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Innovating maritime sustainability: designing a fuel-flexible vessel and engine

Retrofit Solutions

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ABSTRACT

Over recent years, the maritime industry has embarked on numerous initiatives aimed at reducing greenhouse gas emissions across short-, medium-, and long-term horizons.

While the ultimate goal of achieving net-zero emissions by 2050 could be met by replacing the existing fleet with new vessels, the interim targets of reducing emissions by 20% by 2030 and 70% by 2040 present significant challenges and is only achievable with retrofitting a significant number of ships from the existing fleet.

Furthermore, building new ships is not a solution to meet the requirements as it produces far more carbon emissions than retrofitting an existing vessel that gets an "extension of the runway".

Retrofitting an existing vessel to run on low-carbon or carbon-neutral fuel is not only capital intensive but comes with associated risks of re-investment if the fuel type in use needs to be changed during the lifetime of a vessel. The solution is to have a fuel supply system, and consumers that can switch between different types of alternative fuels without major modifications. This paper highlights the development and engineering of such a fuel supply system, and its consumers, that will be installed on a 13,000 TEU container vessel during 2025. The flexibility provides security of investment and deployment of an asset.

The fuel supply system incorporates a C-type tank constructed from specialized steel, capable of transporting LNG or ammonia under cryogenic conditions. Pumps and compressors are engineered to handle both fuel types with the latter working as a boil off gas compressor for LNG operation, and in reliquification mode for ammonia. The fuel preparation rooms have been segregated for safe operation on ammonia and multiple leakage management systems, which includes a knock-out drum, diffusion tank, scrubber as well as an ammonia release management system. Fuel will be supplied under low pressure cryogenic conditions into the engine room through an engine distribution module that is located outside the engine room to segregate the hazardous zones.

The stand-alone retrofittable fuel flexible platform installed on the main propulsion engine harnesses the energy available on it to reduce the stack emissions from a vessel.

The system features an advanced cryogenic injection mechanism, housed within an insulated cold box on the engine, which operates at sub-zero temperatures. Pressure amplification is achieved by the engine's existing servo oil power and phase transformation by thermal energy. Each cylinder has a pressure amplifier that is hydraulically actuated and supplied with cryogenic LNG between pressures of 6-8 bar. Minor module changes enable a switch from LNG to ammonia. No major changes are made on the existing engine components - only new cylinder covers and add-on components from the new injection and control system. The modular design allows for ease of installation and maintenance.

As the main dual-fuel propulsion engine consumes cryogenic LNG or ammonia as secondary fuel, there are two additional boil-off gas consumers to maintain the tank pressure at acceptable levels. To complete the transition to dual-fuel capability, an existing diesel generator has been upgraded to a Wärtsilä 6L34DF engine, and the boiler burner has been adeptly modified to accommodate both fuel types.

INNOVATING MARITIME SUSTAINABILITY: DESIGNING A FUEL-FLEXIBLE VESSEL AND ENGINE

1 INTRODUCTION

This decade has started with a strong focus to decarbonise the maritime industry with IMO adopting the EEXI and CII requirements. Even though shipping accounts for 3% of global greenhouse gas (GHG) emissions it has a significant impact on local air emissions close to ports, and in busy shipping lanes. The maritime industry has embarked on numerous initiatives aimed at reducing greenhouse gas emissions across short, medium, and long-term horizons. While the ultimate goal of achieving net-zero emissions by 2050 could be met by replacing the existing fleet with new vessels, the interim targets of reducing emissions by 20% by 2030 and 70% by 2040 present significant challenges and are only achievable with retrofitting a significant number of ships from the existing fleet. There will be a gradual transitioning from drop-in fuels to low carbon and/or zero carbon fuels based on factors other than technology: availability, safety, cost and crew competence.

Furthermore, building new ships is not a solution to meet the requirements as it produces far more carbon emissions than retrofitting an existing vessel that gets an “extension of the runway”.

Retrofitting an existing vessel to run on low carbon or carbon neutral fuel is not only capital intensive but comes with associated risks of re-investment if the fuel type in use needs to be changed during the lifetime of a vessel. The solution is to have a fuel supply system, and consumers that can switch between different types of alternative fuels without major modifications. This paper highlights the development and engineering of such a fuel supply system, and its consumers, that will be installed on a 13000 TEU container vessel during 2025. The flexibility provides security of investment and deployment of an asset.

