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Contents

Torsten Mundt (DNV GL)

Goal-based short-term measures for the implementation of the IMO initial GHG-strategy

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The International Maritime Organisation (IMO) agreed in 2018 on the initial GHG-strategy to curb CO_2-emissions from shipping.
Measures to combat Green House Gas emissions from shipping are sub-divided in three dedicated time horizons, i.e. “short-term” for the years 2018 - 2023, “mid-term” for 2023 – 2030 and “long-term” beyond 2030. Additionally, “candidate measures” are listed in the strategy that could be possibly applied.

The speech is providing latest regulatory developments and state of play on what IMO is presumably adopting as framework for the short-term time horizon and which of the so-called “goal-based” measures will make the race for entering into an immediate regulation. The technical concept of goal-based measure “EEXI” will be explained in detail as well as the proposal regarding operational measures by making use of a more stringent mandatory SEEMP requirement.

Prof. Gunnar Stiesch, *Dr. Markus Bauer, Dr. Alexander Knafl (MAN Energy Solutions SE)*

Clean and Flexible Solutions for Stationary and Marine Markets

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In order to keep global warming below the 2°C target of the 2015 Paris Agreement, global net GHG-emissions must decline to zero until 2050 the latest. Renewable energy sources, primarily wind and solar power, are developed to replace a substantial portion of today's fossil fuel-based energy supply. However, the volatile nature of wind and solar power sources requires backup installations—so called reserve power—to ensure energy supply even in extended periods of calm winds and low solar irradiation.

Combining short start-up-times, high electrical efficiencies as well as high flexibility and modularity, internal combustion engines are well suited for this purpose. MAN's medium speed gas engines are capable to provide power within 30 seconds from standstill, achieve brake thermal efficiencies in excess of 50% and combined heat and power efficiencies greater 90% at very low emissions levels. Considering further decarbonisation, today's fossil-based natural gas can seamlessly be blended or replaced with renewable synthetic methane without changes to the existing infrastructure. Producing and adding green hydrogen to the gas grid allows to store and buffer excess renewable energy, and utilize it at times when renewables cannot meet the demand.

Within the marine sector where large bore engines are the established prime mover, the reliance on fuels with high energy density is paramount. The International Maritime Organization (IMO) recognizes renewable synthetic gas as a potential future fuel, which can be utilized without any modifications as 100% drop-in fuel in marine gas- and dual-fuel engines that are already deployed today. Replacing current HFO and distillate fuels with natural gas results in CO2 reductions in the range of 25% with the added benefits of significantly lower emissions of sulphurous oxides, particulate matter and oxides of nitrogen emissions.

Considering the overall climate effect of natural gas, methane emissions together with CO2 emissions must be taken into account. Methane is given a global warming potential of 28 over a 100-year time horizon in the latest IPCC assessment report. Efforts to minimize methane slip during exploration, distribution and combustion are essential to maximize the GHG benefits of natural gas compared to other fossil fuel sources. Unburned methane emissions from MAN dual fuel and gas engines have been significantly reduced over the past decade through engine internal measures such as the reduction of valve overlap or crevice volumes. Further potential exists particularly at low load operation, which will become increasingly important with engine power plants acting as control reserve for renewables with lower load factors and more start / stop events. In addition to engine internal measures, MAN is investigating catalytic solutions to further reduce methane emissions.

Looking beyond natural gas, MAN Energy Solutions is offering solutions for renewable Power-to-X fuel production such as hydrogen or synthetic natural gas. With MAN's investment in the electrolyser specialist H-Tech, MAN methanisation reactors, MAN Cryo's fuel storage systems, as well as a range of energy storage solutions such as batteries and electro-thermal energy storage, MAN solutions cover the entire value chain from production, storage and utilisation of renewable fuels.

Dr. Daniel Chatterjee, Dr. Alexander Buttler (MTU Friedrichshafen GmbH)

Power-to-X and the de-fossilization of large engines

The global limit for sulfur in fuel oil used on board ships of 0.50% m/m (mass by mass) enters into effect from 1 January 2020. This will significantly reduce the amount of sulfur oxide emanating from ships and should have major health and environmental benefits for the world, particularly for populations living close to ports and coasts [1].

Meeting the new sulfur limit will require to either use fuel at or below the 0.50% m/m sulfur limit or to employ exhaust gas abatement technologies that reduce the excess oxides of sulfur (SOx) from the exhaust stream for the case of conventional marine residual fuels containing sulfur levels in the vicinity of 3.5%. While scrubber technologies are considered mature, the investments are substantial and only a fraction of vessels will be fitted with scrubbers by 2020. Marine gas oil (MGO/DMA) presents itself as a readily available sulfur compliant solution; this, however, comes at an OPEX premium of approximately 50% at 2017 fuel prices. Additional sulfur compliant fuels include liquid natural gas (LNG), liquid petroleum gas (LPG), methanol and ethane. Over the past years, MAN Diesel & Turbo SE has developed a product portfolio of highly efficient 2- and 4-stroke engines capable of meeting the new regulations when operating on these fuels.

