White paper

Marine engine lubrication after 2020

What to expect in the next decade

October 2018

Contents

Introduction

According to The Swedish Club, main engine damage accounts for 28% of all machinery claims and 34% of the costs, with an average claim cost close to USD 650,000. Lubrication (lube) oil failure is the most expensive and frequent cause of damage, followed by incorrect maintenance and poor fuel management. (The Swedish Club, 2018)

Improper lube oil management combined with abrasive particle contamination is the major cause of damage. Therefore, efficient oil cleaning is essential to minimize the risk for engine wear and damage.

Fuel oil regulations and their impact on marine engine lubrication

Forthcoming regulations for the global use of marine fuel oils with sulphur content no greater than 0.5% are causing marine lubricant oil and engine manufacturers to reassess the lubrication characteristics/requirements of their products. The reduction of sulphur content from 3.5% to 0.5% in 2020 will require a reformulation of marine fuels. It is likely that a higher percentage of cat fine-containing cutter stocks will be used to reach the lower sulphur levels.

Without proper fuel treatment, the higher content of cat-fines will increase the wear of fuel injection systems, cylinder liners and piston rings, leading to further soot accumulation in the cylinders and in the lube oil. In addition, abrasive catalytic (cat) fines can migrate into the lube oil via piston rings blow-by.*

The following section discuss the possible impact IMO 2020 regulations will have on the two marine engine lubrication systems.

* Cat fines are the most abrasive of all substances in heavy fuel oil. These are fragments of a catalyst added to the oil in the refining process. Composed of solid particles of aluminum and silicon compounds, catalytic fines are almost as hard as diamond and vary in size from sub-micron to approximately 50 µm.

Slow-speed engine system oils (2-stroke, crosshead)

Because of the crosshead engine design, the system oil will remain relatively unchanged following IMO 2020 limiting HFO to 0.5%S. However, the cleanliness of the piston ring pack of engines running on this fuel will still require a lubricant with a high detergency level. (CIMAC, 2014)

Medium-speed engine lubricants (4-stroke, trunk)

Unlike the system oil in a crosshead diesel engine, crankcase lube oil in a medium-speed, 4-stroke, trunk marine engine is continuously exposed to combustion products.

However, the lubricant approach for these engines will not be significantly different from the lubricants used today with fuel oils that possess an average sulphur content of about 2.5%(S). Although 0.5%S is a lower sulphur level present than in the majority of residual fuels currently used, it is still a significant quantity, requiring a sufficient BN to neutralize the acidic combustion by-products.

In most cases, it is probable that the content of residual components (like asphaltenes) will be lower than in today's heavy fuel oils; however, a good level of asphaltene dispersancy will still be required. Current commercial products are able to fulfil the lubrication requirements, and a shift towards lower BN (e.g. 12-40 instead of 30-40) and very high BN (e.g. 50 or 55) is unlikely. (CIMAC, 2014)

The lube oil acts as transport medium for insolubles produced in the engine. The degree of engine fouling is determined by the concentration of insolubles and the tendency of the oil to leave deposits. (CIMAC, 2004)

Under normal oil consumption conditions, trunk piston engine oils do not require complete oil changes for up to several years, provided combustion conditions remain normal and is the oil not diluted by raw residual fuel contamination. (CIMAC, 2004)

For the reasons above, trunk piston engines burning residual fuels are best fitted with continuously running centrifuge purifiers/separators of sufficient capacity, cleaning their lubricating oil by removing water, soot and other contaminants.

Based on current regulations for the use of low-sulphur marine fuel oils, and upcoming initiatives for reducing greenhouse gas (GHG) emissions in the marine industry, it is likely that the following marine fuels will coexist in the coming decade.

- Ultra-low sulphur fuel oil (ULSFO) – can be MGO (distillate) or residual-based (IMO 2015)
- Very low-sulphur fuel oil (VLSFO) – probably will be residual-based (IMO 2020)
- High-sulphur fuel oil (HSFO) – used in combination with exhaust gas cleaning (i.e. scrubber)
- Gas – liquid natural gas (LNG) or liquified petroleum gas (LPG)
- Biofuel – hydrogenated vegetable oil (HVO) or fatty acid methyl esters (FAME)

How each of these fuels might impact the lube oil is discussed in the following sections.

