ABSTRACT BOOKLET

12th CIMAC CASCADES 2021

22 SEPTEMBER 2021 | GRAZ, AUSTRIA

On the Way towards Decarbonization – Green Fuels, Hybridization and Digitalization in Large Engine Applications

Decarbonizing Large Bore Engines

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Global marine transport is responsible for approx. 2,5% of global CO2 emissions and, driven by IMO- and additional regional regulations, needs to improve its greenhouse gas footprint. For coastal short distance shipping an uptake of battery hybrid propulsion systems supplementing the traditional combustion engine will be one part of the solution. However, for long range deep sea shipping alternative carbon-neutral fuels are the only viable option providing the necessary energy and power density. A number of different Power-to-X fuels are possible, ranging from green hydrogen to ammonia, methanol, methane and also synthetic e-diesel. Engine technology either can or will soon be able to cope with all of these alternative fuel types, but the (carbon neutral) fuel production cost as well as the respective storage and handling cost will be of crucial importance for the fuel selection. From today's point of view it is very likely, that there will be different optimum fuels for different applications, trade routes and geographic regions.

Consequently, a modular and flexible architecture of dual fuel engines, enabling various fuel adaptions and also retrofits of existing engines with the least possible effort, are of utmost importance to provide ship owners with the necessary flexibility they need to operate and potentially also re-sell their vessels in an economic viable way. MAN Energy Solutions does provide and is further expanding such a flexible and modular engine program for both 2-stroke and 4-stroke engines. While methane, LPG, ethane and methanol can already be burned today in addition to conventional diesel as backup fuel, MAN is currently developing ammonia and hydrogen combustion technologies to extend its carbon-neutral engine portfolio. And the market demand for these future-proof alternative fuel solutions is steadily increasing, having taken a substantial share of the newbuilding market and also a number of successful retrofit projects to existing vessels. Last but not least, a globally harmonized regulation including a greenhouse gas pricing is necessary, in order to support and accelerate the maritime energy transition.

Zero Emission Shipping – from Vision to the HyMethShip Technology Demonstrator

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It is expected that marine transport will continue to increase in the future and without any abatement measures its greenhouse gas emissions will do so. One possibility for emission reduction is the use of new fuels, such as ammonia, methanol or hydrogen. The latter two are used within the HyMethShip concept, a project funded by the European Union’s Horizon 2020 program.

The HyMethShip combines on-board methanol steam reforming with a pre-combustion CO2 capture system as well as a hydrogen-fuelled large bore internal combustion engine. With this system a reduction in CO2 emissions of approximately 97 % and an almost complete elimination of particulate matter and SOx emissions is possible. In the HyMethShip concept, engine exhaust gas enthalpy is used to provide heat for the methanol steam reforming process which in turn produces the hydrogen for the engine combustion. This interaction results in a rather unique set of requirements for the engine combustion system. Like in other engine applications, high efficiency and low engine-out NOx emissions are desired. In addition, there are requirements for engine exhaust gas temperature and exhaust enthalpy flow rate.

The aims of this contribution are to give a deeper insight into the HyMethShip concept and its technology demonstration. For this, the overall concept will be explained and the two key components of the technology demonstrator will be described in more detail: First, the membrane methanol reformer, its design and the working principle will be shown. Second, the combustion engine, especially the needed modifications for enabling hydrogen operation and some development work will be outlined. Finally, the current status of the technology demonstration will be summarized.

Decarbonization of Europe’s Power Generation - Hydrogen-Ready Engine Power Plants for 25% Hydrogen in Natural Gas

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This presentation describes the results of a project evaluating the effects of up to 25% hydrogen content in natural gas on INNIO* Jenbacher* gas engines. A test campaign was performed using a J612 (2 MW) Jenbacher gas engine installed on a development testbench at LEC (Large Engine Competence Center, Graz, Austria). Hydrogen mixing with natural gas up to 25% was investigated at various operating conditions including different engine load, ignition timing, charge temperature, NOx setting and methane number of the natural gas. Additionally, tests with hydrogen blending rate (transient) and operation at maximum hydrogen content were carried out. Finally, a mitigation strategy was applied to counteract the effects of hydrogen mixing.

Detailed combustion analysis shows the impact of hydrogen in natural gas. Due to the reduced methane number of the mixture and the increased laminar flame speed, there is an impact on the knock limit, the combustion stability and the risk for backfire and deflagration. INNIO Jenbacher investigations based on the LEC testing results led to a robust technical concept enabling up to 25% hydrogen content in natural gas.