With the introduction of the 0.50% global sulfur limit, refineries and blenders will start to produce- and blend fuels that comply with the sulfur limit. This will require different refining processes and utilization of oil streams not currently used for marine fuels. The future fuel pool for 0.50% sulfur fuel will include heavily cracked streams, paraffinic fuels, distillates, desulfurized oil, HFO originating from sweet crudes already meeting the sulfur limit, and other types. While these fuels must comply with the current ISO 8217 specifications, it is anticipated that challenges such as instability, compatibility, high cat fines or unfavorable combustion characteristics will arise with some of the fuels.

To prepare for the new 0.50% sulfur fuels, MAN Diesel & Turbo SE is in close discussion with fuel suppliers and refineries to evaluate the impact of the new fuel product on the engines, particularly the fuel handling system, injection equipment, combustion chamber, combustion process, and the exhaust gas treatment system. A first set of 0.50% sulfur fuels have been analyzed at MAN and the results from these tests are presented.

Dr. German Weisser, Dr. Matthias Stark, Dr. Beat von Rotz, Dr. Bartosz Rozmyslowicz, Roger Mäder (Winterthur Gas & Diesel Ltd.)

Extensions of the toolbox applied in large engine research and development as called for by the advent of alternative fuels

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For many decades, the choice of fuels for large engine applications as in global shipping was relatively small and not subject to significant or fast changes. In consequence, the toolbox applied in research and development related to such engines was also rather stable and incorporated a limited number of testing facilities and simulation technologies.

The past few years have already brought about a considerable extension of the variety of fuels used in this sector, on the one hand due to the introduction of more stringent environmental regulations, on the other hand due to the adoption of fuels available as ship cargo. In the case of liquefied natural gas (LNG), this adoption has in the meantime gained considerable momentum, also well beyond the traditional application on LNG carriers.

The clear need for reducing greenhouse gas (GHG) emissions from shipping as f.i. stipulated by the Initial Strategy adopted by the International Maritime Organisation (IMO) further speeds up the diversification of the fuel landscape. Even though technological development in various areas can be expected to reduce the impact of marine transport on global warming, achieving IMO's goal of at least halving the GHG emissions by 2050 will not be possible without reverting to alternative fuels with low net CO_2 balance or even carbon-free fuel variants.

The introduction of such new fuels poses non-negligible challenges to the whole industry, starting from producers and suppliers of the fuels, on-board equipment developers and manufacturers up to the operators, not to forget regulatory bodies and classification societies having to update and extend the corresponding regulations as well as the procedures for their implementation.

Carsten Rickert, Marius Hoff, Robert Graumüller, Dr. Michael Sturm, Andreas Banck
(Caterpillar Motoren GmbH & Co. KG)

Optimization of the dual fuel micro pilot combustion process for marine applications

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Continuously more stringent emission regulations became effective in the past. Thereby, the application of natural gas as fuel in the marine segment significantly gained in interest in the recent years. The ability to achieve the required emission limits with no or reasonable exhaust gas after-treatment efforts provides a big incentive to favor gas and dual fuel engines for propulsion applications.

Advanced injection technologies enable the realization of well-designed thermodynamic concepts of medium speed dual fuel engines. Whereby, high engine efficiency can be provided at the desired emission level. This turns dual fuel engine applications into commercially competitive alternatives to well-established diesel engines.

The fuel-flexibility of a dual fuel engine was one of the main promotors to establish it in the marine segment. The capability to use either gas or diesel as main fuel provides several attractive attributes. A fail-safe back-up operation mode with diesel fuel, an adaptor to changing fuel prices, market or legislative frameworks and independence from insufficient gas infrastructure. Whereby, "Dual Fuel" represents a collective term rather than a specific combustion process. The variety of applications ranges from partial diesel substitution to low emission concepts fulfilling IMO III requirements. The technical expenditures vary accordingly.

The modern dual fuel technology has been object of development efforts for several engine manufactures for more than a decade. Therefore, a considerable population has already been delivered for field operations. Depending on type and model, these engines are already fulfilling IMO II or IMO III emission limits without exhaust gas aftertreatment.

Caterpillar Motoren GmbH & Co. KG has focused on the optimization of micro pilot dual fuel engines for marine applications. Approximately 1 – 5% of the total fuel energy are applied as pilot diesel ignition source. The pilot fuel is increasing the reactivity level of the homogeneous charge during the significant ignition delay. This optimized innovative combustion process provides high power output, an IMO III compliant emission level and a high engine efficiency over the entire load range.

Due to the significantly increased ignition delay, the flame propagation becomes highly dependent on local air-fuel ratio, charge temperature and chemical properties of the individual constituents. Therefore, the pilot fuel injector needs to be optimized to achieve the required spray pattern at the right time. This provides a reliable ignition and a fast heat release of the lean charge at the same time.

This paper describes a comprehensive development approach for pilot injectors being applied for the micro pilot combustion process. Furthermore, the resulting trade-offs within which the thermodynamic concepts of Caterpillar Motoren dual fuel products are placed will be described. The goal of this optimization approach is to minimize environmental pollution and maximize the customer value for marine applications.