Note: This document focuses on medium-speed trunk engine lubrication systems versus low-speed crosshead engine lubrication systems, which isolate the combustion chamber from the fuel oil.

1. ULSFO (0.10% S)

This fuel oil became the prevalent fuel in ECAs as of January 2015. Within the ULSFO fuel market, marine gas oil (MGO) dominates; however, an increasing number of residual-based and cat fine-containing fuels are becoming more common.

Impact on engine lubricant
The use of this cleaner fuel will result in lower contamination of the lubricant, offering the possibility to optimize and adapt the oil system to this lower contamination. Smaller oil volumes, lower oil consumption and less effort for cleaning the oil are options arising from this fuel type. (CIMAC, 2014)

2. VLSFO (0.50% S)

This fuel type will likely dominate the market in 2020 following enforcement of the IMO legislation – derived from heavy fuel oil (HFO) refinery streams, bringing the combined sulphur level as close to the 0.50% S limit as possible.

Depending on supply sources, there will be a wide range of different viscosities and densities available. Likewise, its combustion qualities could vary greatly. Finally, being residual-based, this fuel oil will contain similar or even higher catalytic (cat) fine contents (aluminium and silicon particles) as can be found today.

Impact on engine lubrication
This fuel will require a lube oil that can handle moderate asphaltene levels and possess an adjusted base number (BN) to handle the sulphur oxidation products. It is expected the lubricant BN will be 20 to 30 (mg KOH/g). (CIMAC, 2008)

3. HSFO (3.50% S or more) with exhaust gas cleaning

The use of this high sulphur fuel oil (3.50% S) is acceptable when exhaust gas cleaning equipment (i.e. scrubber) is used – provided stack emissions (SOx) levels are equivalent to or less than those produced by fuels stipulated by global and ECA caps.

Impact on engine lubrication
Using this fuel, today's lube oil will to great extent remain unaffected. However, many modern engines are designed for low-lube-oil consumption, which requires the use of high BN lubricants (50 mg KOH/g or even higher) and/or shorter intervals between oil changes. (CIMAC, 2008)

4. Gaseous Fuel (0.0% S)

Liquified Natural Gas (LNG) and Liquified Petroleum Gas (LPG) as marine fuels are receiving increased interest due to their currently low price and compliance with IMO emissions limits with respect to both SOx and NOx. LNG contains virtually no sulphur and, depending on the marine engine type, produces low NOx.

Impact on engine lubrication
This fuel contains 0.0%S and produces low ash. By using this cleaner fuel, smaller oil volumes, lower oil consumption and less oil cleaning effort are required compared to HFO-operated engines today. (CIMAC, 2014)

It is not fully understood whether LNG-fuelled engines may produce smaller soot particles, which may be harder to remove by oil treatment systems.

However, lube oil treatment systems will still need to remove water and oxidation contaminants, as well as engine wear particles, from the engine.

5. Biofuel (0.0% S)

Biofuel or biodiesel are fuels derived from vegetable oils (e.g. palm oil, soybean oil, rapeseed oil), animal fats (e.g. tallow oil) and waste organic compounds. Most common biofuel types include Fatty Acid Methyl Esters (FAME), ethanol and Hydrotreated Vegetable Oil (HVO).

Except for vessels transporting such cargoes, 100% unprocessed biofuels are unlikely to be used in marine application. These fuels have almost zero sulphur but can have a high acid number (low pH) which can impact fuel delivery systems.

Under current supply logistics, the practice of blending FAME into other distillate fuels is relatively common; this nearly guarantees that some distillate fuels supplied in the marine market contain FAME. (Chevron Marine Products LLC, 2012) The international marine fuel standard ISO 8217:2017 allows up to 7% addition of FAME to certain distillate marine fuel grades.