*Indicates a trademark

Experimental analysis of the influence of current and future marine fuels on particle emissions

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With the last tightening of the IMO regulations on January 1st 2020 (sulfur content in fuel ≤ 0.5% or the use of an exhaust gas cleaning system also outside of the ECAs), a change in the composition of the fleet emissions and the fuel supply is to be expected. In this context, the joint project SAARUS was launched at the University of Rostock, with the aim to investigate ship-based emissions and to reduce them through optimized and expanded exhaust gas cleaning. In addition to reducing SOx emissions, the focus is on separating fine particles that measure less than 2.5 µm (PM2.5). In particular, the health-endangering fine dust fractions (aerosols) with particle diameters below 1 µm are only slightly reduced by conventional wet scrubbers. The approach to further decrease the particle load is therefore to use the scrubber as an optimized particle prefilter to create the boundary conditions for downstream filter technologies. Therefore, an extensive measurement campaign with six different market available fuels took place on a representative medium-speed single-cylinder research engine of the Chair of Piston Machines and Combustion Engines at the University of Rostock. As part of the investigations, the fuel-based changes in emissions and the combustion behavior of a hydrogenated vegetable oil (HVO), a MGO, a limit-compliant HFO (sulfur content ≤ 0.5%), a standard HFO (sulfur content 2.4%) and two highly aromatic heavy fuel oils (sulfur content 0.06% and 1.3%) are analyzed. The focus was on the characterization of the particle load in terms of mass concentration, number, size distribution as well as chemical composition. The following measurement methods were used to determine the particle emissions: gravimetric filter analyzes, tapered element oscillating microbalance (TEOM), scanning mobility particle sizer (SMPS), Pegasor particle sensor, online single particle mass spectrometry (SPMS), filter sampling and two-dimensional gas chromatography / mass spectrometry (GCxGC-TOFMS), high-resolution mass spectrometry (HRMS for organic matter) and inductively coupled plasma / mass spectrometry (ICP-MS for elements). The presentation focusses on the most important findings of this measurement campaign. Especially the influence of the different fuels on the particle load in terms of concentration, size distribution and chemical composition is shown. In a final outlook, the approach for the 2nd measurement campaign and the simulation approach for particle separation in the scrubber are presented.

Sustainable fuels roadmap

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The shipping industry are making big efforts in meeting the carbon emission reduction targets, that is needed for a sustainable future environment. One important aspect is, -of course-, to utilize new and alternative fuels. Today we can see that the shipping is dominated by heavy fuel and diesel oil together with an increasing share of LNG. LNG or methane is the fuel that has the lowest CO2 emissions of the fossil-based fuels and it is hence being considered as a good alternative for many operators, and it has also shown its importance in lowering the local emissions like NOx, SOx and particulate emissions.

When Wärtsilä is looking at the future fuel roadmap, we can see that the alternatives are many and the timeline of the new fuels' introduction and reduction of the fossil fuels are very unsure. This means that flexibility has risen up to be the main parameter for the future fuel roadmap. By being flexible, the engine and the vessel can be optimized to be both economically profitable already today and also in the future, when the availability, cost and legislation will change the landscape.

The most straightforward route towards sustainability is to introduce bio- and synthetic fuels that can be added to the fossil fuels of today. These can be made both as liquids like biodiesel or gases like biomethane and they can easily utilize the infrastructure and the existing equipment. These will all reduce the CO2 footprint by calculation as the carbon dioxide will return into the nature to be reused.

This will however not reduce the CO2 emissions from the engine and vessel itself. So to reduce CO2 emissions from the stack, we need to use a fuel that is not containing carbon. Wärtsilä is therefore developing the engines and systems to be able to utilize both ammonia and hydrogen as fuel. The development is done with different routes. One route is to utilize the engines and vessels of today and blend the ammonia/hydrogen ratio with the existing fuel and then gradually increase the zero carbon fuel according to fuel availability, legislation, fuel price, and technology maturity. Another route is to develop pure ammonia/hydrogen optimized engines. For the retrofit market, the first option is to prefer as the operation is already ongoing and the infrastructure is in place. For new vessels and engines both routes can be interesting.

The engine is by nature very flexible and by utilizing advanced designs and controls the internal combustion engine will be an optimal solution both for today's vessels and also for the shipping in the future.

