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INTRODUCTION

Cylinder oil lubrication is becoming an increasingly complex part of engine operations. New regulations and changing vessel operational profiles, such as slow steaming where engine load and speed is reduced to below the maximum capacity, are impacting engine operations and will continue to do so in the future.

It is important for ship operators to understand the factors that impact cylinder oil lubrication, how they need to plan for these and how to optimise lubricant use to deliver the best results in a challenging market.

WHY IS THE LUBRICATION LANDSCAPE CHANGING?

The introduction of emissions and efficiency-based regulations has catalysed a change in the way ships are operated, fuel types that are used and the technologies installed on-board ships.

A range of different fuels are now being used to power ships alongside traditional HFO such as heavy fuel oil (HFO). Engine designs are evolving to satisfy efficiency demands, which in turn is impacting operating conditions within the engine cylinders’ machinery.

To summarise, three key changes in ship operation, fuel use and engine development that have taken place in the last few years are:

• Changing operational patterns that favour lower-load operations (slow steaming).
• The use of marine fuels alternative to heavy fuel oil (HFO) that have a wider variation of sulphur content.
• The development of new engine designs led by emissions reduction legislation and need for improved energy efficiency.

All of these factors influence the selection of suitable of cylinder oil lubricants, now and in the future.

WHY IS THIS IMPORTANT TO SHIP OPERATORS?

These changes mean that it is vital that different specifications of cylinder oils designed for specific operating conditions and fuel types are matched with ship fuel and engine operating requirements.

Failure to do so can have severe cost implications including significant machinery damage and potentially even catastrophic engine failure incidents.

Incorrect lubricant choice and feed rate management can also significantly raise day-to-day operating costs by driving a higher feed rate than is necessary.

Therefore, choosing the right cylinder oil lubricant at the correct feed rate and matching your cylinder oil to the engine conditions is imperative.

This independent guidance was developed to support informed marine lubricant decisions. It provides information on the current regulations that influence cylinder oil lubricant choices.

It also examines future regulations that must be taken into consideration when making cylinder oil lubricant procurement decisions. The impact of different fuel types and technologies on lubricant selection is also provided.

What is the purpose of a cylinder oil?

The cylinder oil essentially acts as a lubricant by building up an oil film between piston rings and the cylinder liner wall. The oil cleans through the inclusion of detergency agents and also acts as a neutralising agent to the sulphuric acid formed from condensation and the sulphur contained in fuel.

Changes in operating conditions such as a change in the fuel or changes to the engines operating pressure can impact the cylinder oil lubricant performance.

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2.1 Fuel Sulphur Content and Sulphur Oxides (SOx) Emissions

The emission of sulphur oxides (SOx) from ships is regulated internationally by the International Maritime Organization (IMO) and on a regional level by attendant regulatory bodies. Ship SOx emissions are formed in the combustion chamber of the engines due to the sulphur content present in fuel. The concentration of the SOx gases formed is directly linked to the fuel sulphur content. Therefore, it is the reduction in the sulphur content of marine fuels upon which regulatory requirements for SOx emission reduction are based. The legislation also allows operators to comply with regulation by installing appropriate abatement technology.

2.1.1 Emission Control Areas and The Global Sulphur Cap (MARPOL Annex VI, Regulation 14)

The International Convention of the Prevention of Pollution from Ships (MARPOL) Annex VI, Regulation 14 regulates the emission of SOx from ships through the enforcement of a global sulphur cap and the designation of Emission Control Areas (ECA) in which SOx, particulate matter (PM) and/or NOX emissions are limited.

**Emission Control Areas**

There are four MARPOL SOx ECAs:

- The Baltic Sea ECA
- The North Sea ECA
- The North American ECA
- The United States Caribbean Sea ECA

Within these four designated ECAs the permitted sulphur content of marine fuels used is 0.1%.

**Global Sulphur Cap**

The current global sulphur cap requires marine fuels with a maximum 3.5% sulphur content to be used.
2.1.2 The EU Sulphur Directive 2012/33/EC

The European Union (EU) Sulphur Directive demands that ships operating in the Baltic Sea and North Sea ECAs use marine fuels with a maximum sulphur content of 0.1%. This requirement has been in force since January 1, 2015.

This legislation is applicable to all ships irrespective of flag, size or age.
For ships sailing outside of European SOx ECAs, but within European waters, the Directive dictates a maximum marine fuel sulphur content of 3.5%, in line with the global sulphur cap.
The only exception is passenger ships on a regular route which are required to use fuel with a maximum sulphur content of 1.5%
This is expected to change to 0.5% for all ships in 2020 or 2025, dependent on an upcoming announcement from the IMO in late 2016.