Impact on engine lubrication
FAME-based biofuels have a higher flash point and oxygen content than petroleum-based fuels. These negatively affect combustion leading to quicker accumulation of unspent biofuel in the lube oil. To compensate, biofuel is often diluted, which can negatively affect lube oil. (CIMAC, 2014)

Requirements for engine oil treatment systems

When marine fuel burns, sulphur is converted into sulphur oxides (SOx). These oxides reach the engine lube oil via the blow-by gas. These oxides are corrosive to engine piston liners and must be neutralized by the engine lubricant. Marine engine lubricants are developed to cope with this acidity (high BN). (Chevron Marine Products LLC, 2012)

Diesel engines require a lube oil with a variety of properties. Not only must the lube oil neutralize the fuel acidity, it must be capable of cleaning (and keeping clean) engine components, dissipating engine heat, and protecting against rust and corrosion. Moreover, it must perform these actions for extended periods.

The efficiency of a lubrication system and its oil is subject to several stresses; proper monitoring, maintenance and replacing the oil ensures its proper function.

The following are the principal functions of lube oil:

- Reduce friction leading to engine component wear
- Minimize rust by removing oxidation particles
- Cool by removing heat
- Protect engine components against harmful deposits
- Seal engine compartment

Lube oil also helps keep deposits from forming throughout the entire lubrication system, including circulation lines, check valves and sight glasses. With fresh and clean lube oil in the system, marine engine performance and efficiency can be optimized.

Unfortunately, even under optimal engine operation, lube oil becomes contaminated. This is the result of a) accumulation of contaminants, including combustion soot, acidic combustion blow-by products, raw residual fuel and water, and b) the influence of high temperature, aeration and NO_x.

Contamination has costly consequences to marine engines:

- Chemical degradation (reduced BN)
- Corrosion
- Increased oil consumption
- Friction (evidenced by wear and noise)
- Efficiency losses
- Clogging
- Engine failure

With regular checks, oil deterioration can be detected in time; it is recommended to send samples to a laboratory to make the related analysis. The following table displays alerts and condemnation limits for important lube oil properties:

Parameter	Alert limit	Condemnation limit	Unit	Test method
Viscosity at 40°C	Maximum 140	Maximum 150	mm^2/s (cSt)	ASTM D 445
Flash point	Minimum 200	Minimum 180	°C	ASTM D 92/93
Total insoluble material	Maximum 0.7	Maximum 1.0	% m/m [1]	ASTM D 893b
Base number (BN)	Maximum 12	Maximum 15	mg KOH/g	ASTM D 2896
Water content	Maximum 0.20	Maximum 0.30	% m/m	ASTM D 95 or ASTM D 1744
Strong Acid Number (SAN)	0.0	Maximum 0.0	mg KOH/g	ASTM D 664
Calcium	–	Maximum 6 000	mg/kg (ppm)	ICP
Zinc	–	Minimum 100	mg/kg (ppm)	ICP
Phosphorus	–	Minimum 100	mg/kg (ppm)	ICP
FZG gear oil set [2]	Minimum failure load stage (FLS) 9	Minimum failure load stage (FLS) 8	–	A/8. 3/90 (ISO 14635-1)

1 % m/m means by mass, e.g. a water conent of 0.20% m/m means that the water content is 0.20% of the mass of the total solution.

2 To do the FZG gear oil test is recommended one time each year.

NOTE: Use these limits as a guide. You cannot make an estimate of the system oil by one parameter. Get also other oil parameters to find the causes of problems.

(Source: Lubricants: All Engines, WinGD, Issue 001 2018-02)

Lube oil cleaning

The main reason for continuous cleaning of the circulating lube oil is to maintain lube oil performance by removing contamination (dirt, insoluble combustion products and water).

Filters integrated in the system retain residues (particles) from being transferred back to the engine, potentially damaging it. Whereas, separators/centrifuges installed in bypass to the main lube oil service system of the engine remove combustion residues, water and other smaller mechanical contaminants.

