marine lubricants

the future of marine two-stroke engine lubrication

"Mari Innovator" — a third-generation built methanol dual-fueled MR product/chemical IMO 2/3 type tanker, delivered September 2021, built by HMD, Korea.

As shipping faces an era of new fuels and new engine designs to accommodate them, what role will cylinder lubrication play in enabling efficient and reliable engine operation?

A new era of cylinder condition

The maritime sector worldwide is heading towards an unprecedented diversity in fuel options. Having recently gone through one mass fuel switch — the International Maritime Organization's global sulphur cap introduced on 1 January 2020 (IMO sulphur cap — the shipping sector now aims to reduce greenhouse gas emissions in line with the IMO's 2050 ambition, as set out in the Initial IMO GHG Strategy[1], currently to cut emissions by at least 50% and reduce carbon intensity by at least 70% based on 2008 levels (IMO long-range carbon target).

As the IMO sulphur cap saw the emergence of very low sulphur fuel oil (VLSFO), the IMO long-range carbon target will encourage the introduction of more ship fuels. Alternatives like liquefied natural gas (LNG) and methanol are already in use and fuels such as ammonia, hydrogen and ethanol are being developed alongside lower-carbon synthetic and biomass-derived versions of conventional fuels. So-called "e-fuels", which are produced using renewable energy, are also being developed.

Like VLSFO, each of the above fuels bring specific challenges to engine and cylinder condition that can be mitigated by careful handling, specific engine design and an appropriate lubrication regime.

At the same time, engine design will continue to advance — both to accommodate different fuels and to continue advancing efficiency. With new engine designs come new cylinder condition requirements. Higher cylinder pressures or temperatures require better performing lubricants, for example, and new combustion concepts may also demand different properties from lubricating oils.

1. Please refer to Initial IMO GHG Strategy (https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx)

Pat McCloud, General Manager, Chevron Marine Lubricants says: "There are many unknowns about the future of marine fuels and engines. Chevron Marine Lubricants has a clear mission; to help its customers through that uncertainty, delivering robust and reliable lubricant performance that can help keep engines clean and operating well whatever the fuel, whatever the design."

Cylinder condition in the age of sulphur: a quick recap

To explore how different fuels (which may come into play in the future), and engines may affect cylinder lubrication, it is worthwhile to review the changes brought about in recent years, as engine designers and ship operators adapted to emerging trends.

Over the last two decades, there has been a shift in how cylinder condition is maintained in marine two-stroke engines. One starting point is the oil price shock of the 2000s, when the price of crude oil — which had floated at around US$25 a barrel for nearly two decades until 2003 — reached a peak of US$147.02 in mid-2008.

Slow steaming

Ship owners and operators faced higher fuel bills. To cut costs, they came up with a simple solution: slow down. By operating their ship engines at lower load, they burned less fuel. According to a 2011 publication by Maersk, Slow Steaming — The Full Story, the container ship *Emma Maersk* could save 4,000 metric tons of fuel oil on a Europe-Singapore round trip by cutting speed in half, from 24 to 12 knots. At the prices of the time, that equated to a saving of up to US$2.8 million.

In the same publication referenced above, Maersk saw slow steaming as a way to cut fuel bills as well as greenhouse gas emissions. At the same time, significant changes to engine design were also being made. Previously engines had been optimised for high speeds and high engine loads. But a new era focused on fuel efficiency rather than maximal power output demanded different designs.

New engines, new challenges

The fuel efficiency of engines was challenged by the need to meet the IMO's new (at that time) Tier II nitrous oxides (NOx) requirements and therefore keep combustion temperatures relatively low. The solution was found in longer piston strokes to enable slow engine speeds while turning bigger, more efficient propellers.

These modern engine designs improved efficiency, but another challenge emerged. There had always been potential for cold corrosion in two-stroke engines — abnormal wear caused by sulphuric acid forming and condensing on the cylinder liner and piston components. But higher pressures and longer piston strokes exacerbated the issue.

Luc Verbeeke, Senior Engineer, Chevron Marine Lubricants explains: "You need water, sulphur and a temperature below the dew point to form sulphuric acid. One way of controlling corrosion is to make sure that the cylinder liner temperature stays above the dew point to form sulphuric acids. But once you start having ultra-long strokes, it is almost impossible to have equal distribution of temperature in the liner — there will unavoidably be pockets below the dewpoint. So, when those engines started to run slower, cold corrosion started to eat the liner away."

