INTERNATIONAL COUNCIL ON COMBUSTION ENGINES

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CIMAC Recommendation 31

THE LUBRICATION OF TWO-STROKE CROSSHEAD DIESEL ENGINES

By CIMAC Working Group 8 'Marine Lubricants'

The first edition of this CIMAC Recommendation was approved by the members of the CIMAC WG8 'Marine Lubricants' at its meeting on April 22nd 2016.

FOREWORD BY THE PRESIDENT

Lubricating oil is often termed as the blood of an engine. Engine lubricants play an important role of preserving and maintaining the life of an engine by providing for proper lubrication of parts, reduction of wear between components, cooling of engine machineries as well as preventing blow-by gases entering the crankcase. The lubricants also decrease the power required to overcome friction, thereby increasing the power output of the engine, consequently its service life by safeguarding the parts as well as performance characteristics of the engine on the long run.

The CIMAC 'Working Group 8 - Marine Lubricants' has created the CIMAC Recommendation titled "Lubrication of Two-Stroke Crosshead Diesel Engine" which provides an insight into the lubrication of two-stroke low speed diesel engines as used by the engine industry today. The recommendation is put together by a group of specialists in this field and can truly be considered an industry standard of today, mainly useful for users, engineers and associated readers from the relevant fields of work.

The CIMAC Working Group 'Marine Lubricants' works to propagate know-how about marine lubrication, which is also valid for power plant applications, by producing guidelines and recommendations dedicated to deepen our understanding of this important subject. The Working Group comprises of acknowledged experts from engine manufacturers, component and systems suppliers, oil companies, classification societies and ship operators. The new recommendation goes a long way in achieving the Working Group's goals of setting standards and providing for harmonization with regards to lubrication in diesel engines and for its application in the industry today.

I would like to thank all members of the Working Group for their relentless efforts in successfully completing this CIMAC Recommendation, which I'm sure will be extremely beneficial and widely appreciated by the industry for years to come.

Klaus M. Heim,

CIMAC President, May 2017

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1 Introduction

In 1997 the CIMAC Working Group Lubricants published a document which provided guidelines for the lubrication of two-stroke crosshead diesel engines, as CIMAC Recommendation No. 15. That publication compiled insights into the lubrication of low speed diesel engines as generated by the groups' members who represent users, engine and equipment manufacturers, institutions and additive and lubricant suppliers. In the meantime, the Working Group felt that developments concerning the lubrication of low speed diesel engines since 1997 should be incorporated in a new document.

This publication therefore contains the following new information on recent development drivers and the resulting changes that have already taken place as well as those to be expected in the future on:

- Emission regulations
- Fuels and new fuel application areas
- Engine design and configurations
- More varied engine operation conditions (like continuous operation at low load)
- Multiplicity of lubricating systems and concepts
- Evolution of lubricant technologies

1.1 Purpose & Scope

Engines may be operated under various circumstances: under test-bed conditions, in the shipyard, undergoing sea trials or may be on normal service duties at sea or on land. Users also may have different objectives for engine operation: for example, initial running-in, classification society type testing, engine protection and long term economic operation. The latter means reliable, efficient and effective operation that complies with applicable environmental constraints is desired.

These guidelines contain short, precise and readable information that describe the lubrication principles applicable to low-speed two-stroke crosshead diesel engines. The guidelines do not replace nor contradict the recommendations of the designers and manufacturers but are complementary. The recommendations relate to system lay-out, operation, servicing and fluid selection practices and represent the consensus position of the industry experts.

This document is intended for engine owners and operators. In addition, it should be recommended reading for students and for all those involved with, or interested in, the lubrication of two-stroke crosshead diesel engines.

Since there are typically many years between updates of CIMAC guidelines, this document has very specific information – expected to become outdated within a few years – placed in the appendix. Information of a very detailed nature and engine designer specific information is also mostly placed in the appendix to ensure the document, while comprehensive, remains easily readable and accurate.

1.2 Emission Legislation

There continues to be a global drive for lowering harmful emissions to reduce the impact on human health and the environment. Now drastic emission reductions have been achieved for land based transportation, air and maritime transport emission reductions are coming more and more into focus.

The resulting emission legislation is expected to be a major factor shaping the shipping industry well into the next decade and as such is also directly or indirectly of impact on lubrication requirements.

In the late 1980's the International Maritime Organisation (IMO)[1], a specialized agency of the United Nations, started work on the reduction of air pollution from ships. However, it was only with the ratification of MARPOL Annex VI, and its entry into force on May 19, 2005, that there was a direct impact on the shipping industry. Since that time the emissions from shipping have played a major part in the development of the marine industry, with the IMO setting ever tighter limits. Other authorities, such as the European Union and the state of California, have added further requirements to the shipping industry.

As the emissions legislative requirements are expected to change more frequently than this guideline, the legislative requirements are only broadly outlined in this paragraph for the major regulated emissions: carbon dioxides, sulphur oxides & particulate matter and nitrogen oxides. References with specifics on the maritime emissions legislation can be found in appendix I.