<u>Prof. Andreas Wimmer</u> (LEC GmbH / Graz University of Technology), Dr. Nicole Wermuth, Dr. Jan Zelenka, Marcel Lackner, Dieter Barnstedt (LEC GmbH)

Hydrogen / methanol and hydrogen / diesel dual fuel combustion systems for sustainable maritime applications

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Transoceanic shipping is very important for international trade, has high energy efficiency per ton and kilometer, and it is expected to increase significantly in volume in the future. The International Maritime Organization adopted a resolution in April 2018 to reduce greenhouse gas emissions by at least 50 % by 2050 compared to 2008. In order to meet this goal, there is a need to consider new fuels and innovative technology solutions. The HyMethShip project (**Hy**drogen-**Meth**anol **Ship** propulsion using on-board pre-combustion carbon capture) – a cooperative R&D project funded by the European Union's Horizon 2020 research and innovation program - aims to drastically reduce emissions and improve the efficiency of waterborne transport at the same time. The HyMethShip system targets a reduction in CO_2 of more than 97 % and will practically eliminate SO_x and PM emissions. NO_x emissions will be reduced by more than 80 %, significantly below the IMO Tier III limit. The drastic CO_2 reduction is a result of combining methanol steam reforming, a CO_2 capture system, as well as a hydrogen-fueled combustion engine into one system. While the main energy source for the engine will be hydrogen, in order to fulfill the redundancy requirements for marine applications the system will be designed to allow operation with a conventional liquid fuel as well.

The objectives of this paper are to assess the potential and the drawbacks of using small amounts of the liquid fuel in combination with hydrogen fueling in a large bore, high-speed engine.
Experimental investigations of the dual fuel combustion are performed on a single-cylinder large bore research engine featuring either a pre-chamber combustion system with methanol admission to the pre-chamber or an open chamber combustion system with diesel pilot injection. In the paper the performance of the dual fuel combustion systems is compared to the performance of an open chamber combustion concept with hydrogen spark ignition and the impact of the second fuel on ignition, combustion stability, and emissions is evaluated.

<u>Rasmus F. Cordtz</u>, Chong Cheng, Thomas B. Thomsen, Prof. Jesper Schramm (Technical University of Denmark)

Application of methanol with an ignition promotor in a medium speed CI engine

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The negative climate impact forces the maritime industry to replace the conventional fuels - based on fossil feedstock's - with "green" carbon neutral fuels. "Electro fuels" are carriers of electrical energy that is stored in the chemical bonds of liquids and are produced from renewable sources, such as solar and wind power. Methanol is a potential "electro fuel" and is already a well proven fuel for spark ignited engines. It is liquefied at atmospheric conditions, but has a lower energy density per unit volume and much lower cetane rating than diesel.

This work presents the early findings of methanol application in a direct injected compression ignited combustion engine operating at medium speed. A mapped two cylindered and four stroke BUKH DV24 engine with a geometric compression ratio of 18 is used. The engine operates at 1200 rpm and one cylinder is fired with diesel to provide smooth engine rotation and overcome friction. The other cylinder - the experimental cylinder – is fed with air (at slight positive gauge pressure) and fired with methanol containing a fuel additive, in order to facilitate the combustion.

At 5 % m/m fuel additive and $\lambda = 2$, early fuel injections within 40 to 50 crank angles before the top dead center provides an efficient PPCI-like combustion. The rapid heat release rate/pressure rise rate is hampered by advancing the start of injection or increasing the λ-value, but these measures may reduce the fuel utilization significantly. For the optimum injection timing a heated charge air only has a limited influence on the ignition and fuel efficiency.

To operate satisfactory at diesel-like injection timings (10 crank angles before the top dead center) a compression ratio higher than available is needed which is simulated by heating the charge air. The need for heating increases as the additive fraction reduces. At the lowest tested additive content of 3.5 % m/m a charge air temperature of ≈120 °C (corresponding to an effective compression ratio of above 25 without charge air heating) provides a reasonable combustion with a less intense heat release rate, but slightly lower efficiencies compared to the early injections.

Karsten Stenzel, Manuel Cech, Martin Steiner, Tobias Ehrler, Dr. Christian Reiser (WTZ Roßlau GmbH)

