Dual Fuel Technology: A route to reduce emissions

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Synopsis

Naval vessels have a set of key requirements that should be kept to ensure operational capability. Whilst we design vessels for war, the reality is that many are used for various other roles and rarely see combat. How do we ensure navies can play their part in reducing emissions without impacting on capability in times of conflict? Utilising dual fuel arrangements provides the opportunity to reduce emissions during peace time operations whilst also providing an increase in survivability during combat as well as ensuring fuel availability has a reduced impact on the vessel. This paper will explore the work conducted to integrate dual fuel methanol on the BMT concept Ellida vessel an amphibious transport vessel.

Keywords: Dual Fuel; Propulsion; Integration; Marine systems

1. Introduction: Moving away from fossil fuel

The need to meet Net Zero 2050 is widely accepted now, but there are many hard to abate sectors one of which is maritime. The maritime sector are striving to reach this target for the majority of commercial vessels (International Maritime Organization, n.d.). Whilst many areas of the commercial sector are making inroads to reduce emissions, the only way to fully meet the target is by changing fuel away from fossil fuel derivatives.

The commercial sector are investing in a variety of future fuels; electric, hydrogen, ammonia and methanol are all options on the table. As stated by Steve Gordon, Global Head of Clarkson Research: *"2023 was a hugely significant year in the shipping industries decarbonization pathway, with new regulation entering into force and a net zero commitment agreed at IMO. And while we remain only at the start of a vital and unprecedented fleet renewal investment program, a start has been made with 49% of current orderbook tonnage now alternative fuelled*," (Offshore Energy, n.d.).

Whilst biofuel is currently being considered the reality is that it would be impossible to produce the quantities required, especially when in competition with other sectors such as aviation. This then gives a future maritime fuel mix that is significantly varied. Methanol is a fuel that has significant interest from the Commercial sector with several vessels operating on methanol fuel across the globe, although this only supports emission reductions when created from non-fossil fuel sources.

Future naval vessels may well have targets to reduce emissions, whilst there may be the opportunity for Government dispensation. The UK Government has set a target for Net Zero 2050 which includes defence (Department for Energy Security & Net Zero, 2023). What cost does this come at? Some of the potential impacts from this are:

- Reduced operating areas, at least in peace time;
- Lack of fossil fuel availability;
- Long term lack of suppliers;
- Public opinion.

It is envisaged that there could be a requirement to transition from fossil fuel (F76) for naval vessels. This then poses the question about what could be the fuel and how best to integrate them whilst maintaining capability and operational reach.

A potentially leading fuel for naval vessels is methanol, most likely synthetic rather than bio-derived. This is technology that is already available, with commercial vessels operating on methanol at the moment (DNV, 2024). The use of methanol could support a naval energy transition. It is postulated in this paper that rather than pure methanol the use of dual fuel has advantages in the near term as well as ensuring minimal impact on capability and operations. This concept is explored further within this paper, including the vessel considerations and operational impacts.

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2. Methanol as a Fuel

Methanol is a carbon based fuel, containing a single carbon atom, that as stated earlier could be Net Zero depending on the source of this carbon atom. Currently most methanol production is from fossil fuel, which is not practical and 'green' production requires significant scaling. High-level details of methanol are provided in Table 1 with greater detail covered in the following subsections.

Table 1 Comparison of some properties of Methanol & Diesel (Newman & Beard, 2022)

	Methanol	**F-76 (MGO)**
With Tank (Gross) Volumetric Energy Density (MJ/L)	14.2 – 15.1	27.3 – 31.0
General Storage Conditions	Ambient	Ambient
Flash Point (°C)	+12	+61.5
Flammability Limits in Air (vol%)	7.3 – 36.0	0.7 – 5.0
Minimum Ignition Energy (mJ)	0.14	20.0
Toxicity	Humans & Aquatic Life	
Emissions	Low COx, NOx	Standard

2.1.1. Storage

Methanol like almost all of the alternatives has a lower volumetric energy density compared to diesel, ~14.5 MJ/L compared to ~29.2 MJ/L, when including tankage. This equates to ~2.3 times more volume required for fuel. However, methanol is a liquid at ambient conditions which means it can be stored in a similar manner to diesel and that standalone tankage is not required.