Solving cold corrosion

Cold corrosion caused ship operators to adapt their lubrication strategies to minimise the negative effect of sulphuric acid. The best way was to select a lubricant oil with an appropriate amount of alkaline material (indicated as base number or BN) to neutralise the sulphuric acid before it could cause damage. Generally speaking, the more sulphuric acid is formed, the higher the BN needed to prevent cold corrosion — although appetite for BN can vary significantly between engine types and operation, even at the same fuel sulphur content.

As well as highlighting the clear link between fuel sulphur and lubricant choice, another important lubricant practice was reinforced by the threat of cold corrosion: the need for regular analysis of used cylinder oil. By testing oil samples drained from the cylinder, operators could identify warning signs — iron content, for example, or conversely too little alkalinity left in the oil — and adjust lubricant and optimise feed rate or BN of cylinder oil, as required.

2020 turbulence

The link between sulphur and BN, and the need for careful monitoring of drain oil, came to the fore once again as the industry prepared for the biggest ever coordinated switch of fuels in 2020. The IMO's global sulphur cap, limiting the sulphur content in fuel to 0.50%, led to the introduction of an entirely new fuel type, very low sulphur fuel oil (VLSFO). This blend became the predominant choice for ship owners globally after January 1, 2020 (except those choosing to continue burning high-sulphur fuel with the aid of exhaust gas cleaning systems known as scrubbers).

The lower sulphur content of VLSFO meant a lower BN lubricant was needed. Simple enough, but the great fuel switch was not without issues. Being a blend, there is inherent variability in VLSFO depending on the constituent ingredients. This can make it challenging to handle. In a circular last year — Marine Lubricants Information Bulletin 17, "Scuffing and red deposits after fuel transition: causes and solutions" — Chevron identified one emerging challenge for some older engines caused by fuel properties.

To protect against scuffing and other issues, owners need to be aware of the variability in VLSFO types. They also need to monitor engine fuel combustion parameters, adjust them when needed and perform frequent port inspections. In addition, drain oil needs to be checked regularly and corrective action taken, if necessary, by adjusting lubricant BN, feed rate or both. Chevron's DOT.FAST test kit allows vessels to quickly understand what is going on within their engine and take timely preventative action.

History lessons

From cold corrosion to VLSFO, the recent past of cylinder condition highlights some useful insights as the maritime sector prepare for future fuels and engine design changes:

1) There can be no one-size-fits-all approach to cylinder lubrication: High-sulphur fuels require different oils to low-sulphur fuels and the fuels shipping uses in the future are likely to raise further, different condition challenges requiring new formulations.

2) Cylinder condition depends on the engine as much as fuel: Whether it is super-long stroke pistons exacerbating cold corrosion, or older engines struggling with the challenges of VLSFO, engine design and condition must be taken into account in cylinder lubrication.

3) Any lubrication regime for new engine designs or new fuels will require vigilant monitoring for indicators of potentially problematic cylinder condition factors.

Picking from the palette of different fuels for the future

Perhaps the greatest unknown factor in managing cylinder condition in the future is which fuels will be preferred. One authority on the subject is CIMAC, the International Council on Combustion Engines. According to Peter Müller-Baum, Secretary General of CIMAC, the four most likely candidate "net-zero" carbon fuels suitable for deep-sea shipping are green ammonia, green methanol, LNG and synthetic hydrocarbons.