Function of centrifugal separators

A centrifugal separator uses centrifugal force to remove particles and water from lube oil in a single operation. The contaminants – in the form of sludge and water – are forced outwards, while clean lube oil is continuously transferred back into the engine.

The level of contaminants on the lube oil system depends mainly on the output and type of engine and type of fuel. In addition to particle content, particle size has strong impact on the separation efficiency. Different engine types and fuel types can generate different size ranges for the soot particles.

The increasing difference in density between water and lube oil with increasing temperature is the basis for centrifugal cleaning (purification). Cleaned oil and separated water are continuously discharged during operation.

Parameters affecting separation efficiency

Separation efficiency is dependent upon including temperature (controlling both lubricating oil viscosity and density), flow rate, particle size and proper separator care and maintenance. A separator's ability to separate contamination from lube oil is regulated by Stoke's Law (see equation below).

$$v_c = \frac{d^2\,(\rho_P - \rho_{LO})}{18\eta}\,\omega^2 r$$

Settling velocity (v_c) *depends on:*

Particle size, d

Particle density, ρ_P

Lube oil density, ρ_{LO}

Dynamic viscosity of lube oil, η

Centrifugal acceleration, ω

Particle position on circular radius, r

Density and viscosity

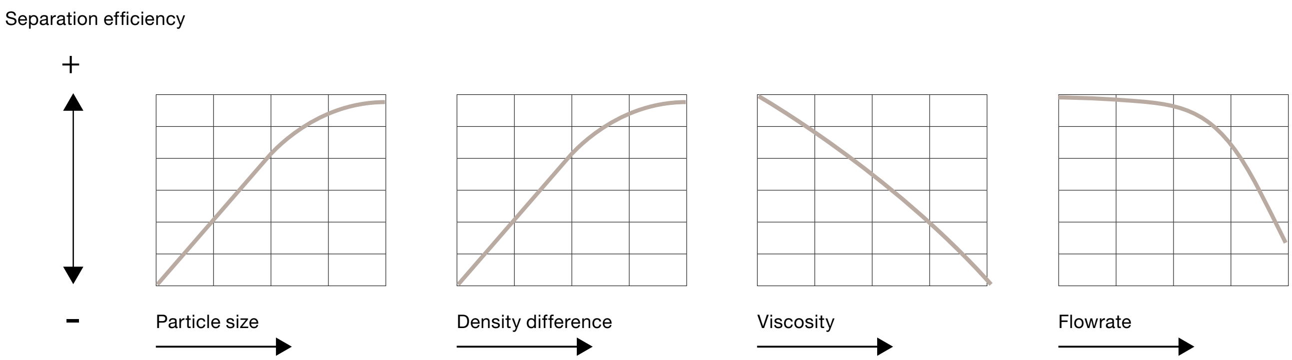
The greater the difference in density between the contamination particles and the lubricating oil, the higher separation efficiency. The settling velocity increases in inverse proportion to viscosity. However, since both density and viscosity vary with temperature, separation temperature is the critical operating parameter.

Temperature

To ensure centrifugal forces are able to separate the heavy contaminants in the relatively limited time that they are present in the separator, oil entering the separator unit needs to be heated. An inlet temperature of 90°C or 95°C with only small variations (maximum ±2°C) is recommended for lube oils.

Particle size

The settling velocity increases rapidly with particle size. Typically, this means the smaller the particles the more challenging the task of separation. However, in a centrifuge, centrifugal force enables the efficient separation of particles which are only a few microns in size.



Operation and design flow rates

Separation efficiency is a function of the separator flow rate (i.e. operation flow) – the higher the flow the less efficient separation becomes and, conversely. As flow rate decreases, particle separation increases (Stoke's Law). The required flow needs to reflect the quantity of contaminants entering the system and the separator's continuous operation time.