Although international shipping is the most energy efficient mode of mass transport and only a modest contributor to overall carbon dioxide (CO_2) emissions, a global approach to further improve its energy efficiency and effective emission control is needed as sea transport will continue growing apace with world trade[1].

In July 2011 the IMO adopted technical measures for new ships (the Energy Efficiency Design Index – EEDI) and operational reduction measures for all ships (the Ship Energy Efficiency Management Plan – SEEMP). These measures are the first-ever mandatory global greenhouse gas (GHG) reduction regime for an entire industry sector.

Sulphur oxide (SO_x) emissions generated by the merchant fleet represent a significant contribution to the global emissions[2]. It is generally recognized that SOx emissions are a function of the sulphur content of fuel and that reducing the sulphur content of fuel will also result in lower particulate matter emissions.

Through the revised MARPOL Annex VI, which entered into force on July 1st 2010, the IMO has set in motion the global reduction of these harmful emissions through regulating the amount of sulphur in marine fuels. Alternative methods for reducing SO_x and particulate matter emissions (e.g. exhaust gas scrubbing systems) are also allowed as long as they are shown to be at least as effective in reducing these emissions as the sulphur limits in the regulations.

The regulation defines the sulphur content of the fuel where compliance is to be achieved on the basis of the fuel as loaded. There are different sulphur limits applicable inside and outside Emission Control Areas (ECA's); these being areas where the IMO has agreed that a higher level of protection is required. At the time of publication of this document, ECA's where such fuel sulphur limits or equivalent measures are applicable are essentially the North Sea, the Baltic Sea and a 200 nautical mile zone off most of the US and Canadian coastline.

The regulations in the revised Marpol Annex VI are staged over time. A significant change has taken place on January 1st 2015, when the maximum fuel sulphur content allowed in the ECA's went down from 1.00 mass% to 0.10 mass%, effectively leading to heavy fuel oil (HFO) no longer being a compliant fuel in these areas unless an effective alternative SO_x and particulate matter control measure is taken on board (such as an exhaust gas scrubber).

The revised Marpol Annex VI furthermore prescribes the marine fuel sulphur content to go down from 3.50 mass% (outside the ECA's) to 0.50 mass% (outside the ECA's), or to take measures to ensure an equivalent reduction of SO_x and particulate matter. This major global change is set to take place on January 1st 2020, or five years thereafter should a review in 2018 conclude the former date is not feasible.

The third major regulated emission, also included in the revised Marpol Annex VI concerns emission of Nitrogen Oxides (NO_x). This regulation sets limits for the emitted amount of NO_x per energy unit (g/kWh) depending on the engine's rated speed (revolutions per minute – rpm), the construction date of the ship and the actual speed of the engine in operation (rpm). The limits of "tier I" and "tier II" set forth by this IMO regulation are already in effect globally for ships constructed after January 1st 2000 and January first 2011 respectively. These limits can typically be met by modern or optimization engines.

The much more stringent IMO tier III NO_x limits will apply to new ships (after a certain date) in NO_x ECA's; note these NO_x ECA's can be different than the abovementioned SO_x ECA's. These limits cannot be met by further engine optimization but require a drastic design change such as significant Exhaust Gas Recirculation (EGR) or the installation of Selective Catalytic Reduction (SCR) in the engine exhaust. The applicable date for tier III is as early as January 1st 2016 for the North American and US Caribean Sea ECA's.

Although currently not directly regulated on a large scale, Particulate Matter (PM) is an area of attention for legislators and is expected to be further regulated in the future.

It is important to note that the emissions legislation can (directly or indirectly) have a significant impact on the lubrication requirements for large bore two-stroke engines. The application of SCR may for example limit the application of certain compounds in the lubricants, while the reduction of sulphur level in the ECA's may lead to new two-stroke lubricant requirements for prolonged operation on distillate fuel; CO_2 reduction through reduced vessel speed and engine load is in some cases already driving a higher amount of corrosive wear in the combustion space, requiring better protection of the lubricated parts.

2 Engine and Lubrication Fundamentals

2.1 The Engine

Two-stroke engines are defined as that group of reciprocating internal combustion engines that have a combustion stroke on each second stroke, or in other words, each cylinder has a power stroke on each crankshaft revolution. Two-stroke crosshead diesel engines are also called low speed or large bore engines. In general, low speed engines are defined as engines that have a rotational speed below 300 rpm.

This type of reciprocating engine is furthermore characterised by the use of a crosshead guide system. A rigid rod connects the piston to the crosshead bearing assembly and passes through a seal and guide. The crosshead bearing assembly in turn transmits forces to the crankshaft by means of a connecting rod. The basic engine design and layout features are illustrated in Figure 1.