Ammonia and methanol: A balancing act

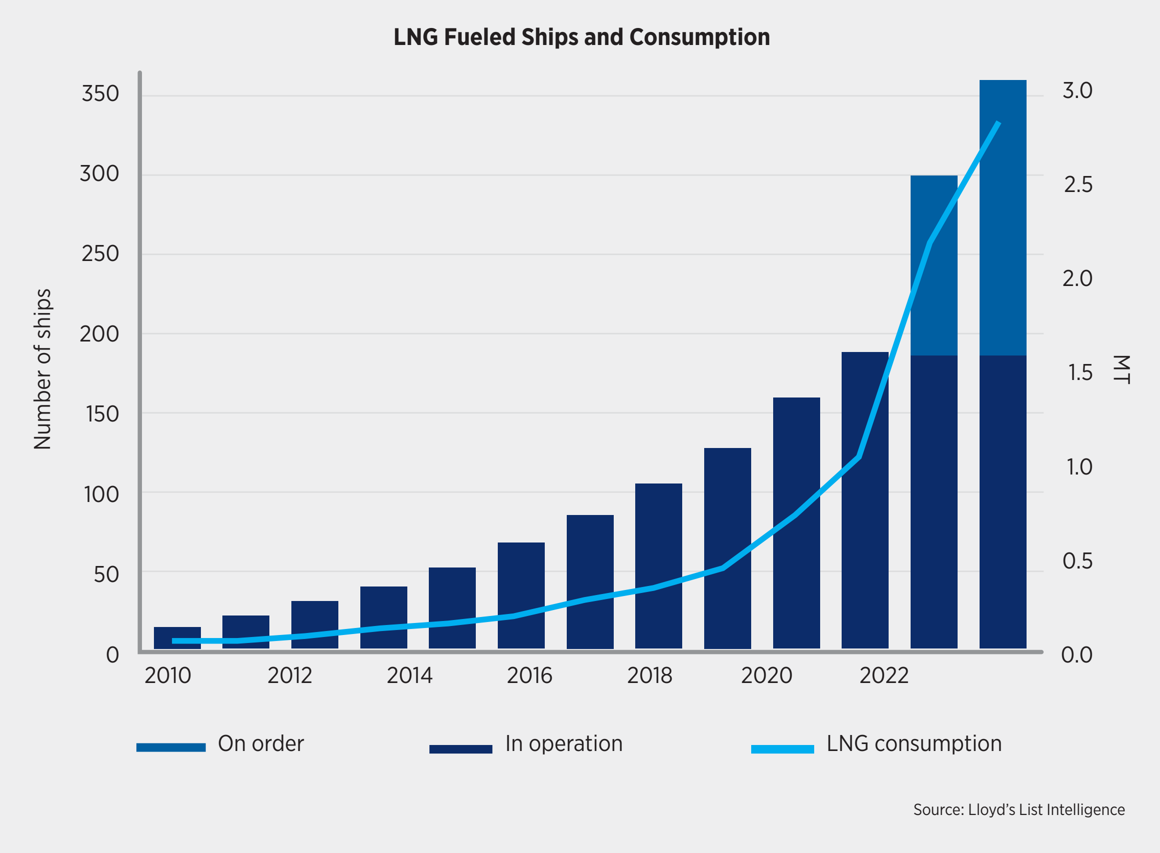
Ammonia and methanol are likely candidates because they offer cost-effective production processes. Methanol is a well-established industrial product while ammonia, which uses nitrogen rather than carbon as a carrier for hydrogen, is less expensive to make than other synthetic fuel options which use carbon.

"Ammonia will probably be cheaper than other options based on hydrogen because you don't need that extra energy to add carbon," says Müller-Baum. "That's why it is interesting. The problem is that it's highly toxic and therefore difficult to handle."

Methanol is not as hazardous, and ports and ship operators already have experience of it both as a cargo and as a fuel. Since 2016 a series of seven methanol carriers have been powered by methanol-burning MAN B&W engines lubricated by Chevron Marine Lubricants.

“Methanol is advantageous in many ways,” says Müller-Baum. “On the other hand, the fuel itself will most probably be more expensive than ammonia because you need more energy to produce it.”

Between ammonia and methanol, there is a trade-off between lower production costs (ammonia) and lower supply infrastructure costs (methanol). As wide availability of green ammonia or green methanol has yet to be established, it is challenging for ship owners facing investment decisions to make a choice. To make investment simpler, engine developers are promising the availability of retrofit options — meaning that ships can start operating on one fuel today before upgrading engines to run different fuels when they become available.



LNG: A realistic step to lower-carbon shipping?