Hydrogen direct injection (H2DI) on spark ignited stationary engine

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The carbon dioxide content of the air and the average temperatures have increased enormously since the Industrialisation. This increase was scientifically proven through ice core drillings. It is essential to prevent a further global warming. This goal can only be achieved by rethinking the energy consumption and conversion with the aid of climate-friendly technologies. The combustion engine which has been the subject of criticism can feature a part of these climate-friendly technologies. The excess of renewable energies can be used to produce green hydrogen by using electrolysis. With the aid of an efficient hydrogen engine, green hydrogen can again be converted into electricity and the waste heat can be used to heat buildings during times where there will be no renewable energies. The Power-to-Gas technology by means of hydrogen has the lowest conversion losses compared to other Power-to-X-technologies. At the same time, hydrogen is the only carbon-free fuel gas. The way of injecting hydrogen has an important impact on the engine's efficiency. For external mixture formation the Hydrogen is injected into the intake manifold of the engine (H2-PFI). Air displacement is a disadvantage of such a common injection which reduces the engine's efficiency. Furthermore, unintentional backfires can occur due to the fuel-air-mixture existent in the intake manifold. Hydrogen Direct Injection is much safer and more efficient. However, it is technically very demanding. Regarding the engine's efficiency and avoidance of NOX-Emissions, the injection timing and the pressure are of vital importance. This article presents the results of tests on a hydrogen engine using Hydrogen Direct Injection. The experimental prototype is a three-cylinder petrol engine with a total displacement of approximately 1 litre. The tests are a part of a Real-World Laboratory. One aim of this project is to develop a Mini-CHP-Demonstrator unit with Hydrogen Direct Injection.

David Humair, Prof. Kai Herrmann, Patrick Cartier, Pascal Süess, Silas Wüthrich (FHNW Schweiz), Prof. Konstantinos Boulouchos, Dr. Christophe Barro, Dr. Bruno Schneider, Christian Schürch (LAV-ETHZ)

Characterization of dual-fuel combustion processes

Lean-burn concepts are an attractive solution for the compliance with future emission standards towards reduction of CO2 emissions, combined with considerably lower particulate as well as NOX and SOX emissions – all that with efficiency comparable to diesel combustion. In this regard, lean burn gas/dual-fuel engine market is spread over a wide range of application areas, particularly targeting maritime industry. However, dual-fuel ignition and combustion processes of pilot spray ignited lean-premixed gas/air charge still pose considerable challenges to ensure reliable operation between misfiring and knocking as well as in terms of cyclic stability.

A novel "optical engine" test facility ("Flex-OeCoS") enables the investigation of pilot spray ignition and the ensuing transition to a turbulent premixed flame. The experimental test facility features ability to achieve engine relevant compression/combustion pressures and temperatures at variable speeds (flow/turbulence) for an adjustable range of gas/air charge composition. Process conditions are tunable with high procedure variance (e.g. variable valve timing, number of cycles) to approach characteristic conditions for ignition and combustion influencing parameters. The optically accessible combustion chamber offers enormous flexibility to apply optical measurement methods to acquire inflammation and flame kernel growth.

The focus of the paper lies on the experimental test facility and its flexibility in terms of fundamental pilot spray ignited lean-burn gas/air charge dual-fuel investigations. Moreover, initial results of ignition process and flame propagation in the "Flex-OeCoS" test rig based on operation and boundary conditions will be presented. The influence of a variety of affecting parameters has been investigated: gas/air charge composition, process gas temperatures and pressures, injection rate/duration, flow field (turbulence), and pilot fuels with different properties. Conclusions shall give extended insight into the thermo-chemical processes of dual-fuel combustion and the acquired reference data will be used to validate and further develop numerical CRFD methods.

Björn Henke (LKV, University of Rostock), Sascha Andree (LTT, University of Rostock), Karsten Schleef, Sebastian Cepelak, Prof. Bert Buchholz (LKV, University of Rostock)

Potential for nitrogen oxide and methane emission reduction in medium-speed dual-fuel engines

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Against the background of the ongoing intensifying discussion about the emission legislation within the maritime sector the so called dual-fuel engine concept is one possible approach to minimize the air pollutants but to keep high efficiencies at the same time. For the optimal usage of such combustion processes a far reaching understanding of the fuel injection, mixture formation and the ignition behaviour is an essential needing.

For this purpose, experimental investigations of these boundary conditions of the dual-fuel combustion process had been carried out at a medium speed single cylinder research engine with both several injector concepts and different injection strategies, as part of a scientific work at Rostock University.

The common rail pilot injector constitutes an important aspect of mixture formation and ignition behaviour. The main task of the injector is to drop a µ-pilot amount of diesel into the combustion chamber, which initializes the ignition of the homogeneous natural gas air mixture. It can be crucial at which position within the cylinder head the injector is located. Depending on the position of the injector, the nozzle contour must be adapted in order to hit the largest possible combustion chamber volume with the diesel spray and thus to realize an optimal combustion behaviour. For this reason, a comparative study was conducted on a medium-speed four-stroke engine, in which various injector concepts were examined and thereby show the potentials of an optimal position.

Subject of this study are the pilot injection quantities which are provided by single and multiple injection and which determine the resulting ignition and combustion behaviour.

Criteria that describe the combustion behaviour are centre and duration of combustion.

Other important parameters are knock intensity and misfiring - which have a significant impact on combustion stability - efficiency optimization, fuel consumption and exhaust emissions. Special focus was placed on nitrogen oxide emissions, as these are subject to legal regulations, but also to methane emissions, as these have a major impact on the greenhouse effect.

Sebastian Dörr *(Lubtrading GmbH)*

Sustainable shipping – how to choose the right energy carrier

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Since ancient times maritime transportation is back bone of economic growth and social development. But 2 % of global energy demand for shipping force us to develop new innovative solutions to reduce green house gas emissions as well as limited emissions and noise – with even growing fleets worldwide.