To ensure optimum cleaning of the lubricating oil, the separator rating should be higher than the design flow rate (Q) as calculated by the following equation:

$$Q_{LO} = \frac{P\ V\ n}{t}$$

Q_{LO}: Required design flow [L h^{-1}]

P: MCR (Maximum Continuous Rating) in [KW]

V: Nominal system oil volume equal to 1.36 [L KW^{-1}]

n: Number of separation passes per day

t: Effective run time: 23.5 h

The required number of passes (n) varies by fuel type and engine manufacturer. MAN recommends n(HFO) = 7, n(MGO/MDO) = 5 and n(dual fuel engines with LNG/LPG) = 5. (MAN Diesel & Turbo, 2016). Wärtsilä recommends n(HFO) = 5 and n(MDO) = 4. (Wärtsilä, 2018).

Water in oil

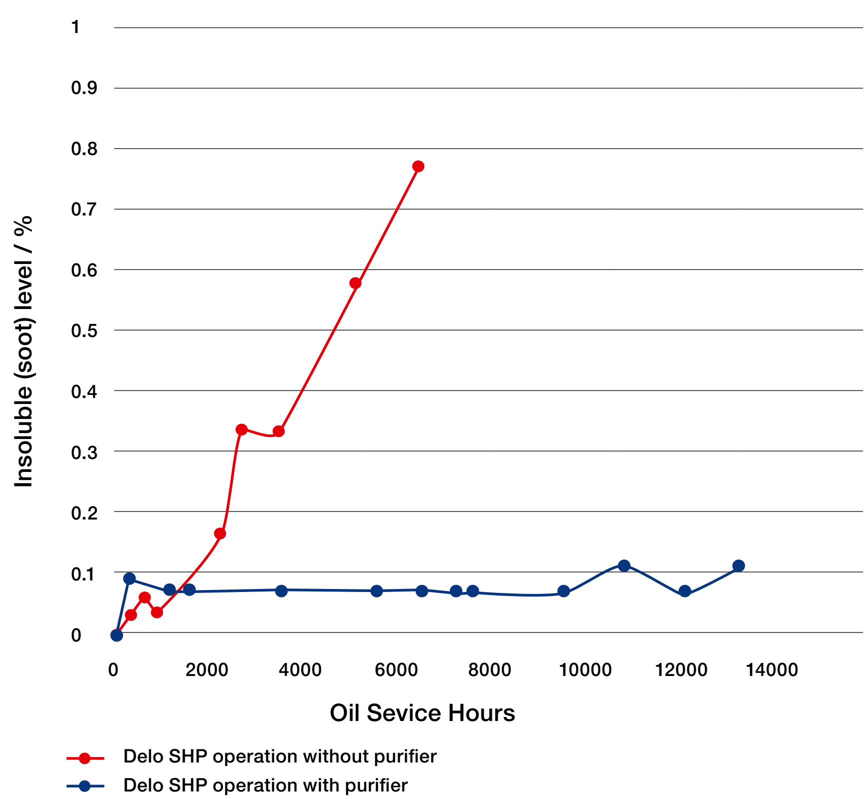
Water in oil tends to wash the oil film off the cylinder walls and can contribute to corrosion by reacting with the sulphuric acid derived from the combustion of the fuel sulphur. (CIMAC, 2008)

Furthermore, middle alkaline lubricants can form water-in-oil emulsions which can be difficult to remove. Such emulsions, if circulated, will reduce the load carrying capacity of the oil in bearings, possibly leading to failures. Emulsified oil, therefore, should be replaced as soon as possible. (CIMAC, 2008)

Detergents and dispersants in oil

Detergents and dispersants are commonly added to lube oils to suspend soot and prevent formation of larger particle agglomerates, and to keep polar compounds in solution. However, these additives also prevent the separator from performing at its best.

A recent test performed by Chevron confirms the importance of separators for reducing soot build-up in lube oil. Without purification, oil viscosity sharply increased, requiring shorter intervals between oil replacement. However, when a lube oil separator was used, insoluble soot levels remained constant over a long period, significantly increasing the service life of the engine oil.



Impact of purification on soot load in medium speed engines (Source: Chevron Lubricants).

