR flow while still keeping good acceleration performance can be quite challenging. The main difficulties to overcome are the delay in the scavenge receiver oxygen measurement and the upper limit in the amount of fuel that can be burned with EGR diluted air without producing black smoke. Previous oxygen feedback controllers struggled during accelerations, but a new approach to EGR control based on adaptive feedforward (AFF) has been tested successfully. Nevertheless, further analysis and tests are required before deploying the new controller to more EGR ships. A simulation platform is a great asset to test the controllers before expensive and time-limited real-world experiments have to be conducted on board of ships. With this purpose, a new EGR flow controller is introduced to track the AFF controller EGR flow setpoint in a complete ship simulation model. This new EGR controller complements the previous AFF controller and determines the control signals of the engine EGR blowers. Several acceleration scenarios are simulated, and they identify the low load area as the most challenging concerning EGR control performance due to the slower air path engine dynamics. Controller robustness in this low load area against errors in the flow estimates used by the controller is analysed. Pressure sensor bias in the EGR flow estimator is identified as the most critical factor, which could lead to black smoke formation. This issue could be prevented with better sensor calibration or by using a differential pressure sensor in the estimator instead of two absolute pressure sensors. Errors in the parameters of the flow estimators do not affect the performance as much. This is a useful result because, for a newly built engine, the right parameters of the flow estimators might be difficult to obtain.

Keywords: Split-range control; Exhaust Gas Recirculation; Marine pollution; Engine control

1 Introduction

Developing a clean and efficient transportation sector is one of the most important goals for any society. Road transport started to define more strict emission limits of CO_2 and other pollutants several decades ago. While marine freight began to be regulated later, but in the past years, significant steps have been taken to reduce its environmental impact. The latest is the stricter Tier III emission limit, which enforces a substantial NO_x reduction for vessels built after January 2016 in certain coastal NO_x Emission Control Areas (NECAs), see International Maritime Organization (2013).

One method to reduce the thermal NO_x formed during the combustion is Exhaust Gas Recirculation (EGR). By recirculating burned gases back into the cylinders, the heat capacity of the air is increased which results in lower cylinder peak temperatures and thus less NO_x formation. EGR has been widely investigated in the automotive sector, e.g., Nieuwstadt et al. (2000); Ammann et al. (2003) among many more, but it has only recently been introduced in large two-stroke diesel engines.

Maintaining a high EGR rate when the vessel is manoeurving in a NECA without smoke formation is a challenging task for the current EGR controllers. The reduced oxygen availability during EGR operation limits the amount of fuel that can be burned without visible black smoke formation. This issue together with the industry trend to downsize the engines for fuel economy can reduce the vessel manoeuvrability. Moreover, the oxygen measurement contains inherent delays due to a required gas extraction process, which caused the original PI feedback to perform poorly in these situations. Hence, better EGR controllers that more appropriately handle these acceleration scenarios are crucial for the emission reduction and introduction of EGR on marine diesel engines.

The controller developed in Nielsen et al. (2017b), that uses an adaptive feedforward (AFF) algorithm, showed to have a great potential to improve the acceleration performance during vessel engine testing. However, before the proposed solution can be adopted widely to more EGR engines, further testing has to be carried out to verify the robustness of the complete installation. Since engine testing is limited by the amount of available EGR engines built and also due to high costs of vessel testing, a full vessel and EGR engine model was developed in Llamas

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Eindüsung von Harnstoff-Wasser-Lösung mit Zweistoffdüsen für großskalige SCR-Systeme unter Druck

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Kurzfassung

Die selektive katalytische Reduktion (SCR) wird für die Seeschifffahrt als eine möglicherweise zielführende Technologie gesehen, um die aktuellen Stickoxidgrenzwerte einzuhalten. Aufgrund der Variantenvielfalt und der daraus resultierenden starken Einbindung numerischer Methoden in den Entwicklungsprozess wird die Eindüsung wässriger Harnstofflösung für den Einsatz in großskaligen SCR-Systemen untersucht. Dazu wurde am ITV ein Heißgasprüfstand aufgebaut, mit dem der Sprayaufbruch unter verschiedenen, gut definierten Bedingungen optisch analysiert werden kann. In dieser Arbeit wurde die Zerstäubung mittels Zweistoffdüse untersucht, wobei der Fokus auf dem Verhalten der Zerstäubungsluft unter verschiedenen Druckbedingungen lag. Der Druckeinfluss ist von Interesse, da bei Schiffsmotoren gegebenenfalls auch SCR-Systeme vor Turbolader eingebaut werden. Mit Hilfe der planaren Laser-induzierten Fluoreszenz wurde die Zerstäubungsluft lokalisiert und mittels Imaging-Methodik Aufnahmen des Sprays erzeugt. Der Vergleich beider Methoden zeigt, dass Spraytropfen und Zerstäubungsluft für den Düsennahbereich auch unter verschiedenen Drücken die gleiche räumliche Ausdehnung aufweisen.