The main requirement for methanol tanks is to be able to withstand the corrosive nature, requiring either specialist coatings or stainless steel to mitigate. Currently there is a requirement for cofferdams to be used which is included in the spatial requirements stated before. But there are now solutions becoming available to reduce this spatial requirement, such as the Sandwich Plate System (SRC , n.d.). The cofferdams are not required if methanol is stored below the water line at the shell, because methanol is soluble in water. Unlike the double bottom required for diesel tanks on commercial vessels, which could alleviate some of the spatial constraints mentioned.

2.1.2. Safety

Methanol has a flashpoint of +12°C which means that vapours will be released that in sufficient concentrations could ignite in air. Therefore methanol is classed as a low-flashpoint fuel and a vessel would need to comply with the IGF code (IMO, 2022), it should be noted that the criteria for low flashpoint is +61°C. To mitigate against this tanks should utilise nitrogen inerting to minimise the accumulation of vapours.

Flammability is a concern with methanol as it has a wide flammable range, 7.3 – 36.0 vol%, although it should be noted that the Lower Flammability Limit (LFL) of methanol is greater than the Upper Flammability Limit (UFL) of diesel. This means that diesel vapour could ignite at lower concentrations compared to methanol, but also that it only has a small range to ignite in comparison to methanol. The other factor to consider with flammability is the ignition energy, these are generally parabolic functions. The saddle-point of which is known as the minimum ignition energy and is generally at the stoichiometric mixture, which for methanol is extremely low at 0.14 mJ compared to diesel at 20.0 mJ. Either side of this point it is more difficult to ignite as the concentration increases or decreases. Methanol also burns with a pale blue flame that is almost invisible.

Toxicity is the other significant risk to crew on-board. As stated in Table 1, methanol is toxic to humans and aquatic life, although for aquatic life toxicity is low. The thresholds for humans is 30-240 mL (ingestion), which can occur via ingestion, inhalation or skin contact. However there are methods to mitigate methanol toxicity, including fomepizole or ethanol (National Library of Medicine, 2023).

2.1.3. Availability

Methanol currently has limited availability across UK & Europe compared to diesel, although has slightly better availability globally. This is shown in Figure 1.

Figure 1 Methanol Bunkering Locations (DNV, 2024)

2.1.4. Prime Movers

There are two main methods to release energy from methanol, combustion or chemically. Combustion is via either Internal Combustion Engine (ICE) or possibly a Gas Turbine (GT), whilst chemical release of energy is via Fuel Cell (FC).

Currently methanol ICE is still in the infancy although more OEMs are providing solutions for this and there are ships in operation with methanol. The engines can come as dual fuel rather than pure methanol (DNV, 2023). Regardless of the approach used, methanol is likely to require a pilot fuel which would support the use of dual fuel instead of just methanol.

Fuel cells involve a chemical reaction to create the energy. There are various types of fuel cell, although many of these are only suitable for pure hydrogen (99.999% purity). This would then require ‘cracking’ of the methanol to release the hydrogen for use in a fuel cell. Solid-Oxide Fuel Cells (SOFC) which operate at higher temperatures do not require ‘cracking’, although these are low-medium TRL at the moment.

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2.1.5. Emissions

Methanol will still produce COx emissions regardless of the prime mover, although it could be captured to support a carbon cycle for synthetic production. If methanol is combusted then NOx would be produced as well. There may also be other emissions which would be associated with lubricants that are used.

However, methanol produced from non-fossil fuel sources, i.e. bio or synthetic derived, would be net-zero. This is currently accepted within several regulations including FuelEU Maritime.