Alternative Fuels – A measure to reach climate targets

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The Paris climate goals against global warming pushes the industry and society into action. Large engines make a significant contribution of 5 -7 % of the world-wide CO2 emissions. Consequently, large engines are forced to reduce their greenhouse gas and CO2 emissions significantly. The application areas of large engines are Construction and Industry, Power Generation, Marine and Railways. Large engines are because of several reasons difficult to replace by batteries and fuel cells. That is the reason why CO2 neutral or even CO2 free large engine applications are already in development to achieve the greenhouse gas emission goals for 2030, 40 and 50. Pilot applications will enter the market even by 2022 and the ramp up of new technologies will happen prior to 2030. CO2 emission reduction can be fulfilled by improved engine and vehicle efficiency, by carbon capture and storage technologies and by bio- and e-fuel applications. This paper shows the application options for bio- and e-fuels in large engines.

Due to the fact that electrolysis-based drop in fuels (e-Diesel, e-Kerosine,) have a low production efficiency, relatively high production costs and will be very likely occupied by off highway and airplane applications, alternative fuels will be required. Today hydrogen, ammonia, methane, methanol and ethanol seem to be the most promising alternative fuels for large engine applications. The physical and chemical parameters of these fuels differ a lot from Diesel and natural gas. Differences in viscosity, lubricity, density, energy density, vapor pressure, evaporation energy, flash point, flame-ability, ignition energy, cetane number, octane number and flame propagation require significant adaptions at the fuel injection/admission system as well as the combustion system.

All alternative fuels require individual mixture preparation and combustion systems for best fuel consumption and lowest exhaust emissions. The capability of retro fit and dual fuel use must be considered in all concepts. The paper is showing the application areas and pros and cons of different mixture preparation systems for the alternative fuels of large engines.

On the Way towards Defossilization of Diesel Engines

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The highly efficient Diesel engine is state of the art in many areas, especially in heavy-duty applications, in the industrial sector or in the marine area. An increasingly critical view due to the emission of greenhouse gases and harmful pollutants requires an investigation of alternatives to conventional Diesel fuel. Oxygenated synthetic fuels such as oxymethylene ether (OME) are a promising approach to reduce these emissions and to turn the Diesel engine into a sustainable powertrain concept. The soot-free combustion of OME allows an optimization of the combustion process towards minimum emissions and maximum efficiency. Climate neutrality of the fuel is achieved by using renewable energies and binding of existing carbon dioxide, for example through the conversion of biomass.

The fuel was investigated on a heavy-duty single-cylinder research engine, which was additionally modified for fully optical accessibility. The fuel system was adapted for the use of OME, and injectors with a larger nozzle flow were used to compensate for the reduced volumetric lower heating value of OME compared to Diesel fuel. The optical experiments showed that, in contrast to Diesel fuel, no soot luminosity is detectable with OME, even with poorer mixture preparation, as it occurs at low injection pressures. In addition, earlier ignition and faster combustion can be observed, which are due to the shorter ignition delay and the high oxygen content of OME, respectively.

To optimize emissions and efficiency, several engine parameters were varied with OME. Unlike Diesel fuel, even high rates of exhaust gas recirculation (EGR) do not lead to increased soot formation. The soot-NOx trade-off is thus resolved for OME, allowing a high level of in-engine minimization of NOx emissions. This is also achieved by the measures of lowering injection pressure and reducing boost pressure, with no soot formation occurring either. The promising combustion properties of OME further enable the use of Miller valve timing. Here, the intake valves are closed well before the bottom dead center. This leads to a reduced combustion temperature, which in turn results in reduced NOx formation. At the same time, engine efficiency is increased. Tests have shown that nitrogen oxides can be reduced by up to 40 % in this way, while at the same time efficiency is increased by more than 3 %. In combination with Diesel fuel, on the other hand, the use of Miller valve timing proved not to be reasonable, as the lower combustion temperatures lead to an increased tendency to soot formation. By combining this measure with reduced injection pressure and boost pressure, nitrogen oxides are lowered by up to 60 % for OME. This opens up the possibility of a simplified engine without the need for EGR, with the remaining nitrogen oxides being removed via exhaust gas aftertreatment (selective catalytic reduction).

The studies have shown that OME is a promising substitute for conventional Diesel fuel. By optimizing the combustion process, the lowest possible emissions can be achieved, which in combination with a closed carbon cycle makes the fuel a sustainable option for future mobility.

Hybridization and Electrification of propulsion systems for Inland Water Ways

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On the 1st of January 2020, the EU Stage V emission standards entered into force for non-road main and auxiliary engines with a reference power above 300 kW, being effective for internal combustion engines installed in non-road mobile machinery (NRMM) like inland waterway vessels.