Beside hardware improvements and new vessel concepts the availability of sustainable energy carriers in global scale becomes key question to achieve such goals!

What is the right energy carrier for shipping?

What does that mean for engine development, vessel design and infrastructure?

How could a roadmap for such fuels or energy carriers look like?

Maritime logistics is like aviation a complex global system and highly competitive.

This does not allow local exotic solutions but requires multi stakeholder agreements and road maps to ensure an efficient transition. The presentation is focusing on liquid fuels from existing diesel to first generation biofuels, HVO to ptx.

Kim Pedersen, Hendrik Noack, Henrik Trolle (Umicore AG & Co. KG)

Catalyst substrates and coating technologies for clean large engines

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Global emission regulations for non-road mobile machinery are generally clustered into engine power classes. The highest one is being defined commonly for rated powers greater than 560 kW. Engines from that class cover a wide range of power outputs, typically 1-15 MW for 4-stroke and >20 MW for 2-stroke, and they are in many ways different to engines from lower power classes from the perspective of exhaust aftertreatment. There is a broad variety of applicable legislative frames depending on the uses case, e.g. locomotives, generators or marine. Fuel consumption, and hence, back pressure have an enormous importance since the absolute fuel consumption can be tremendous for high power engines. Besides Diesel engines, there is a growing number of gas and dual-fuel engines present in that segment. While land based Diesel engines and inland waterway applications in Europe and North America operate solely with low sulfur Diesel, we are faced with a scattered landscape of fuels in Asia and, in particular, when it comes to marine applications globally. This ranges from various fuel sulfur contents to residual oils or blends used in seagoing vessels. All this is leading to partially very different aftertreatment requirements. In this paper, general challenges and potentials of aftertreatment systems in the large engine segment will be discussed. That includes coating technologies such as oxidation catalysts and VWT-SCR as well as the implications of back pressure limitations on particulate filter design. In addition, the advantages of fiber based corrugated substrates are presented.

Dr. Daniel Peitz, Dr. Dominik Gschwend, Simon Schiegg (Hug Engineering AG),Yannick Loulidi (Anglo Belgian Cooperation NV)

Near zero emission medium speed engine for EU Stage V & ULEV

Near zero emissions for large engine operation are a long term target, which requires advances in several technical fields, such as fuels, engines and exhaust aftertreatment. However, today IMO restricts only NOx and SOx emissions for sea going vessels, while carbon monoxide (CO), hydrocarbons (HC), particulate matter on mass (PM) or number (PN) base are not considered. On shore as well as in inland water or coastal shipping in the EU and USA, large engines are already exposed to regulation considering all these emission components. Additionally, regional authorities start to foster the compliance of work vessels like tug boats and dredgers with such advanced emission regulation near shore, in harbors or in special low emission zones. Public awareness of engine emission impacts on the environment and health motivate reduction of the visible plume from leisure vessels such as cruise ships, ferries or yachts.

Medium speed diesel engines remain the prime technology for power generation and propulsion in industrial marine applications due to their high efficiency, reliable operation even at high operating hours, robust design with little need for service and competitive price. However, recent emission requirements as the ones mentioned above can no longer be achieved by the optimization and adjustment of engine design parameters alone, they need the combination with an advanced emission control system.

The Anglo Belgian Corporation (ABC) and Hug Engineering engaged in a development project to enable a medium speed diesel engine to run in compliance with *EU Stage V* emission limits for non-road mobile machinery, outperforming *US EPA Tier 4 final* emission requirements, and thereby enabling the classification according to the *ultra low emission vessel (*ULEV) notation for IMO registered ships.

On an engine testbed, a 2 MW ABC DZC series engine was combined with a modular Hug exhaust gas aftertreatment system containing a diesel particulate filter (DPF) with active regeneration and a selective catalytic reduction (SCR) system with possibility to include also an oxidation catalyst. In order to achieve the challenging emission requirements as well as to optimize overall operating costs, the engine was de-tuned from its IMO Tier II settings to a fuel-optimized low PM emission setting. This was only possible on the expense of increased engine-out NOx emissions, which were reduced by the SCR system down to *EU Stage V* levels and beyond. Variations of engine- and aftertreatment-setups were tested on full scale in generator and propeller operation mode cycles, yielding a final robust concept to achieve well-below *EU Stage V* emission limits. For further CO2 emission reductions beyond the ones achieved via the fuel consumption savings, the entire system was chosen to consist of biofuel- and synthetic-fuel-ready components, which will be one of the next steps.

This novel concept of an ultra-low emission medium speed diesel engine was recently chosen to be implemented as a propulsion and power system into a latest generation wind turbine installation vessel containing 25 MW total installed power which will be briefly presented as well.

Dr. Marco Ferro (OMT SpA), Dr. Marco Coppo (OMT SpA / OMT Digital srl)

Towards the digital engine: the OMT smart injector enables performance monitoring and condition-based maintenance

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The advantages of engine digitalization are multifold, from cutting fuel consumption thanks to operation optimization, to reducing downtime with condition-based maintenance. To achieve the full potential of engine digitalization, all the key systems, including the fuel injection system, need to offer both data collection and data analytics capabilities.