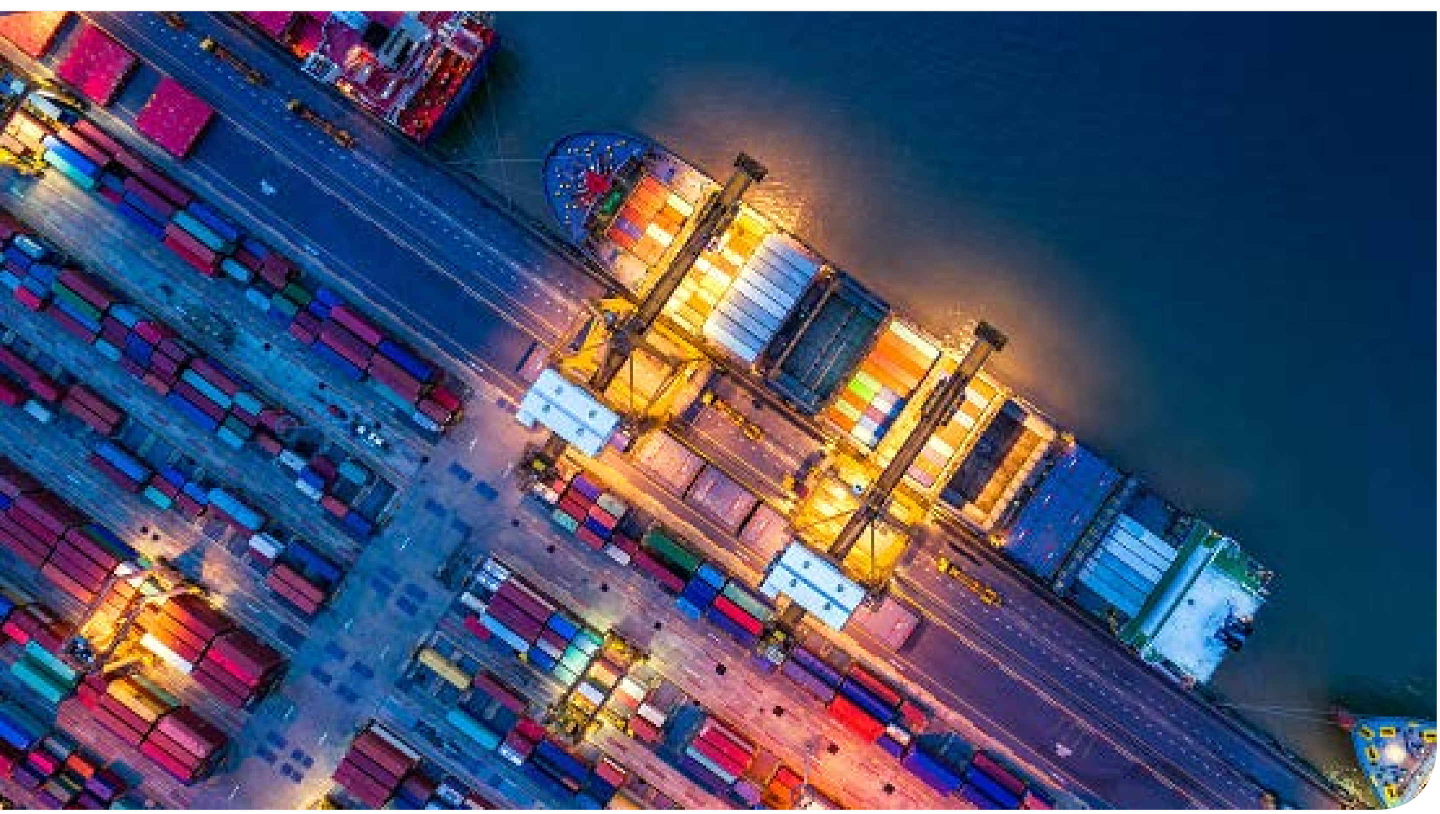
Benefits with separators

Centrifugal separators are known for their highly efficient cleaning abilities, consistent and reliable performance, and minimal maintenance and attendance requirements.