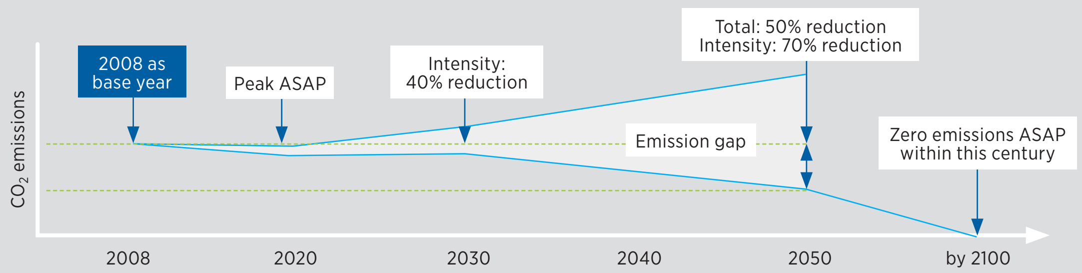
There are two other pathways that do not rely on retrofitting engines: which are LNG and synthetic hydrocarbons. Engine technologies already exist for these fuels and these technologies are widely deployed and are fully ready to burn alternative fuels as they become more available.

Fossil LNG is relatively widely used in shipping — primarily by gas carriers but increasingly by vessels in other segments. The fuel in its current form does not offer sufficient CO_2 reductions to meet IMO’s 2050 target, but it does reduce some pollutants, such as sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM). And its lifecycle CO_2 impact could be improved in the future if the methane molecule is synthesized, using captured carbon and renewable electricity, or biomass. These lower carbon options can initially be added to fossil LNG as drop-in fuels to cut emissions, and later — as supply increases — potentially replace fossil LNG altogether.

Even if carbon-neutral LNG is not available in the future, the engine technology it requires will be able to be retrofitted for methanol and/or ammonia fuel. These make LNG a versatile option in today’s uncertain fuel market.

“That is why ship operators may look at LNG orders for the next few years, when these other fuels are still more or less a vision of the future,” says Müller-Baum.

IMO strategy on CO_2 emissions



Short-term 2018–2023

- Tighter EEDI and SEEMP
- Energy-efficient indicators
- ! Speed reduction
- National action plans

Mid-term 2023–2030

- Energy-efficient measures for new and existing ships, using new indicators
- ! Carbon pricing / MBM
- Plan for low-carbon fuels

Long-term 2030+

- ! Development of zero-carbon fuels
- New/innovative emission-reduction mechanisms

Source: Achieving the IMO decarbonization goals, July 2020, DNV

Synthetic hydrocarbons: lower-carbon copies of today's fuels

The fourth pathway also delivers synthetic fuels akin to green ammonia, green methanol. The processes already exist to convert renewable energy and captured carbon into synthetic hydrocarbons. These hydrocarbons can be produced in any form — including the marine diesel and heavy fuel oil that ships have burned for more than a century. The synthetic versions are chemically identical, except that they will not use fossil carbon, and can then move towards the target of net-zero emissions over their production-to-use lifecycle.

Such synthetic hydrocarbons would allow ship operators to use conventional engines and fuel handling solutions. But, according to Müller-Baum, their future availability is even more uncertain than ammonia or methanol.

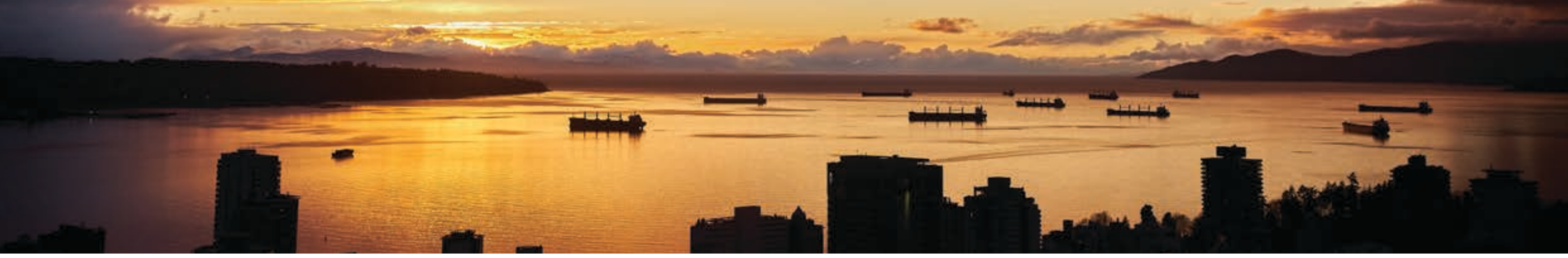
"Technically, it is not rocket science," Müller-Baum explains. "But it is rather energy intensive, which makes it more expensive than other options. However, if there is a huge industry producing these kinds of fuels — synthetic kerosene for aviation, for example, or synthetic gasoline for automobiles, it maybe not be so expensive to also produce fuel for shipping. But producing these fuels for shipping alone would not be profitable from today's point of view."