This then means that when operating the vessel in dual fuel mode, methanol with diesel pilot fuel, then the emissions would be reduced by circa 85%. Localised carbon emissions still occur but the overall impact on the environment is only from the pilot fuel, although this may be negligible if this is also synthetic or bio derived. This route also significantly reduces the quantity of bio or synthetic diesel that would be required.

3. Ship Integration

3.1.1. Dual-Fuel System Arrangement

Dual-Fuel marine engines allow for operating in two modes (Diesel Only & Methanol), noting the Methanol mode does require a small amount of Diesel as a pilot fuel as detailed earlier in this paper. Each type of fuel requires its own dedicated fuel supply system (pumping arrangement, pipework) to transfer the fuel from the storage/service tanks to the engine for combustion. This typical arrangement, results in duplicate of fuel supply systems as well as dedicated fuel tanks for each type of fuel, which on commercial vessels can be accommodated within the design, but is a challenge for warships given available space is a premium.

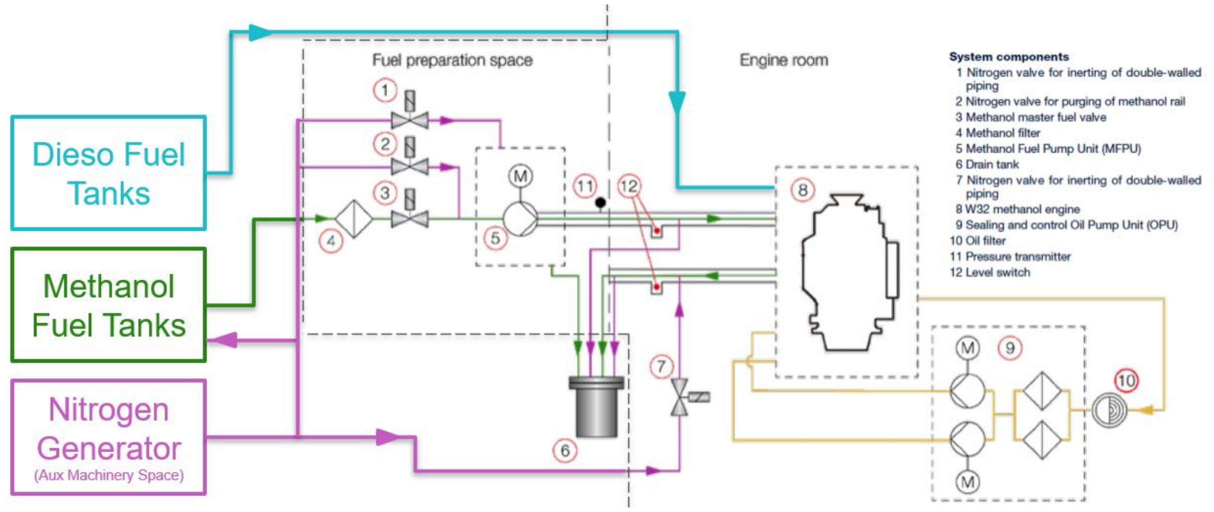

Figure 2 Dual-Fuel System Layout for Methanol & Diesel supplied Marine Engine (Wartsila, n.d.)

3.1.2. Design Considerations

It has already been stated that a methanol vessel would need to align with the IGF code. This means that the vessel design needs to be adapted to conform to these additional standards, above the typical standard applied for warships (e.g. Lloyds Rules for Naval Ships).

Methanol has similar storage requirements to Diesel (i.e. non-cryogenic or compressed storage). The amount of design change to incorporate compared to Diesel is considerably less than any fuel requiring stand-alone (cryogenic or compressed) storage. This provides the opportunity to potentially consider retrofit installation of methanol as an alternative fuel within a vessel, rather than new-build only.