2.1.3 Hong Kong Air Pollution Control Regulation

The Hong Kong Government Environmental Protection Department has implemented the Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation. This regulation took effect as of July 1, 2015.
The regulation requires all ships above 500 Gross Tonnes (GT) to switch to fuel with a sulphur content of no more than 0.5% while the ship is at berth apart from the first hour and the last hour of the time berthed. An alternative fuel such as marine gas oil (MGO) or liquefied natural gas (LNG) may also be used.

2.1.4 Future Emission Control Areas

China
In December 2015, China announced that it would establish an ECA in the Pearl River Delta, the Yangtze River Delta and the Bohai Bay waters. This has now been in effect since January 1, 2016.
The Chinese ECA is regionally legislated and not created under IMO MARPOL Annex VI ECA regulations.
It has a sulphur limit of 0.5%.
The ECA regulation limits are currently in force for ship berthing at the ports of Shanghai, Ningbo, Zhoushan, Suzhou and Nantong.
This will extend on 1 January, 2017, to ships berthing at further key ports within the ECA. As of 1 January, 2018, all ports within the ECA will be included.
Finally, at 1 January, 2019, all ships sailing within ECAs will have to use fuel of a maximum sulphur content of 0.5%.

The Rest of the World
The establishment of ECAs covering the entire Atlantic seaboard of Europe, the Mediterranean Sea, coastal Korea, the Sea of Japan, the Australian coast, the shipping lanes of Singapore, Malaysia and Indonesia have been speculated upon.
However, none of those listed above have placed firm intention of establishment as yet.
2.1.5 The 2020 or 2025 Global Sulphur Cap Reduction

In late 2016, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) is expected to take a decision on whether or not to implement the reduction in the global sulphur cap from 3.5% to 0.5% from January 1, 2020 or to postpone the implementation until January 1, 2025.

This reduction will force the global fleet to switch to using marine fuel with a maximum 0.5% sulphur content, such as low sulphur residual fuels, distillates and LNG, or by installing scrubbers.

2.2 Nitrogen Oxides (NOx) Emissions

The emission of nitrogen oxides (NOx) from ships is regulated both internationally by the International Maritime Organization (IMO) and regionally by attendant regulatory bodies.

Ship NOx emissions are produced in the engine as a result of the reaction of nitrogen and oxygen during fuel combustion.

2.2.1 NOx Emission Control Areas (MARPOL Annex VI, Regulation 13)

The International Convention of the Prevention of Pollution from Ships (MARPOL) Annex VI, Regulation 13 regulates the emission of NOx from ships through designation of NOx ECAs.

The legislation incorporates tiered stages of compliance that permit different levels of NOx emissions based on the ship’s construction date (or the installation date of additional or non-identical replacement engines) and the rated engine speed (RPM).

Regulation 13 applies to all installed marine diesel engines with a power output of more than 130kW, irrespective of the tonnage of the ship.

Tier I and Tier II regulations apply to global waters, whereas Tier III NOx emission limits apply only to ships constructed on or after January 1, 2016, operating in NOx ECAS.

There are currently two operational NOx ECAS: the North American ECA and the United States Caribbean Sea ECA.
2.2.2 Future NOx Emission Control Areas

An Annual Meeting of the Helsinki Commission (HELCOM) agreed on a roadmap that included the submission of a proposal to the IMO for a Baltic NOx ECA in 2016, which is intended to take place in parallel to a similar NOx ECA submission from the North Sea countries.

No other NOx ECAs are under consideration at the current time.

2.2.3 United States Environmental Protection Agency, Clean Air Act

On January 1, 2014 the United States (US) Environmental Protection Agency (EPA) Tier 4 regulation entered into force.

This applies to large ocean going ships and any vessels flagged under the US and stipulates that PM and NOx must be reduced by a further 90% and 80%, respectively, compared with previous tiers.

To meet Tier 4 emission standards, engine manufacturers will produce new engines with advanced emission control technologies, often integrating engines with selective catalytic reduction (SCR) to meet the NOx reduction level required.

There are no current plans to modify the remit of the EPA Clean Air Act relating to marine vessels.

2.3 The Energy Efficiency Design Index and The Ship Energy Efficiency Management Plan

The Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) entered into force in January 2013.

The EEDI applies to new ships greater than 400 gross tonnes (GT) and varies with ship type, size and function.