Shipowners cannot, sadly, afford to wait and see if synthetic hydrocarbons — or those derived from biomass — will emerge and enable their fleets to use them without changing their engines.

LNG is a slightly different case. If this hydrocarbon becomes widely available as a synthetic fuel, owners of today's gas-fueled engines will be able to switch to the new fuel. But if synthetic LNG is not available, it is likely that gas engines will be able to be retrofitted to use other new fuels more easily than conventional diesel engines. From the perspective of future fuels, LNG-fueled engines may therefore offer more flexibility even if synthetic LNG does not become available.

Future fuels and cylinder condition

Each of the four future fuels described above — ammonia, methanol, LNG and synthetic (including biofuel) hydrocarbons — has its own impact on cylinder condition. For synthetic hydrocarbons, the challenges would be similar to those accompanying use of current HSFO, marine diesel or whichever fuel is to be replicated. For LNG and methanol, there is already growing understanding of the required lubrication regime. Only ammonia remains unknown.



Gas engine growth

The first dual-fueled two-stroke ship engines were ordered in 2013. Over the preceding eight years, the gas-fueled fleet has grown to 221 vessels (excluding LNG carriers), according to DNV's Alternative Fuel Insights platform, with a further 394 vessels on order. Engine developers and lubricant suppliers including Chevron Marine Lubricants have already had plenty of experience. Much of this experience was put into CIMAC's Guideline On The Lubricating of Reciprocating Gas Engines. The general advice for two-stroke engines is:

> *When the engines are operated on gas, the resulting fuel mix (gas and pilot fuel) is generally equivalent to an ultra-low sulphur fuel as the gas contains very little, if any, sulphur, and the amount of pilot fuel is small. When the engine switches over to liquid fuel operation, the engine acts like a diesel engine, and it may be subject to cold corrosion. Some general advice can be given for operation on gas:*
>
> - *Use cylinder oils with good deposit control to avoid deposit build up.*
> - *Cylinder oil feed rates should be kept as low as possible.*
> - *Lubricant oil quills or injectors must be kept in good working order to maintain correct oil dosing and distribution.*
> - *Drains (scavenge air, water mist catcher, receiver, and piston underside) must be kept clean and fully operational.*
> - *Cylinder condition should be monitored, and action should be taken based on observations. As wear is generally low, actions to address deposit build-up should be the priority.*

MAN Energy Solutions and WinGD engines operated on LNG are treated similarly to ultra-low sulphur fuel oils with a sulphur content of 0.10% or lower.

First movers on methanol

Another widely discussed fuel, methanol, has been used as fuel on a series of seven methanol carrying tankers for more than five years now. The engines are lubricated by Chevron Marine Lubricants, which documented early experience in a dedicated whitepaper "Methanol and marine: lubricants in a lower sulphur, lower emissions future".

Marinvest's MAN ME-LGIM engines have been lubricated with Chevron Marine Lubricants oil since 2016. In a recent Chevron Marine Lubricants webinar, Marinvest technical director Frederik Stubner explained how the company had initially been concerned about the effect that prolonged dual fuel operations would have on cylinder liner and piston ring wear. Regular scrapedown oil analysis using Chevron's DOT.FAST® service and frequent in-situ liner measurements were used to monitor cylinder condition. The ship operator reported that cylinders appear much cleaner when burning methanol than conventional liquid fuels.

Engine developer approaches: MAN Energy Solutions

For MAN Energy Solutions, many of the future fuels are already in service. The company already has two-stroke marine engines operating on LNG, methanol, ethane and LPG. According to Julia Svensson, Research Engineer, MAN Energy Solutions, lubrication requirements remain consistent across these fuels.

"In all cases [except the forthcoming low-pressure ME-GA dual-fuel LNG engine] our engines use the Diesel process, so the concept of what is needed from the lubricant is similar. For all low-sulphur fuels the recommendations are essentially the same as for 0.10% and <0.50% sulphur fuels."