To better respond to the need of product digitalization OMT has spun off the start-up company *OMT Digital* and the two companies together have worked to create a smart injector able to measure and analyze its operative characteristics. Inside the smart injector, an in-house designed and manufactured piezoelectric sensor collects the time series of control-volume pressure during each injection, while a thermocouple and a current sensor measure injector temperature and injector driving current.

An electronic card mounted on the injector head performs the necessary conditioning and digitalization of the acquired signals, transmitting them over a bus orchestrated by a dedicated hub, which provides also the CAN and Ethernet interfaces for connecting it to the engine control unit and to a data processing computer. The raw data are then processed via a mix of traditional signal processing and machine learning techniques creating Value Added Data (VAD in the following) describing the injector performance during each injection cycle, such as the instants of control-valve opening and of injection start/end or the opening/closing velocity of the nozzle needle. The calculated VADs are the ground for estimating the Key Performance Indicators (KPIs in the following) for each injector and for the whole injection system, and are made visible to the engine-room crew via a web-based dashboard as well as well as being transmitted to a cloud-based storage for further analysis and knowledge generation at OMT headquarter. The actual performance can be compared with the expected behaviour of the injector at any specific operative point, providing information on sudden anomalies or on long-term trend of the injector. This knowledge can then be used as a basis for compensation strategies by the engine control unit or for maintenance indications.

In this paper a description of the OMT smart injector and of the whole system architecture is provided, together with a discussion on the data analytics algorithms applied to ensure robust identification of VADs, and some of the results collected so far during tests performed both on OMT test benches and on a customer laboratory engine.

Dr. Michael Willmann, Emanuel Rauer (Woodward L'Orange GmbH), Benjamin Stengel (LKV, University of Rostock), Dr. Fabian Pinkert, Erwin Swiderski (FVTR GmbH)

Potential of intelligent Injection components for multiple fuel combustion in large engines

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Local intelligence and IoT devices bring new functionalities and options to industrial equipment and offer several opportunities for all stakeholders from component supplier, engine manufacturer to the end user.
Injection equipment is emission/fuel-consumption relevant, cost intensive and demanding in service. Any device, that improves the functionality in these three fields will be a significant benefit for large engines.
Intelligent injectors are one possible step in that direction. A possible architecture for such a component is presented. It consists of a sensor, which is able to detect the injection behavior, a microcontroller to process and store relevant data and a communication interface to share information with other systems around the engine.
Since the main functionality is software based, this is a flexible and scalable system which allows to go in different directions, depending on where the focus is set in different applications.
In this study different functions are addressed. Drift compensation helps on one side to keep stringent emission goals over live time without large margins in new engines for possible drift. On the other hand, it allows to use the equipment far beyond the "mechanical" life time restricted mainly by wear. Condition monitoring allows to detect damages or excessive wear before they get critical for the engine. The combination of condition monitoring, load recording and damage models are a first step in direction of condition based maintenance, which allows to use components until they reach their physical end of life, without endangering engines availability.

Last but not least, a monitored injector is the base for the optimized use of multiple fuels. It keeps the injection process under control, independent from changing fuel properties, which is one important sub-process in the complete chain of combustion.
Experimental tests of the intelligent injector were performed at a single-cylinder research engine and an injection chamber at various operation conditions using 30% and 70% blends of diesel fuel with oxymethylen ether (OME) and paraffinic diesel (PD), respectively. The pressure signal from the injector's control volume (NFC-technology) allowed a clear determination of the start/end of injection. Due to the decreased caloric value of OME, the injection duration had to be increased significantly with OME-blends. Moreover, using the NFC technology, it was possible to show that the OME blended fuels tend to inhibit needle lift and closing compared to reference diesel while impacts of PD on the needle dynamic were negligible. Combustion analysis showed the improved ignition behavior with higher ratio of E-Fuel (OME/PD) due to their higher cetane number causing a decreased peak in premixed

combustion. With PD-blends soot emissions could be reduced at constant center of combustion and similar NO_x emissions. As a result of the prolonged injection with OME-blends, the center of combustion shifts to late. When the center of combustion was kept constant by an earlier start of injection, OME-blends showed increased NO_x emissions but superior soot reduction due to the significant amount of fuel-bound oxygen.

Tests at an optically accessible high pressure- high temperature injection chamber were used to show the changes in spray breakup and mixture formation due to the mixing of diesel fuel with OME. The changes in the mixture formation help explain the findings on the engine. The results give an outlook regarding the possibilities to use the injector performance for maintaining a stable combustion process when running the engine on OME Diesel blends.

Raphael Ryser (ABB Turbo Systems Ltd.)