The Stage V regulation calls for limit values for emissions of nitrogen oxides (NOx) of 1.80 g/kWh, hydrocarbons (HC) of 0.19 g/kWh, carbon monoxide (CO) of 3.5 g/kWh and particulate matters (PM) of 0.015 g/kWh. Additionally, for engines with a reference power ≥ 300 kW, Stage V introduced particle number (PN) emission limits (1x1012 #/kWh).

Furthermore, the European Union aims to be climate-neutral by 2050. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement.

The European inland waterway network covers a length of over 41.500 km, divided into navigable rivers, lakes and artificial canals. In this network, more than 17000 vessels are in operation and especially for longer distances it is challenging to find a zero-emission propulsion solution. Pure battery-electric propulsion systems can be a solution for e.g. ferries covering short distances. But insufficient local grid capacity for charging the batteries within the required time as well as weight limitations for some applications can be barriers for this technology.

For some applications, such as inland waterway transportation and for coastal and short sea shipping, fuel cell technologies for propulsion and auxiliary power are seen as one of the most promising solutions to address not only decarbonization, but also other emissions reduction targets in maritime transportation.

Proton Exchange Membrane Fuel Cell Systems (PEM FCS) with its high power density, high dynamics and efficiencies of >60 % at low loads and ~45…47 % at rated power (efficiencies based on lower heating value of H2) are a proven technology from automotive and heavy duty applications. Adapted to marine requirements and regulations, PEM FCSs are a perfectly suited power source within an electric marine powertrain, especially in a hybrid configuration with e.g. batteries. Although hybridization leads to a higher system complexity it also offers more degrees of freedom for optimization to adapt to the requirements of a specific vessel.

In the presentation the following topics will be addressed:

- Overview about European inland waterway transportation and its legislation
- Introduction to PEM fuel cell stack and fuel cell system technology
- PEM fuel cell systems within a hybrid propulsion system
- Overview of hydrogen fuel cell vessel projects
- Challenges for fuel cell systems in marine applications.

Hybridization in Large Engines Applications

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Today's ship power and energy systems benefit from hybridization in multiple dimensions. The fuel consumption and greenhouse gas emissions are reduced, and the level of redundancy is increased. Additionally, the spinning reserve capabilities are enhanced and enable efficient utilisation of the resources. The transient behaviour of the machinery is also improved.

To reach the full potential of such a system, the integrator must ensure the appropriate integration of the main engine into a system with optimally sized rest of the components, fulfilling concrete operational requirements. They all should be controlled as a coordinated whole, otherwise the outcome may lead to undesired system behaviour, including worsened fuel consumption.

This presentation discusses the challenges WinGD faced, and the approaches taken to deal with them when it comes to development and deployment of integrated systems.

Development and deployment of a 2-stroke marine engine digital twin

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The topic of digital twins has grown in importance in recent years. Currently, digital twins in the marine sector are primarily used for health monitoring and predictive maintenance. In this context, this presentation will initially focus on the development of an operational engine performance digital twin for large two-stroke marine engines including their particularities. Afterwards, current application developments and examples for the digital twin will be shown and an outlook on future developments will be given.

Novel approaches for vibration monitoring by a cloud-supported system architecture

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For decades there have been multiple generations of monitoring systems established that are designed to continuously monitor torsional vibrations in a powertrain. Such torsional vibration monitoring systems are a well-known and wide-spread instrument to supervise the vibratory behavior of a rotating component in a driveline. The main purpose of these monitoring systems is an inline comparison with reference data that gives direct feedback to the operator of the installation when safety levels are reached or exceeded. However, the tendency towards more and more complex propulsion systems – driven by e.g. hybridization or alternative fuel concepts – lead to a variety of load profiles and context information that must be considered for vibration monitoring purposes. Additionally, the market shows an increasing demand for performance optimizations and predictive analyses that are typically beyond the scope of standalone vibration monitoring modules and they cannot be entirely handled on the edge due to limitations on computational power and data storage. In this talk it is illustrated how a vibration monitoring system with extended connectivity options can be designed that addresses all the issues from above: on the one hand side it is shown how a continuous data push into a cloud infrastructure can be established and how the data can be used for improved system analyses and condition monitoring. On the other side, the importance of 3rd party system integration is discussed which allows the combination of different data sources to obtain an even better system understanding and enhanced vibration analysis.