It is a measure of the amount of carbon dioxide (CO2) emissions per tonne-nautical mile. A smaller EEDI value means a more efficient ship in terms of energy consumption per tonne-nautical mile.

A reference level was established for each ship type upon which incremental staged reductions are required every five years.

The regulation currently does not apply to passenger, mixed-use vessels (ferries, roll-on roll-off [Ro-Ro] ships or vehicle carriers, and cruise ships) and other specialty vessels for which deadweight tonnage is not an adequate representation of transportation capacity.

The staged EEDI targets are:

- An overall 10% improvement target in vessels’ energy efficiency applies to new ships built between 2015 and 2019.
- Ships built between 2020 and 2024 will have to improve their energy efficiency between 15% and 20%, depending on the ship type.
- Ships delivered after 2024 will have to be 30% more efficient.

In addition to the EEDI regulation, the new Chapter 4 of Annex VI requires all ships or ship operating companies to develop and maintain a SEEMP, which provides a mechanism for monitoring efficiency performance over time and forces consideration of new technologies and procedures to optimise performance.
3.1 Options for SOx Emission Reduction

There are four main SOx emission reduction strategies to ensure regulatory compliance is achieved:

1. Use a fuel that has a sulphur content less than 3.5%, 0.5% or 0.1% dependent on regulatory jurisdictions the ship will sail within.
2. Install an exhaust gas cleaning system (EGCS) also known as a scrubber. This would allow for the continued use of residual marine fuel of any sulphur content.
3. Switch between fuels of different sulphur content when entering and leaving enforcement zones.
4. Use dual-fuel engines in LNG operational mode.

Strategy 1: Choosing the Type of Fuel for Compliance

Different fuel types exist that achieve different levels of regulatory compliance.

Higher sulphur content fuels are less expensive but may require additional treatment of the exhaust gas through abatement technologies to enable the ship to comply with the regulation applicable in the area of sailing. With lower sulphur content fuels, although more expensive, such abatement technologies are not necessarily required to meet the same regulation.

**Heavy Fuel Oil (up to 3.5% sulphur)**

Heavy fuel oil (HFO) contains up to 3.5% sulphur and is a high viscosity fuel that requires preheating to enable injection into marine engines.

Due to its low cost it is widely used. When sailing in ECAs, HFO may only be used in combination with emissions abatement technology to achieve the required compliance.

**Distillate/HFO Blends (can be used for 0.5% sulphur regulations)**

Either distillates or blended fuels comprising of middle distillate fuel and HFO to a combined sulphur content of up to 0.5% are an option for compliance in certain regions.

This will also be important in 2020 or 2025 when the global sulphur cap reduces to 0.5%.

**Distillate Fuel and Marine Gas Oil (with a sulphur content of up to 0.1%)**

Both distillate and certain specially developed marine fuels with up to 0.1% sulphur content, but similar characteristics to traditional HFO, can be used for compliance in ECAs.

Strategy 2: Install Exhaust Gas Cleaning (Scrubber) Technology

The installation of a marine scrubber negates the need to use fuels of lower sulphur content.

As stipulated by MARPOL Annex VI, Regulation 12, for the continued use of HFO, the exhaust gas cleaning technology must be capable of reducing the ship’s exhaust gas emissions to an equivalent SOx level of that produced by fuels stipulated by the global sulphur cap and, if operating within a SOx ECA, the sulphur limit within the ECA must be achieved.
Strategy 3: Carry out Fuel Switching

In order to take advantage of the price differential between higher and lower sulphur content fuels, it is common to only utilise fuel of either below 0.5% or 0.1% sulphur content when required. HFO with a maximum of 3.5% fuel sulphur content is typically utilised outside of these requirements.

Strategy 4: Use a Dual-Fuel Engine

Dual Fuel engines enable ships to operate either on conventional marine fuels or LNG. Compliance with sulphur regulations can be achieved by switching to LNG fuel when operating within emissions restricted regions.

3.2 Options for NOx Emission Reduction

Today, engines are built with integrated technology that enables them to achieve the IMO’s Tier I NOx standards without additional technology or modifications. In order to meet Tier II, internal engine modifications such as the Miller Cycle in four-stroke engines, Changes to engine timing and peak pressures through the use of electronic control of exhaust valves and fuel injection in two-stroke engines can be used.

Ships built on or after January 1, 2011 tend to have these technologies integrated during engine construction and therefore do not require further modification for Tier II compliance.