2 DEVELOPMENT STEPS

2.1 Engine design

The selected engine at the start of this project was a 12RT-flex96C-B with rated output of 68 MW. Initial testing on the laboratory engine were done with boundary conditions set for this product reference type. During 2022 it was becoming evident that vessel speed would be reduced, and consequently the required engine power output. The latter would have a significant impact on brake specific fuel consumption and fuel slip resulting from the low power output to compression chamber volume ratio. Fuel slip was an important aspect that was considered, as methane slip contributes to GHG emissions and ammonia slip would lead to high levels of toxicity in air.

An upgrade was made to reduce the cylinder bore from 960 mm to 720 mm resulting in a swept volume reduction of 45% (figure 1). This reduced the fuel consumption by 12-14% (figure 2) and NOx emissions by 25-30%. The GHG impact from various operating profiles can be in the range of 6000-8000 tonnes per year (figure 3).

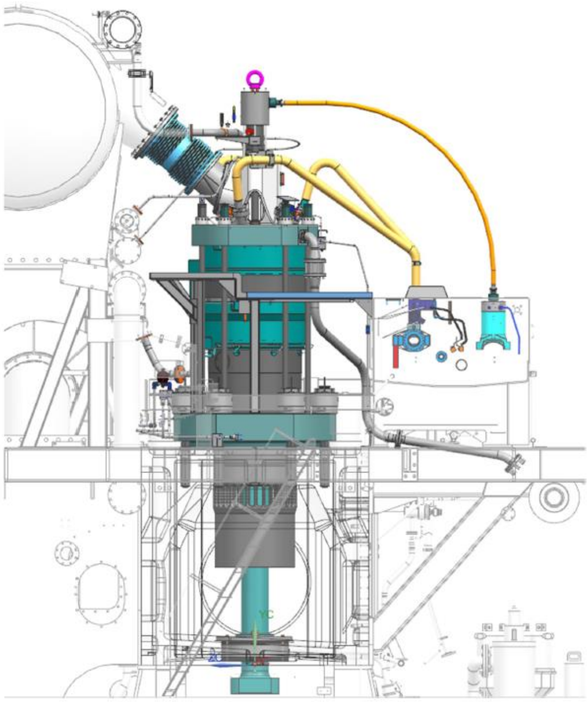

Figure 1. Layout of upgrade

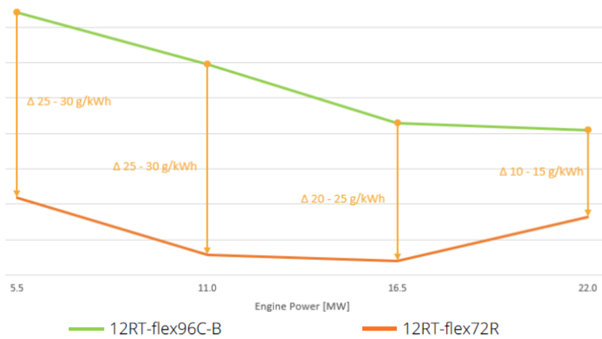

Figure 2: Fuel savings

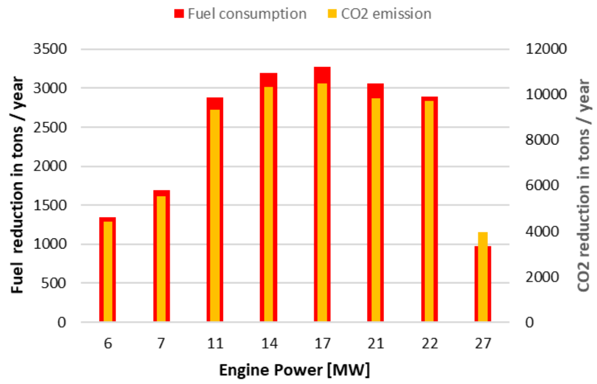

Figure 3: Annual savings

The cylinder cover of RT-flex72R is designed with a second set of holes to accommodate the alternative fuel injector, and the turbochargers are replaced with new ones having a higher-pressure ratio. The latter was supported by preparing an additional foundation on the scavenge air receiver and strengthening it to withstand the higher charging pressure.

Beginning in 2025, the engine will be equipped with an additional set of injectors specifically designed for LNG. The system's ability to handle ammonia will be improved by gradually incorporating more components that are currently in development.

Conversion of the engine to RT-flex72R made some space available between the cylinder liner and rail box to mount the servo oil distribution blocks and jumper pipes that are suitable for LNG and ammonia. Utilisation of this space was investigated to fulfil the following criteria.