The value of turbocharging for combustion and performance in the application of alternative fuels on large engines

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Global consent for action in environmental and climate protection brought up ambitious plans for a reduction of greenhouse gas emissions like the Paris agreement and the ambition levels formulated by International Maritime Organization (IMO). Large engine industry plays a major role in the achievement of these goals as a main supplier to the power generation and marine businesses. A complete abatement is only possible with carbon-reduced or carbon-neutral fuels. Apart from synthetic and biogenic substitutes for fossil diesel oil, heavy fuel oil and natural gas a range of unconventional energy carriers have emerged as candidates. For the moment neither has it been decided, yet is it foreseeable, which fuels will establish as primary choices in the marine and powerplant markets. Even so, especially in the view of typical product lifecycles, it is worth investigating the technical consequences of the combustion of the proposed alternative fuels for the engines and their components.

The chemical and physical properties for some of the alternative fuels differ quite a lot from the current fuels, while others remain still relatively close. This implies that for almost every fuel a dedicated combustion concept needs to be applied, including the type and layout of injection system. Another important aspect is the management of air mass flow and the temperature level at start of combustion, where turbocharging assumes an important role.

For this technical paper ABB Turbo Systems picked the recently most discussed alternative fuel types, such as methanol, hydrogen and ammonia. By considering particularly the thermodynamic properties and the chemical properties like stoichiometric air to fuel ratio and the lower heating value the turbocharging conditions could be derived. Operating limits like for the ignition were respected as far as possible. Technical boundaries on engine side like maximum pressures and temperatures were oriented on state-of-the-art engines. Based on these constraints different turbocharging strategies were defined and compared according their suitability and their effect on engine performance.

Prof. Koji Takasaki, (Kyushu University), Dr. Atsushi Takeda (Nippon Yuka Kogyo Co. Ltd.), Dr. Daisuke Tsuru (Kyushu University), Dr. Kosuke Okazaki (Japan Coast Guard Academy)

Review and prospect of marine fuel study

This paper titled ‘Review and prospect of marine fuel study’ covers the following three parts.

Part 1 reviews some studies for smooth shift of marine fuel from conventional high-sulphur HFO (Heavy Fuel Oil) to VLSFO: Very Low Sulphur Fuel Oil (sulphur: 0.5% or less), in compliance with SOx regulation from this year. As it concerns some cylinder tribological issues, this paper is included in the session for ‘Tribology’.

Part 2 reviews the combustion studies of alternative fuels with zero-sulphur and lower CO2 emission, methanol, LPG (Liquid Propane) and methane. Moreover, a past study on the diesel-cycle type hydrogen fuelled engine is introduced.

In part 3, roadmap to clear the IMO GHG reduction target for 2050 and concept design of zero-emission ships planned by the Shipping Zero Emission Project, Japan is introduced. The roadmap will stimulate the researchers to develop the zero- or low-emission fuels and marine engine systems.

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eta-up – Numerical and experimental temperature field analysis of a marine diesel engine piston

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The maritime cargo transportation these days is still dominated by efficient two- and four-stroke large-bore diesel engines, which have been optimised ship engine manufacturers in terms of low fuel consumption, high durability and low maintenance requirements. Current emission legislation as well as increased public recognition of emission from ships lead to increased investigation of alternative propulsion systems and fuels, but up to now, there is no scenario, in which the classic diesel engine will be replaced in high numbers any time soon. Therefore, there is still a need for optimization of the classic diesel internal combustion engine.

It was determined that ship engines, in comparison to fast running light- and heavy-duty engines, have potential to improve their mechanical efficiency. Based on this fact the eta-up project was founded in order to investigate the potential of friction reduction and rise the total efficiency.

Therefore, an existing test bench with a MaK 6M20 was upgraded to analyse a wide range of friction influencing parameters, such as the installed bearings, the lubricating oil mass flow or the interaction between piston and liner. The aim of these investigations was the reduction of the frictions losses and therefore a reduction of the fuel consumption.

Another main issue of this investigation was the acquisition of the spatially resolved piston temperature field and the transferred heat flows at the piston crown and piston cooling chamber. This information is needed to better understand the thermal load on the piston so that a critical operating point, with high thermal stress, can be detected and avoided early. For this purpose, CFD-CHT simulations were carried out, to reproduce the interaction between the gas exchange and combustion process in the combustion chamber and the heat conduction in the piston material. This approach in turn was used to simulate the piston temperature field. These simulations also include a comparison between two piston geometries and take various engine loads and speeds into account. To ensure sufficient validation of these simulated results, wireless data transmission telemetry was implemented on a specially machined piston, which is capable of transmitting time resolved data of up to 16 thermocouples at a time out of the crankshaft housing. Both, fast resolving surface thermocouples, to record the transient temperature gradients at the piston crown, and sheath thermocouples, to record the piston core temperature, were used. The locations of the thermocouples were chosen in order to quantify the heat transfer from the piston crown to the cooling gallery. In this paper the applied simulation and temperature measurement methods as well as the obtained results are presented.