Noting, a new-build design that has already accounted for a methanol fuel can be optimised to minimise any impacts. The following areas of design are impacted by combining a methanol fuel on board a vessel:-

3.1.3. Tank Design & Arrangement

Current engine technology for Methanol requires a pilot fuel to support the combustion process within the engine, requiring a continued supply and storage of Diesel within the vessel arrangement.

Commercial vessel design has adapted to provide independent fuel storage tanks for the two types of fuel (either Methanol or Diesel). For vessels dedicated to operating on methanol fuel, and typical pilot fuel consumption

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of 15%, fuel storage tank capacity would likely be split to match the 85:15 ratio to optimise fuel capacity for maximum range of the vessel. This is shown in Figure 3.

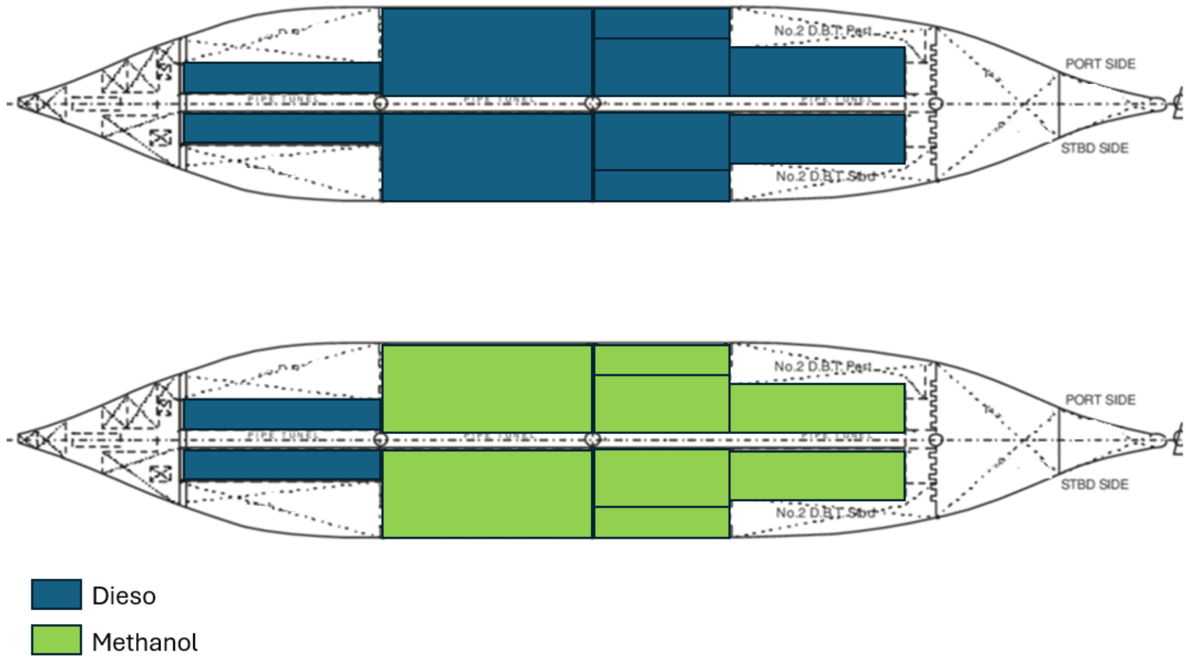

Figure 3 Typical Tank Arrangement Diesel Only v Methanol & Diesel

Although Methanol can be stored at the same ambient temperature and pressure as Diesel, the corrosive nature of the fluid is not supported by a standard bare steel tank. To mitigate this, either a specialist coatings (Zinc Sulphate) can be applied to the standard steel tank, or alternatively the use of a different material (e.g. Stainless Steel). The latter is considered a very expensive alternative due to the size of these tanks within a naval vessel, but may be more appropriate for fuel header tanks or service tanks.

Design guidelines for Methanol fuel tanks within commercial vessels require protective cofferdam with vapour and liquid leakage detection. However, as Methanol is soluble in water , the cofferdam arrangement is not required below the waterline, unlike double hull requirements for Diesel Tanks, see Figure 4. This has been mitigation for commercial vessel to store additional Methanol within their design, given Methanol has a lower volumetric energy density than Diesel.