- Safety issues related to vibration and leakages
- Maintenance friendly arrangement
- Complexity in retrofitting the installation
- New injector placement
- New cylinder cover design (geometry and holes)

The arrangement of components on the cylinder cover and around the cylinder liner is designed to support an ease of transition from LNG to ammonia (figure 4 & 5) as a fuel with minimal changes to the installed hardware. Fuel distributors mounted on the cylinder covers, including the jumper pipes between them, are designed to handle LNG in gaseous and ammonia in liquid form. A high-pressure servo oil distributor mounted on the adapter block supplies actuation power to the alternative fuel injector, which receives the signal from an embedded control module suitable for driving up to six injectors. Pressurised servo oil supply to the distributor is from engine driven pumps with pressure regulation as a function of load. The oil system for alternative fuel injector actuation and sealing is segregated, with a separate tank, as a safety measure in case there is contamination from fuel.

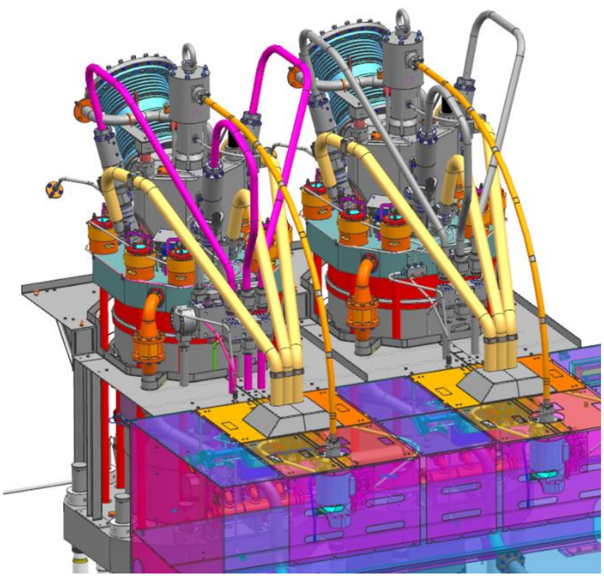

Figure 4: On engine arrangement

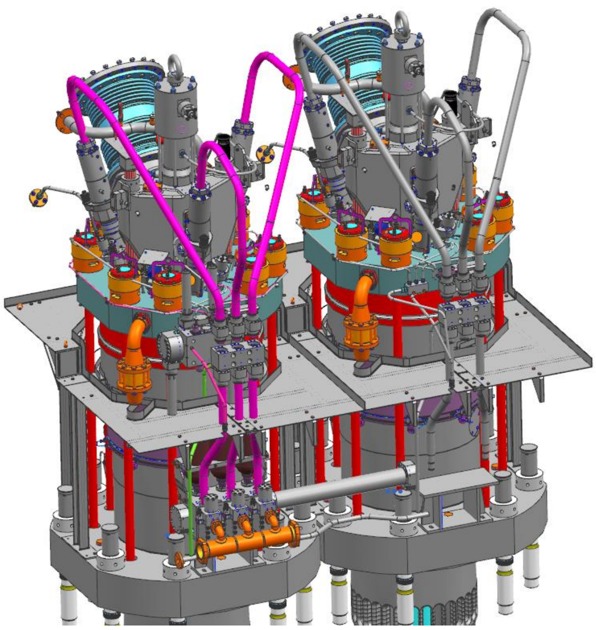

Figure 5: On engine distribution

2.2 Fuel supply system

The 2-stroke main engine high pressure pumps are fed with liquid fuel, and the 4-stroke dual fuel auxiliary engine and dual fuel boiler are supplied with natural gas fuel. An existing auxiliary engine operating on diesel will be replaced with a Wartsila 6L34DF engine. The dual fuel main engine will initially run on LNG and later on ammonia with back up as fuel oil.

The system includes the following main components:

- Fuel Tank including TCS;
- Deepwell fuel pumps, inside the fuel tank
- Pre-heaters and knock-out drum
- BOG Compressors
- Fuel Vaporizer and Fuel Heater
- Engine Distribution Module with buffer tank
- Purge Tank (comprising the Purge Skid);
- Glycol pumps and Glycol Heaters
- Bunkering stations

The fuel storage tank is of C-type with a design pressure of 6 barg allowing holding time of up to 21 days with partially filled tank and no consumption. Two key criteria's for selecting a C-type tank were dual carriage and integration into the ship's hull. It has a volume of 3200 m^3 and designed to carry 1900 tons of ammonia or alternatively carry 1200 tons of LNG. It is made of manganese steel and certified by Bureau Veritas for dual carriage. The tank material had to go through additional tests on resistance to stress corrosion cracking. The standard material used for carriage of ammonia is stainless steel (304L). Use of this special steel reduced the plate thickness by 35% compared to SS 304L. This reduced the weight of the tank and the associated risks related to welding a thicker stainless steel plate. Furthermore, it reduces the structural load on the tank top in its mounted condition. Fabrication of tank with insulation is complete (figure 6).