Methanol engine from MAN Energy Solutions

MAN ES also recommends cermet piston ring coating for all engines running on low-sulphur fuels, in order to increase the margin against damage to the piston rings and cylinder liners. Svensson also notes that lubrication recommendations can change as MAN ES learns more about how engines operate with these new fuels, and as engines get updated.

In the past two years, MAN ES has introduced a new approval structure for lubricants that places a greater demand on cleanliness for products used with their newer engines (Mk 9 and above). These new Category II requirements, which will be discussed in more depth in the following chapters, will naturally apply to all of the new engines running on LNG, methanol and other low-sulphur alternative fuels.

MAN ES also notes the distinction between fuels currently in use and another future fuel candidate — ammonia. An ammonia engine is under development and is expected to be available commercially by 2024. It is too early to describe cylinder condition concept or lubrication requirements for this new engine type.

Engine developer approaches: WinGD

WinGD designs two-stroke engines that include a low-pressure, Otto-cycle dual-fuel engine capable of running on LNG and fuel oil. This engine concept in particular offers the potential for future fuel flexibility, although its Diesel-process engines will also be candidates for running on liquid future fuels.

WinGD currently validates lubricants for its dual-fuel engines under two categories: those that have passed a validation test in the field on gas mode (known as ‘DF validation’), demonstrating “a good ability to keep the piston running components clean .. at optimised low feed rates”; and those that have passed a field validation test in liquid mode and are allowed for gas operation “based on their performance” (known as ‘general usage’).

“If a fuel contains something that can be aggressive to the material of the cylinder liner or other components it can damage it. So, we need to have a countermeasure to protect these components.”

Roger Mäder, Head of Tribology, WinGD

According to Roger Mäder, Head of Tribology, WinGD, the current tribology concept works for both liquid and gaseous fuels. However, detailed lubricant requirements cannot be confirmed until more testing of future fuels have been carried out.

“First actions are the testing of future fuels at WinGD facilities,” says Mäder. “Then the continuous testing and validation of cylinder lubricants is important — not just the validation but also follow up together with oil companies about how they behave in the field.”

New fuel types might have different combustion concepts as well as different fuel properties and different combustion by-products.

“If a fuel contains something that can be aggressive to the material of the cylinder liner or other components it can damage it. So, we need to have a countermeasure to protect these components. Smart material combinations are important, as well as how you neutralise acids and how lubricants react with these fuels.”

Future engines and cylinder condition

The impact of new fuels is just one element of future cylinder condition. Arguably more important is the impact of engine advances to further increase fuel efficiency.

Fuel efficiency will help ship operators minimise emissions until lower-carbon fuels are widely available. And once running on those fuels, which could come at a significant premium compared to today’s fuels, efficient engines will help to keep costs manageable.

The major avenue for increasing fuel efficiency in two-stroke engines is through increasing combustion pressure. This can have an impact on cylinder cleanliness if the lubricant is not sufficiently resistant to higher temperatures. For future cylinder oils, increasing thermal stability and reducing the potential for forming deposits in cylinders will be crucial.

A new level of cylinder cleanliness

MAN ES has attempted to address the problems of cylinder cleanliness in new engine designs by setting more demanding lubrication requirements, explains Julia Svensson.

"During the past few years when engine development has been fast and we have been pushing out different engines with increasing pressure, we saw that some of the cylinder lubes were not up to the task. For these engines with high pressures and small clearances, the lubrication needs to keep the engine clean so that deposits are not obstructing anything, and the engine can really perform."

After removing no objection letters for some low-BN oils because they were not providing the expected cleanability, MAN ES introduced its Category II. Eventually, a list will show the lubricants granted the Category II status which are applicable for all engines and recommended for MAN engines Mk 9 and above. Cylinder oils granted this status must have excellent overall performance, with special focus on cleaning ability.