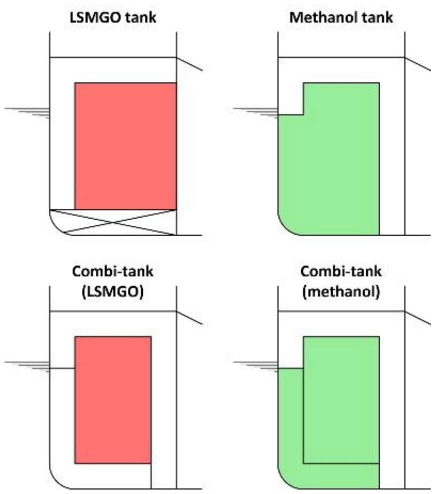

Figure 4 Cross section of Fuel Tank Arrangements (Royal IHC, 2024)

This would unlikely be a mitigation for Naval vessels, as they are typically single skinned hulls with no accommodation for double hull due to the spatial constraints. The inclusion of inboard cofferdams would actually result in less storage capacity within the vessel. However, new technology is in development to replicate the

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cofferdam protective arrangement in the form of a sandwich construction plate to separate the tank boundaries (SRC , n.d.).

These tanks are also not to be vented to the open deck (via air escapes) for natural ventilation, as Methanol vapours in the tank need to be managed. Nitrogen purging (section 3.1.4) is required, and results in the tank being pressurised, with a need for a pressure relief valve on each tank directed to the open deck within a safe area that is not near air intakes into the vessel.

3.1.4. Methanol Fuel Supply System

Methanol combustion with current Dual Fuel Marine Engines requires higher pressure injection into the combustion cylinder in comparison to Diesel only. Each engine supplier has differing concepts (Low Pressure Methanol Supply, ~10-25Barg, or High Pressure Methanol Supply ~400 Bar). Either fuel supply process begins with Methanol being pressurised at a dedicated Pump Module mounted separately to the Engine. This Methanol Fuel Pump System will be housed in dedicated compartment (Fuel Preparations Compartment), and be gas and water tight to surrounding spaces and vented to the open air following the same requirements as tank venting.

Pipework for Methanol in comparison to Diesel has further requirements for its design and construction, for pipework that passes through enclosed spaces then the use of double-walled pipes is required. The fuel pipe is enclosed in an outer pipe or duct that is both gas and liquid tight. Such double walled piping is not required in cofferdams surrounding fuel tanks, fuel preparation spaces or spaces containing independent fuel tanks as the boundaries for these spaces will serve as a second barrier.

IMO MSC.1/Circ.1621*INTERIM GUIDELINES FOR THE SAFETY OF SHIPS USING METHYL/ETHYL ALCOHOL AS FUEL* provides a set of key requirements and standards for designing suitable pipework within a vessel for handling Methanol, however their applicability to Naval vessels may require review and agreement for non-compliance. Notably, *5.7.1 Fuel pipes should not be located less than 800 mm from the ship's side,* will unlikely be compliant within naval vessels due to spatial constraints (typical pipe runs (all services) run along the ships sides).

3.1.5. Fire detection & Fire-Fighting

Methanol is a methyl alcohol (CH3OH) that burns in a completely different way than hydrocarbon fuels and has a much lower flashpoint of 12°C. Methanol fires are nearly invisible to the naked eye during in daylight, and there is little or no smoke direct from the flame, posing a great issue in attempting to detect and extinguish the fire. Early detection of methanol fires requires different technology from early detection of gasoline and diesel fires, utilising Vapor Detection and Thermal Imaging.