Figure 6: Multi-fuel tank

The deep well pumps (figure 7) mounted on the tanks are suitable to handle LNG as well as ammonia. Its electrical motor is rated to handle the higher density of ammonia and has a special sealing arrangement to prevent leakage of the toxic fluid.

Figure 7: Deep well pumps

The boil-off gas (BOG) compressor is an unconventional design that will handle both LNG and ammonia (figure 8). It has two operating modes; pressurised gas supply and reliquification. During LNG operation the compressor supplies pressurised fuel of 6 bar to the Wartsila 6L34DF auxiliary engine, for electrical power generation, and auxiliary boiler for steam generation. When operating on ammonia it acts as a reliquification compressor supporting the process of converting gaseous ammonia to liquid and returning it into the fuel tank. The suction head is made of special material to handle ammonia in addition to a preheater added on the line to raise the suction temperature. It has a special shaft sealing arrangement that acts as a dual barrier to prevent gaseous ammonia leakage past the shaft (figure 9). One of these barriers is a separate barrier circuit. The pumped media never leaks to the atmosphere unless the reservoir pressure is lost. A cooling coil inside the reservoir takes care of the heat removal. The barrier liquid enters the media through the inner seal faces.

Figure 8: BOG compressor

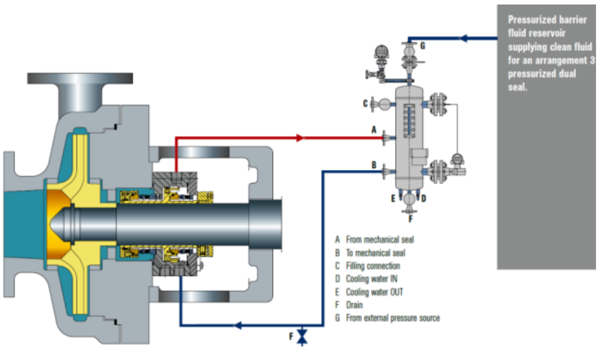

Figure 9: Double seal arrangement

2.3 Ship design

The fuel storage tank including fuel preparation rooms and auxiliary equipment will be located in a cargo hold. Segregation of fuel preparation and auxiliary equipment rooms within the cargo hold is done as a risk mitigation measure to limit the dispersion of gaseous fuel, especially ammonia, in event of a leakage (figure 10). This increases the complexity of the design as the structure in this part of the vessel becomes very rigid affecting other areas forward of the hold. An overview of the 3-hold fatigue analysis is shown in figure 11. Stiffeners need to be added to bulkheads in forward holds to prevent buckling. Strengthening of structure around the tank containing hold needs to be done as the number of ventilation ducts, as well as fans, need to be increased to ensure adequate ventilation. In this arrangement air is induced into the rooms with fans located close to the air exit.

The bunker stations are located below the torsion box on the same level as the existing liquid fuel bunkering station but further away from it to avoid weaking of the structure and ensuring safe mooring position for the fuel supply vessel. It also has provisions for leakage containment and firefighting. Space reservations are made for installation of additional ventilation and scrubbing equipment prior to ammonia trials.

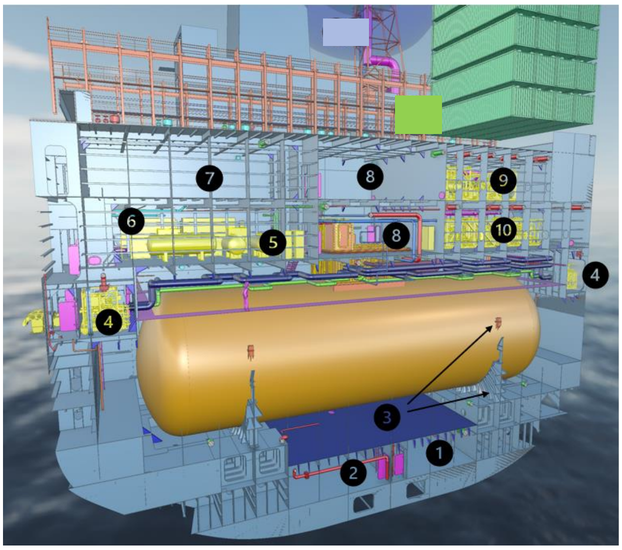

Figure 10: Cross-section of cargo hold showing equipment arrangement

1. Purge Skid room
2. Pump room + structural diffusion tank + cofferdam
3. THS including tank cradles and anti-flotation supports
4. Bunker stations
5. Aux. Equipment room
6. Switchboard room
7. Equipment room
8. Two lobbies
9. Fuel preparation room 1
10. Fuel preparation room 2