Compliance with NOx Tier III regulations cannot be achieved by engine modification alone but requires additional NOx abatement technologies to be fitted.

The current options available are:

- Dual-Fuel Engines: These engines run on residual or distillate fuel liquid fuel in addition to burning LNG fuel to achieve compliance.
- SCR Technology: Selective catalytic reduction is a post-combustion technology that allows for the continued use of traditional HFO oils as the resultant NOx emissions are treated by the SCR system.
- EGR Technology: New generation engines that use exhaust gas recirculation (EGR) technology operate by introducing exhaust gas into the combustion chamber, which displaces oxygen and lowers the temperature of combustion in order to reduce the formation of NOx.
IMPACT ON CYLINDER LUBRICATION

Not utilising the correct cylinder oil lubricant in two-stroke engines with an optimised feed rate has serious financial implications for ship operators:

1. Cylinder oil lubricants are a single use product. If feed rates are not optimised, then there can be costly, unnecessary oil consumption.
   
   Many vessels have the feed rate set higher than is necessary by up to 50% or more which means that a significant volume of cylinder oil is wasted every year through over lubrication. On a single large vessel this over lubrication can cost as much as an additional $100,000 in a year.

2. Incorrect use of lubricant and mis-match to the type of fuel used can have serious mechanical consequences including excessive wear of engine components.
   
   This can cause shortened life spans of engine components and costly replacements through to potentially catastrophic engine failure.

In order to stay competitive in a challenging market it is critical ship operators utilise the correct lubricants as well optimising the quantities utilised for each vessel.

4.1 Impact of SOx Regulations on Lubrication

4.1.1 Operation with Traditional Marine Fuels

During combustion the sulphur in the fuel is subject to oxidation and SOx (sulphur dioxide SO₂ and sulphur trioxide SO₃) formation. The SOx compounds react with the water created from combustion to sulphurous and sulphuric acids.

These corrosive compounds, if not neutralised, will corrode the cylinder liner wall. One of the principal functions of the cylinder oil lubricant is to act as a neutralising agent.

The BN (Base Number) of a lubricant represents the ‘neutralising power’ of a lubricant.

What is the base number (BN) number?

The BN is what is often referred to as the ‘alkalinity’ or ‘base’ of a lubricant, however it is actually the quantity of acid, expressed in terms of the equivalent number of milligrams of alkaline potassium hydroxide, that is required to neutralise all alkaline constituents in one gram of sample.

The higher the sulphur content of the fuel, the more acidic compounds form and the higher the BN of the lubricant that is required for effective neutralisation.

Therefore, a careful balance is required.

The BN of the lubricant must be matched to the sulphur content of the fuel being burnt.

What Are the Risks?

A BN too low? The corrosive sulphuric by-products of combustion remain un-neutralised. These create excessive corrosion of the cylinder liner leading to metal to metal contact and scuffing as oil control is lost.

A BN too high? There is more base (calcium carbonate, CaCO₃) than is required. This starts to form hard deposits. These deposits can cause fouling of the piston crown which in turn can lead to bore polishing as well as deposition of ash in the combustion chamber, exhaust valves and turbocharger. Again, loss of oil control results in metal to metal contact and adhesive wear.
Heavy Fuel Oil (with a maximum of 3.5% sulphur content)
Recommendation:
• For newer-generation NOX Tier II compliant engines and earlier engines with modifications to operate under low load conditions, cylinder oils of up to 100BN are recommended by OEMs.
• For older engines and those not operating under conditions where cold corrosion is likely to be a problem a 70BN remains the standard.

Distillate/HFO Blends (with a maximum of 0.5% sulphur content)
Recommendation: 25 – 40BN cylinder oils for two stroke engines. Extra care with regard to monitoring and control of feed rates is advised.

Distillate Fuel and Marine Gas Oil (with a maximum of 0.1% sulphur content)
Recommendation: Low BN cylinder oils (~25BN) for two stroke engines.

4.1.2 Fuel Switching
As the BN of a lubricant must be carefully matched to the sulphur content of the fuel and the operating conditions of the engine, switching between fuels of differing sulphur contents causes a mismatch.

What Are the Risks?
It will depend on the length of time a vessel operates with a lubricant that is not matched to fuel sulphur content.

Recommendation: Since the introduction of switching between fuels with varying sulphur content there has been no ‘safe period’ that has been established by OEMs. Vessels have been found to be particularly at risk when leaving ECAs.