Dr. Alexander Boucke, Prof. Gunter Knoll (IST mbH), Philipp Roming, Prof. Peter Eilts (ivb, Technical University of Braunschweig)

eta-up – Reduction of friction losses of medium speed ship engines: simulation techniques and modelling

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As part of the research project eta-up, ‚supported by the German Federal Ministry for Economic Affairs and Energy, measures are being researched that contribute to significantly reducing friction losses of current medium-speed large bore engines, in order to raise the mechanical efficiency of these engines to the level of high-speed diesel and gas engines, particularly in ship applications. A key objective is to achieve a significant reduction in the primary energy requirements and operational emissions of ships with unchanged performance requirements. The aim is to halve the frictional losses on the large engine, which corresponds to an increase in effective efficiency of around 5% at nominal load. In particular, a comparison of a new piston concept, derived from the now common design in the high-speed engine, with the standard piston is examined.
For this purpose, technical solutions that have been successfully implemented on high-speed engines in recent years are to be re-evaluated with regard to their effectiveness.
In addition to experimental research on a 6-cyl. MaK M20 engine, optimization potential is identified using the latest simulation techniques for multi-body dynamics for thermo-elasto-hydrodynamically coupled tribosystems.
Within the project, IST mbH is responsible for the provision of validated simulation models, on the basis of which ivb carries out parameter studies to identify the system behavior and measures to reduce friction on the large engine.
As part of the project, a piston concept, which is new for large engines, will be examined in measurement and simulation to determine its impact on friction losses. Instead of the traditionally tall piston, a much lighter and shorter piston with split skirt is used, similar to pistons in use in high speed engines currently.
Taking into account the tribological, mechanical and thermal loads on the crank mechanism, piston, piston rings and liner, the main parameters influencing the frictional power loss are determined and validated using the measurements on the test engine.
Various model levels are set up for examining the individual contributions to friction in the simulation:

- Crankshaft with main bearings to investigate the friction, running-in behavior and the temperatures
- Crank drive of individual cylinders considering a section of the engine housing to investigate the friction output of big end bearing and the piston assembly without piston rings
- EHD model of main and big end bearings with simulation of the coupled oil supply

Piston rings with consideration of the secondary piston motion and gas dynamics to investigate the friction losses at the piston rings

Rainer Runde (WESSELS Reederei GmbH & Co. KG)

MV „Wes Amelie“ field report after 3 years of operation

MV „Wes Amelie“ is a 1000 TEU Container vessel which has been converted to LNG in Summer 2017. The presentation will contain the following topics:

- Project development and Project realisation,
- Technical features of the System, Operation of the System, Technical challenges
- Development of LNG bunker procedures and it`s infrastructure
- Economic considerations for the use of LNG
- Ecological effects through the use of LNG
- Challange: Methane Slip
- Solutions: Methane catalyst, CO_2 neutrality with synthetic Methane

Outlock, actual Projects of Wessels Reederei and Wessels Marine

Dr. Horst Brünnet (Schaller Automation Industrielle Automationstechnik GmbH & Co. KG), Prof. Andreas Schütze, Henrik Lensch (Saarland University)

Selective methane detection in the crankcase of large 4-stroke engines

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The increasing population of LNG gas-fueled engines as a consequence of challenging emission regulations leads to another possible source for explosions within the crankcase: methane. Mainly caused by blow-by effects, unburned methane enters the crankcase or the piston underside by passing the piston rings and may accumulate to levels close to the lower explosive level (LEL), depending on the oxygen concentration. Even though the severity of methane induced explosions compared to oil mist explosions is still scope of current discussions within the technical community, it should be avoided either way. Current regulations especially from the marine classification societies and recent guidelines from CIMAC suggest the application of gas detectors in the crankcase of dual-fuel engines. In general, the monitoring of methane levels within the crankcase may also help to improve the performance of the combustion or the design of the piston ring / liner, respectively, and as a consequence to minimize the greenhouse effect caused by the emission of unburned methane via the crankcase ventilation. However, the harsh environment within the crankcase poses serious challenges for existing industrial gas detection equipment, such as infrared detectors. As the total number of other flammable gases such as ethane, butane, propane or volatile organic compounds can be significant, the measurement principle may not be suitable, leading to overestimated or – even worse – underestimated methane measurements. Additionally, normal oil mist concentrations due to the operation of the large engine and relative humidity levels of 60 % RH and higher have to be considered as well.
This paper presents a new approach to selectively detect methane in the crankcase of large 4-stroke engines with the help of an active atmosphere extraction. This principle is already successfully used for the detection of dangerous oil mist concentrations within the crankcase, where Schaller Automation has built-up a strong experience and data base over the last 50 years. The measurement system consists of a sensor array with multiple gas sensors to determine the methane level independent of other flammable gases, a digital humidity sensor and an electrochemical cell to measure the oxygen concentration. The combination of the signal information is used to develop a stable algorithm which is then applied to account for various humidity levels, operational oil mist, accompanying flammable gases, blow-by products and sulfur compounds. Results of different measurement campaigns acquired with comparable test systems and an online gas chromatograph (GC) as reference at the Caterpillar MaK 1M34DF research engine of the University of Rostock and a Pielstick PC 2-5V DFC power plant engine are presented and discussed. Furthermore, the methane distribution within the crankcase is simulated with the help of a new overset mesh CFD approach with the software Star-CCM+ in order to qualitatively determine possible areas of methane accumulation.