Current naval vessel typically have Aqueous Film Forming Foam (AFFF) as one form of fire-fighting onboard, however this means of tackling a Methanol fire is not appropriate for use, as solvent properties of Methanol cause the foam to degrade. IMO's interim guidelines for ships using methyl or ethyl alcohol as fuel, MSC.1/Circ.1621, establish a requirement for an approved alcohol-resistant foam system for ships running on methanol, expected to be alcohol-resistant Film-Forming FluoroProtein (AR- FFFP). This is required for bunker stations, fuel preparation rooms, tank top and bilge wells in the engine room. However, a CO2 system may substitute the foam system in the engine room, which is more common on later naval vessels (e.g. Type 45 Destroyers).

Managing the safe storage of Methanol onboard in all tanks (storage and service) and piping requires nitrogen purging.

In addition to integrating systems specifically dedicated fight methanol fires, the design of the vessel should aim to restrict and segregate Methanol from as many areas of the ship as possible, and provide protection boundaries (e.g. airlocks) when entering methanol areas (Methanol Fuel Pump Rooms, bunker stations) from non-hazardous areas.

Minimising vapours in tanks and double-wall pipework though Nitrogen purging, the vessel can either accommodate sufficient storage of Nitrogen to support its operation (with the requirement to re-supply) or generate Nitrogen locally as required. The latter provides a greater capability for the vessel and reduces any limitation or demand for re-supply on for naval vessel, especially when in conflict.

However, Nitrogen generating plant would be additional equipment acquiring a location within the vessel design. Typically, this would be within the engine room or auxiliary machinery space. Within a Naval vessel this would likely be duplicated in two locations (a level of separation) to allow for redundancy. Each plant is to be sized to generate Nitrogen 125% of Methanol discharge rate, however the demand can vary significantly based on typical operating conditions (consuming Methanol) or the need to empty Methanol Storage tanks.

- *Assumed Discharge Rate of 625m3/hr from Methanol Tanks (most extreme scenario – Emptying tanks) = 125% N2Production Capacity =* ***782m3/hr*** *Production Rate for Nitrogen Generator.*

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- *Typically Fuel Consumption ~ 4.3m3/hr @ 18knots. 125% N2Production Capacity =* ***5.4m3/hr*** *Production Rate for Nitrogen Generator.*

Due to spatial constraints in a naval vessel design, a consideration based on optimising the vessel design and accommodating two large plants or the potential to limit the discharge rate to accommodate smaller plants is advised, as will vary on each size/class/type of naval vessel.

3.1.6. Propulsion System

Integration of dual-fuel Engines or Generator Sets (depending on your P&P arrangement), have negligible impact on the ship design for the engine itself, it's the supporting systems to enable alternative fuel (methanol in this case) use on the engine that drive change in a vessel design (see all other sections noted within Section 3.1).

Commercial marine engines for dual-fuel are now readily available, with a greater range of engines expected over the next few years. Methanol as an alternative fuel for dual-fuel engine share the same common engine architecture, with the key changes made to the fuel injections system. This allows for in-service engines to be retrofitted at any point during its life, with upgrade packages, rather than entire engine replacements to accommodate an alternative fuel use.

The vessel would still need to install Selective Catalytic Reduction (SCR) System to remain compliant with IMO Tier III NOx emissions, as operation on either fuel (Diesel or Methanol) generate NOx.

3.1.7. Bunkering / Replenishment at Sea (RAS)

Dual-fuel vessels will require means of receiving both types of fuel, typically via a bunker station. Dedicated bunkering stations will be required, as guidance for Methanol states that Bunkering stations are not to be used for any other purpose than bunkering methyl/ethyl alcohol fuel.

The bunkering station should be located on open deck so that sufficient natural ventilation is provided. Bunkering stations that are not located on open deck are to be suitably ventilated to ensure that any vapour being released during bunkering operations will be removed outside.