Moreover, integrating a centrifugal separator is simple process, because no modifications are necessary to existing systems. The separator module is installed in a bypass loop, separate from engine operation.

Lube oil centrifugation benefits are numerous:

- Solids and water removal in a single operation
- Highly effective cleaning ability, down to small particle sizes
- Large-volume cleaning
- Minimal service and maintenance requirements
- Prolonged engine lifetime
- Lower operational expenses (OPEX) compared to cartridge filters



What to expect in the next decade

The 2020 regulations will cause more changes to global marine industry than did the 2015 regulation to use 0.10% S in only certain areas; the impact of this transition will affect approximately 75% of total global marine fuel usage.

There are still numerous unanswered questions regarding the impact the 2020 IMO regulations will have on marine engine lubrication systems.

Evidence suggests that the use of a centrifugal separator, to remove contaminants (insolubles and water) from the lube oil, will continue to promote engine longevity and efficiency, regardless of the fuel oil used.

Loss prevention essentials

Here is a handy checklist for avoiding main engine damage, resulting from lube oil failure:

- Implement robust onboard fuel and lubrication oil management systems.
- Check that the feed has correct flow and temperature – a separator inlet temperature of 95°C, or 90°C for cross-head engines, is recommended.
- Use the separator manual to find the correct gravity disc – aim to have the gravity disc with the largest hole diameter without causing a break of the water seal.
- Keep the separator disc stack clean – use a Clean-In-Place (CIP) unit at regular intervals.
- Follow the separation manufacturers recommendations for maintenance intervals – periodic (preventive) maintenance reduces the risk of unexpected stoppages and breakdowns.
- Always use genuine replacement parts – otherwise safe operation of the equipment is not guaranteed, and the warranty may become invalid.
- In addition to onboard testing of lubrication oil, submit samples for laboratory analysis at regular intervals, at least every third month.
- Carry out drip sampling when bunkering the fuel oil – avoid consuming the fuel until analysis results are available.
- Always take engine alarms seriously, for example oil mist detection, and investigate thoroughly – a fully functional alarm system is essential for the safe operation of the main engine.

Bibliography

- Chevron Marine Products LLC. 2012. *Everything You Need to Know About Marine Fuels.*
- Chevron Marine Products LLC. 2013. Information Bulletin 4: Base Number.
- CIMAC. 2014. *Guideline by WG8, Marine Lubricants, 1st edition.*
- CIMAC. 2013. *Guideline for the Operation of Marine Engines on Low Sulphur Distillate Diesel.*
- CIMAC. 2004. *Guidelines for Diesel Engine Lubrication – Oil Degradation.*
- CIMAC. 2008. *Guidelines for the Lubrication of Medium Speed Diesel Engines, 2nd Updated Version.*
- MAN Diesel & Turbo. 2015. *MAN L32/44 GenSet Project Guide – Marine: Four-stroke diesel enginecompliant with IMO Tier II.*
- MAN Diesel & Turbo. 2016. *Project Guide – Marine.*
- Wärtsilä 50DF Product Guide - a19 – 25 July 2018*.*
- The Swedish Club. 2018. *Main Engine Damage.*
- WinGD. 2018. *Lubricants: All engines – Issue 001.*

About Alfa Laval

Alfa Laval is a leading global provider of specialized products and engineering solutions.

Our equipment, systems and services are dedicated to helping customers to optimize the performance of their processes. Time and time again. We help our customers to heat, cool, separate and transport products such as oil, water, chemicals, beverages, foodstuff, starch and pharmaceuticals.

Our worldwide organization works closely with customers in almost 100 countries to help them stay ahead.

How to contact Alfa Laval
Up-to-date Alfa Laval contact details for all countries are always available on our website at www.alfalaval.com

100000XXXX-1-EN XXXX

How to contact Alfa Laval
Contact details for all countries are continually updated on our web site.
Please visit **www.alfalaval.com** to access the information directly.