Minimising deposits

Luc Verbeeke, Senior Engineer, Chevron Marine Lubricants, explains that there are high BN products that can be used with MAN ES's modern engines — Chevron Marine Lubricants' Taro Ultra 100 and Taro Ultra 140 both have Category II approval — but a Category II low-BN oil would be the ideal solution to match fuels with low sulphur content. Fortunately, a new low-BN cylinder oil, Taro Ultra Advanced 40, will become available in the second half of 2022. MAN ES has approved this 40 BN oil as a Category II lubricant suitable for its Mk 9 and later engines. In the interim, MAN ES recommends intermittent switching between 40 BN and 100 BN oils, when needed, to ensure cleanliness.The search for greater cleanliness at low-BN is not limited to MAN diesel engines. For Otto-cycle engines such as WinGD's dual-fuel LNG engines, there is an added impetus in finding low-alkaline yet low ash solutions.

Luc Verbeeke, further stated that the Otto-cycle concept of compressing a fuel-air mix and then igniting it — as opposed to the Diesel process of igniting fuel as it is injected — means that lower deposits are even more important.

"Because you are igniting a mix with a pilot fuel, of course, any other sort of ignition will also ignite the mixture — say a glowing piece of deposit on the piston crown. This means you can get uncontrolled combustion. The calcium carbonate or metals in general from cylinder oil additives will not help you at all. So, we believe that lower ash products are required."

"Deposit formation can be an issue if an oil is overheated, or thermal stability is exceeded. Especially for fuels with low sulphur, you don't have a lot of acid formation, so you don't need a lot of BN but you still want to have clean components and therefore high detergency. This has been a trick to have a low ash product but with high detergency."

Protecting engines with after-treatment

According to Luc Verbeeke, lower ash products will be needed not just for low-pressure Otto engines, but for future low-pressure engine designs using other fuels. There will also be a need among engines using exhaust gas after-treatment such as selective catalytic reduction (SCR) and particulate filters to lower emissions such as NOx and particulate matter, respectively. After-treatment is likely to become a more important element of many marine engines — whether to remove sulphur, to lower NOx (selective catalytic reduction or exhaust gas recirculation), to reduce methane slip or to minimise particulate emissions (diesel particulate filters) in line with potential future regulation.

The presence of after-treatment in the post-combustion chain means that engines will have to work harder to expel exhaust, which could lead to less complete scavenging. This means more combustion by-products would

likely remain in the engine cylinder. If those by-products include ash from the metallic elements in lubricants, this could lead to more deposits in the cylinder. Even if ash deposits are not problematic in the cylinder, the fouling that ash can cause along the post-combustion chain means that it should be minimised, especially where after-treatment is deployed.

Requirements for future cylinder lubrication

It is clear that fuels will not be the only factor to influence cylinder condition in the future.

Many of the candidate fuels have already been in operation on two-stroke low-speed engines using the Diesel and Otto process, and the lubrication requirements for Diesel engines to date appear similar for all low-sulphur fuels. This of course may be updated as further experience is gained and may be entirely different as other fuels emerge — for example ammonia.

As Otto-cycle engines emerge to burn fuels beyond LNG, and as exhaust after-treatment becomes more widely used, lower ash cylinder oils may be needed to keep engine cylinders and the post-combustion chain clean from deposits that can contribute to sub-optimal combustion.

As well as developing engines for different fuels, such as methanol, ammonia, hydrogen, biodiesel and any other potential candidates, the general advance of engine design will continue to focus on improving fuel efficiency. This will be driven by higher temperatures and pressures in the cylinder, putting lubricant under increasing stress. This more demanding environment is reflected in MAN ES's Category II requirements as well as in WinGD's requirement for lower-ash yet high detergency products and a separate 'DF validation' process.

"As a pioneer of cylinder lubrication for the different fuels .. as well as an early developer of low-ash marine oils, Chevron Marine Lubricants is well placed to meet the needs of users of future marine engines."