SCR beschichteter Dieselpartikelfilter für schnelllaufende Viertakt-Dieselmotoren im Marinebereich

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Kurzfassung

Im Rahmen eines F&E-Projekts ist für Marinedestillatmotoren ein kompaktes Abgasnachbehandlungssystem zur Einhaltung aktueller und zukünftiger Partikelanzahl- (PN), Partikelmasse- (PM) und Stickoxidgrenzwerte ohne zusätzliche Beschränkung des Schwefelgehalts im Kraftstoff entwickelt und am Motorprüfstand validiert worden.

Die Kombination von selektiver katalytischer Reduktion (SCR) und Dieselpartikelfilter (DPF), die als SCR beschichteter DPF (SDPF) in der Automobilindustrie zum Stand der Technik gehört, ist nicht eins zu eins auf Marineanwendungen übertragbar. Gründe hierfür sind die erforderliche Schwefelresistenz der Katalysatoren und die Aschespeicherfähigkeit des DPF.

Es wurde gezeigt, dass durch den Einsatz eines schwefelresistenten Dieseloxidationskatalysators (DOC) und gleichzeitiger Minimierung der Rußemissionen des Motors bei einem Schwefelgehalt von 0.5 % im Kraftstoff noch ausreichend NO_2 zur passiven Rußregeneration im DPF bereitgestellt werden konnte. Die Optimierung des Gesamtsystems ermöglicht somit nicht nur den Verzicht auf ein Brennersystem zur aktiven Regeneration des Filters, sondern auch die Minimierung des zusätzlichen Kraftstoffverbrauchs zur intervallartigen Temperaturanhebung über den DOC zur Förderung der passiven Rußregeneration.

Des Weiteren ist festzuhalten, dass zur Optimierung des Gegendruckverhaltens sowie zur Steigerung der NO_X-Reduktion eine verbesserte Verteilung der SCR-Beschichtung sowohl über das hochskalierte DPF-Substrat im Ganzen als auch speziell in den Filterwänden erforderlich ist.

Die Messungen der Partikel- und Stickoxidreduktion an einem ausgewählten Betriebspunkt geben die erfolgreiche Einhaltung der zukünftigen Gesetzgebung für die europäische Binnenschifffahrt, welche zwingend ein DPF-System voraussetzt, wider.

SCR coated DPF for Marine Engine Applications

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Abstract

In context of this paper, a compact exhaust after-treatment system (EATS), which is applied to marine distillate engine applications, has been developed and validated to fulfil existing and upcoming emission legislations. In detail, a coating for selective catalytic reduction (SCR) in combination with a diesel particulate filter (DPF) enables the simultaneous reduction of NO_X and particulate matter (PM) in one component. In addition, the EATS comprises a diesel oxidation catalyst (DOC), which is installed upstream to the SCR coated DPF (SDPF) to provide the required NO_2 for the passive soot regeneration and the fast SCR. The layout of this EATS is state of the art for automotive applications. Nevertheless, the requirements of the desired application, especially the high sulphur resistance, result in a significant development effort. It is shown that the investigated DOC systems provide a remarkable NO_2 generation while using marine distillate fuels with a sulphur content up to 5000 ppm. Furthermore, it has been observed that substrates made of cordierite (Crd) lead to a significant deterioration of the SCR performance of the vanadium-based coating after hydrothermal aging (HTA) at 650 °C. Contrary to this, the combination of DPFs, which consist of silicon carbide (SiC), and vanadium-based coatings, enable a sufficient NO_X reduction as well as the required sulphur resistance and hydrothermal stability up to 650 °C. In addition, the backpressure behaviour of the SDPF system has been observed in full-scale on an engine test bed, showing the advantage of an asymmetric cell structure of the DPF.

Introduction

The reduction of pollutant emissions has become a major challenge for engine manufacturers including those of diesel engines for marine applications. Since 2016 ships, which enter the North American coast as well as parts of Canada and the Caribbean Seas, have to fulfil Tier III NO_X-