Therefore, the advice is to switch lubricants when switching fuels, always taking care to align the timing of fuel change with lubricant change.

4.1.3 Operation with Alternative Fuels (such as LNG, methanol, ethane and LPG)
For dual-fuel operations, two very different types of fuel are utilised interchangeably.

Recommendation: Operators can either switch between two types of cylinder oil lubricant- one for gas and one for liquid fuel operation.

Alternatively, depending on the predominant operating profile of the vessel, it is possible to utilise a single lubricant for their dual-fuel engines designed to match main operating condition.
4.2 Impact of NOx Regulations & EEDI on Lubrication

4.2.1 Tier II NOx Reductions & EEDI

Tier II NOx regulations (combined with Energy Efficiency Design Index (EEDI) guidelines) have led to the development of new engine types to meet the requirements.

By utilising longer piston strokes these newer engine designs achieve improved fuel oil consumption.

What Are the Risks?

To achieve this the cylinders are operating under increased peak pressures and reduced operating temperatures.

This creates conditions below the dew point meaning that water may condense on the cylinder liner walls leading to significant sulphuric acid formation as compared to traditional engine designs.

If the excessive sulphuric acid is not neutralised by the cylinder lubricant it accelerates cylinder liner wear.

The phenomenon is known as cold corrosion.

Recommendation: Firstly, if cold corrosion is suspected it is important to identify how serious the problem is. OEMs recommended that cylinder scrape down monitoring is done to understand what is happening in the engine.

MAN Diesel recommends the use of a ‘Sweep Test’ and Wärtsilä recommends its ‘Quick Test’.

These tests should be done as part of an established condition monitoring programme. They ensure that the performance of the engine is known so that the feed rate can be set appropriately, and the tests should be repeated whenever parameters change, such as a new fuel in use.

Not only will it enable the correct cylinder oil to be selected but it will enable the feed rate to be optimised to suit the engine, operating conditions and cylinder oil in use.

4.2.2 Tier III NOx Reductions

The impact on cylinder oil lubrication will depend on the NOx abatement technologies fitted:

Selective Catalytic Reduction (SCR) Technology

SCR is post combustion technique.

Cylinder oil lubricant selection therefore should be based upon matching the BN to the fuel sulphur content of the marine fuel used. The possible effect of cold corrosion must also be considered.

Specific considerations for SCR technology:

- Cylinder oil lubricant additives can have an impact on the long term performance of SCR catalysts, therefore the suitability of the cylinder oil lubrication match with the technology is a key factor to consider.
- A cylinder oil lubricant that has low sulphated ash is recommended to increase both the lifespan of SCR systems and the associated soot filters.
Exhaust Gas Recirculation Technology

Newer engines may now integrate EGR technology, which works by filtering, cooling and recycling a fraction of the exhaust gas back into the combustion chamber. This lowers the oxygen content of the scavenged air, resulting in a reduction of peak combustion temperature to reduce the formation of NOx.

4.3 Impact of New Generation Engines and Changing Operational Profiles on Lubrication

In order to comply with NOx Tier II regulations, there is the new generation of engines. Engine operating profiles are also changing to increase low-load and part-load operation.

What Are the Risks?

The new generation of engines are particularly susceptible to the issue of cold corrosion (see section 4.2). Cold corrosion can also be an issue or further exacerbated when the ship operates at low load for long periods of time as the engine is operating at lower temperatures in this state.

Recommendation: OEMs’ recommendations will vary and the OEMs must be consulted for each specific engine type for optimal lubricant selection under different load conditions but a cylinder oil scrape down monitoring programme is always recommended.

In newer engines a number of design changes are being implemented including changes to the liner cooling systems and cylinder oil injection points to address cold corrosion.

Engine model, engine modification, engine load and fuel sulphur content must be taken into account when selecting a cylinder oil lubricant.

THE FUTURE

As legislation around the fuel-related emissions from shipping operations continues to evolve, coupled with the drive for efficiency, the role of cylinder oil lubricants and their requirement to perform under varying engine conditions will become progressively more challenging.

The anticipated drop in the global sulphur cap in 2020 or 2025 will impact marine fuel use across the global fleet and this in turn will mean that ship operators will need to reconsider the cylinder oil lubricants used on a vessel by vessel basis.

In addition, the need for a monitoring programme to ensure the safe and efficient operation of the engine will become increasingly more important.

It will therefore be vital for ship owners and operators to not only select the lubricant that best fits their needs, but also to choose a supplier that compliments their operational requirements and can provide the right level of global support for their fleet.

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