Pat McCloud, General Manager, Chevron Marine Lubricants

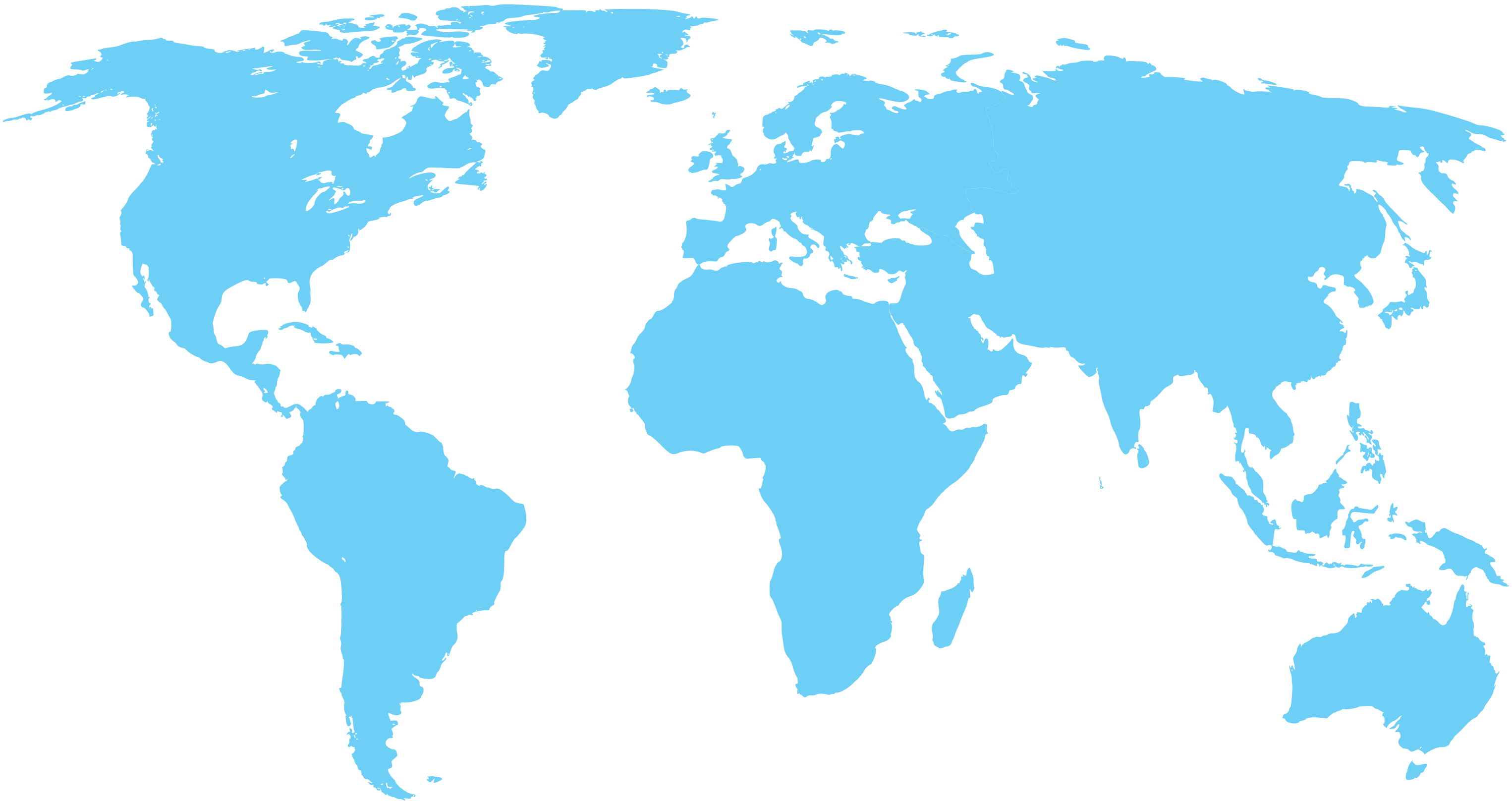
But amid all these emerging requirements, the basic reason for lubricating cylinders in the first place should not be ignored. Julia Svensson from MAN ES puts it clearly.

"Sometimes we forget what the obvious things a lubricant is supposed to do: to lubricate the piston and liner; to reduce the friction, introduce wear protection and minimise the risk of seizures; to neutralise acids if any and take care of oxidation products; to keep cylinder components clean to ensure the free movement of the rings; and to prevent excessive deposit build-up. These have always been the requirements. It is still true and it is not anything new."

Satisfying these challenging future development demands will be Chevron Marine Lubricants' mission, says General Manager Pat McCloud.

"As a pioneer of cylinder lubrication for the different fuels — such as fuel oil, LNG, methanol, ammonia and biodiesel — as well as an early developer of low-ash marine oils, Chevron Marine Lubricants is well placed to meet the needs of users of future marine engines," he says. "Combined with our efforts in making global supply ever easier, these investments will ensure that our customers are well served to operate their engines safely and reliably today and into the future."

Chevron



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