Key capability for a warship is to be able to replenish at sea, and not require a visit to local port to taken on fuel and other supplies. Although, current Naval oilers lack the capability to store and transfer Methanol, future capability would be expected if Dual-fuel vessel become a common vessel design for warships. To allow RAS'ing, the typical arrangements to transfer Methanol across to the vessel (from Oiler), would required connections at the both bunkering station to be of dry-disconnect type equipped with additional safety dry break-away coupling/ self-sealing quick release. As detailed within Section 3.1.4, the fire-fighting requirements also extend to the bunker stations, to manage the store and transfer of Methanol.

3.1.8. General Arrangement changes

Given all the additional equipment with strict requirements for the safe storage, handling and use of Methanol onboard a vessel, the general arrangement of any vessel will change to accommodate these measures.

The following key changes for the vessel arrangement apply (in addition to the tank arrangement):-

- ***Dedicated Fuel Preparation Rooms***; Additional compartment to separate Methanol Fuel Pump Systems from other machinery. Typically located outside an engine room, an internal compartments within the engine room is allowable with an airlock arrangement to provide the necessary separation for safety. Redundancy measure for a naval vessel will require two sets Of Methanol Fuel Systems, locate in different areas (minimum of two WTB separation).
- ***Accommodation***; Accommodation spaces are not to be placed above Methanol tanks (applies under commercial guidance, this may be a challenge for a naval vessel given spatial constraints).
- ***Nitrogen Generation Plant***; Generation and storage of Nitrogen for purging pipework and tanks. Redundancy measure for a naval vessel will require two sets Of Nitrogen Generation, locate in different areas (minimum of two WTB separation).
- ***Bunker Station****:* The bunkering station should be separated by A-60 class divisions from machinery spaces of category A, accommodation spaces, control stations and high fire risk spaces, except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, sanitary and similar spaces where the insulation standard may be reduced to class A-0.

Spatial constraints of Naval vessels (typically known for fully utilising all areas onboard and having little to no spare space) creates a technical challenge to integrate Methanol fuel onboard. Although guidance and standards

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are available for commercial vessels, implementation on a naval vessel may prove impossible. Whilst their full applicability may be open to interpretation/negotiation for defence standards/customers to achieve a suitable level of agreement within a Naval vessel.

4. Operational Implications

The availability of methanol was discussed in section 2.1.3. It was clear that currently methanol is not widely available compared to MGO. However, this is the benefit of a dual-fuel arrangement. There is a reduced risk of a stranded asset.

The use of methanol would have an impact on range, although this can be overcome by utilising just diesel when required.

The Replenishment-at-Sea (RAS) of Methanol fuel requires further investigation to determine the viability. However, it is not envisaged that oilers will be carrying both fuels.

Naval vessels are inherently well known for the levels of redundancy, this is similar to how commercial dual fuel vessels now operate. Although this adds greater complexity for a naval vessel as there may be a requirement for multiple methanol equipment.

Fire-fighting requires significant thought to overcome a methanol fire. Conventional methods are not suitable and as such further investigation into suitable foams is required.

5. Dual Fuel Operations

Previous sections have highlighted the considerations and implications required to accommodate Methanol fuel for use on a vessel. Within the commercial industry, typical shipping operations are pre-determined and provide the opportunity to ensure Methanol fuel availability. In defence, warships do not have this luxury of pre-determined routes and operations, especially when utilised for immediate aid support or conflict. Hence, the ability to operate on both fuels is key. Although warships predominately operate in a peace keeping scenario, their capability to deployed in conflict/warzone at short notice is fundamental to the purpose of the vessel. Compromising this capability through the use of Methanol fuel, needs to be minimised/resolved before Naval vessel may consider adopting its use.

Adopting a dual-fuel ready vessel, with supporting fuel systems and a tank arrangement that could accommodate any fuel (Methanol or Diesel) to be stored would allow the vessel to operate as environmentally friendly (green-Methanol) during peacetime, and revert to full Diesel when required without losing any original capability.