11. Multiple accesses, platforms and airlocks
12. ARMS room
13. Venting mast
14. Ventilation Fan room

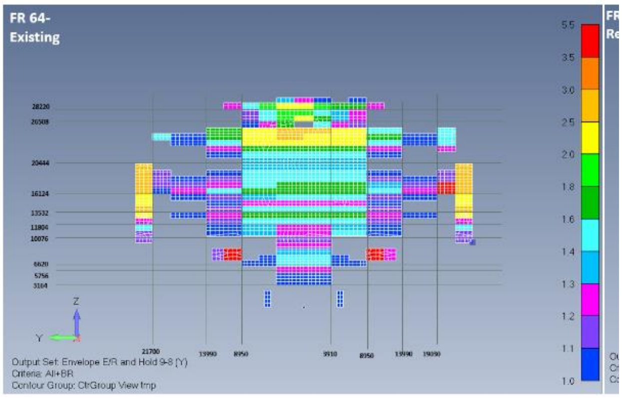

Figure 11: Stress map showing before and after retrofit to be mitigated

Ammonia release management system

The innovative system mitigates the risks associated with future fuels, such as ammonia, which can be hazardous to both health and the environment unless handled and stored with great care (figure 12). With WARMS, typical emissions comprise nitrogen (N2) and water (H2O), with ammonia (NH3) emissions less than 30 ppm. In fact, in most cases NH3 emissions are close to negligible.

Below are some highlights of the design:

- Designed for IECEx certification to Zone 1 (IIC, T3, EPL Gb); Electrical and mechanical
- Custom combustion design considerations
  - High ignition temperature issue is resolved with high energy exciter
  - Low flame speed and flame instability issues. Use of AM (3D printed) burner internals and a novel swirler to control low flame speeds, and avoid issues with offset geometry, bad tolerances etc.
  - Burner is designed to run rich, with low NO values (close to zero ppm)
  - N2O emissions are calculated to be zero (<1 ppm), confirmed by testing
  - NH3 slippage is in the <10ppm range, normally not detectable
- Design does not require incinerator start-up time
- Able to run on non-carbon pilot fuel, such as NH3; no fossil fuels onboard and less maintenance

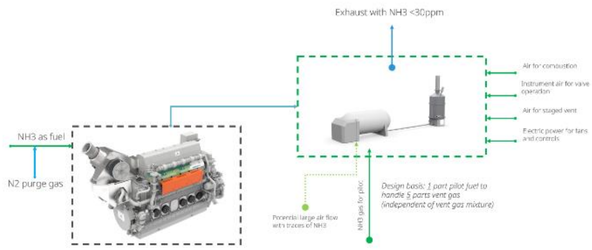

Figure 12

In case ammonia leakage is detected by sensor heads mounted in the fuel preparation rooms and tank holding space ventilation air which is routed through a scrubbing tower uses water as a media to trap the ammonia contained in the air. This water is collected in a diffusion tank which would be discharged to a shore reception facility when the ammonia in water has reached the saturation level. The dilution ratio is double of the classification requirements.

3 CONCLUSION

The past few years have witnessed multiple marine environmental legislations coming into force globally, most recently the adoption of amendments to MARPOL annex VI that will require ships to reduce their greenhouse gas emissions. Compliance with this new legislation to reduce greenhouse gas emissions is challenging as it could result in a stranded asset that can no longer be deployed for business. Building new ships is not a solution to meet the requirements as it produces far more carbon emissions than retrofitting an existing vessel that gets an “extension of the runway”.

In order to keep current fleets in operation, the market needs reliable solutions in the span of a decade. Wartsila and MSC are partnering to demonstrate the world’s first fuel flexible vessel and engine design that has unique equipment and design features that are not existent in the market today. The focus is to reduce net emissions from the stack with a holistic approach to energy management and fuel sharing modes. The first step on efficiency improvement has been done with re-powering the engine. The second step is to operate on LNG followed by a third step to ammonia. This will also provide freedom of deployment for the vessel using fuels that are available on the trading route.

4 ABBREVIATIONS

BOG - Boil-off Gas

CII- Carbon Intensity Index

EEXI - Energy Efficiency Existing Ship Index

GHG - Green House Gases

IECEx - International Electrotechnical Commission - Explosive atmospheres

IMO - International Maritime Organisation

TCS - Tank Connection Space

WARMS - Wärtsilä Ammonia Release Mitigation System

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