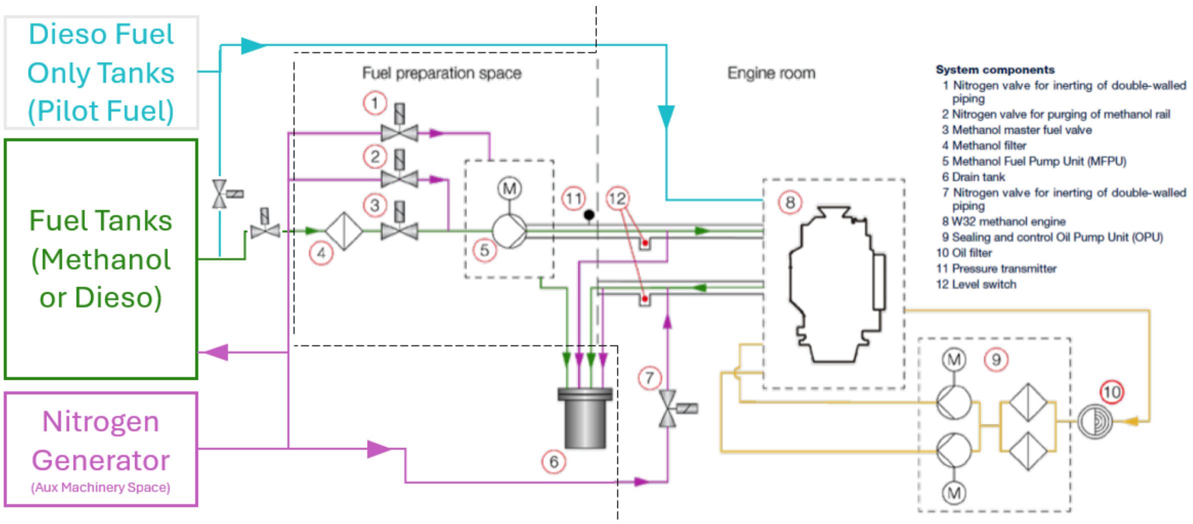

Figure 5 Concept fuel supply arrangement to allow dual use tanks (updated from Figure 4)

Guidelines from Class society state “Tanks need to be properly cleaned when changing fuel in the tanks”. This would restrict a naval vessel when required to change to either fuel rapidly and impact their operational capability. The following concerns regarding contamination of fuels have been raised from Engine Suppliers.:-

- **Diesel in MeOH engine mode;** is not consider an issue, as a pilot fuel (Diesel) is used, however the fuel supply system would need to be designed to account for removing contamination., At present, there is a fine filter

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before the Methanol high pressure pump to protect it from particles etc. so if Dieso entering that filter without pre-treatment then the filter will be clogged quite rapidly. The tolerances in the MeOH fuel supply system, incl. the Injector part for MeOH, are very small and may be very easily clogged if Dieso is entering.

- **MeOH in Diesel engine mode;** MeOH hasn't the same "lubricating " characteristics as diesel, meaning that when MeOH entering the Diesel supply system there is a lot more wear on components (pumps etc) and with a risk of seizure.

These restrictions and concerns pose a challenge to adopting a Methanol fuel within naval vessels, however, developments in fuel technology and fuel supply systems, may allow for acceptable contamination levels within the combustion process of a dual-fuel engine in the future, given the technology is still in it's infancy.

6. Conclusions

The use of a dual fuel arrangement would allow the use of 'green' fuels and thus a reduction in the net carbon emissions of a vessel. Whilst there is an impact on the operational capability, mainly a range reduction, this can be overcome by just reverting to F76 when required.

The use of dual fuel does come at a price, with increased complexity, especially if tanks are to be dual use.

However, it has been shown that it could be feasible for a vessel and as such is a consideration for the future fleet, whilst we await the energy source for the fleet after next.

There are still challenges to overcome, at least with RAS, fire-fighting and coatings, although these are challenges that should be embraced to solve the problem for the future.

Acknowledgements

The views expressed in this paper are that of the author and do not necessarily represent the views and opinions of BMT Ltd.

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