Two-stroke engines are commonly used as the main propulsion engine in ships and are sometimes used for land based power generation plants. The main benefit of using a crosshead two-stroke engine in ships is that a high efficiency propeller can be directly coupled to the engine without the need for a transmission system. This allows for a compact and economical layout and the engine can be started forwards or in reverse to allow vessel manoeuvring. These engines have multi fuel capability and typically can operate on various grades of heavy fuel oil (HFO, also called residual fuel oil) or distillate fuels (e.g. diesel), or blends of these fuels[3]. At the time of publication of this document gas fueled two-stroke engines are also available but their commercial use is very limited

These engines typically have the following features:

▪ large bore	26 to 98 cm
▪ high stroke to bore ratio	up to 5:1
▪ mean piston speed	about 9 m/s
▪ in line configuration	4 to 14 cylinders
▪ high Brake Mean Effective Pressure (BMEP)	up to 21 bar
▪ high peak cylinder pressure	up to 200 bar
▪ high power output at low speeds	up to 87 MW at 100 rpm
▪ very high thermal efficiency	about 50%
▪ very low specific fuel consumption	As low as 160 g/kWh

- very efficient operation over a wide speed and load range
- turbocharged and intercooled
- variable and controllable fuel injection timing and duration for electronically controlled engines
- variable exhaust valve timing
- very robust construction and a long reliable operating life – over 100,000h / 30 years
- optional power take off (PTO) and/or Power take In (PTI) systems
- optional waste heat recovery systems
- optional exhaust gas abatement technologies

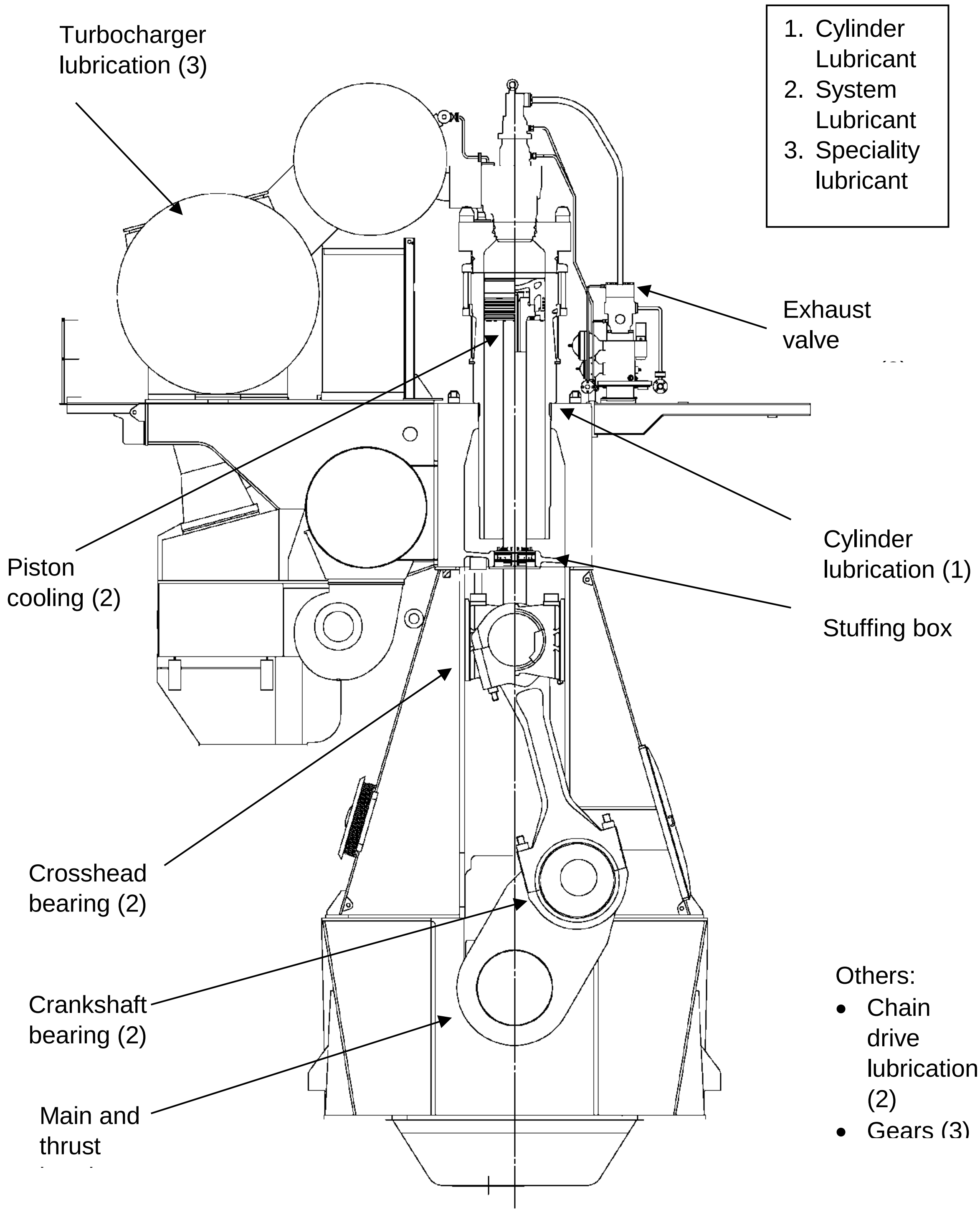


Figure 1: Schematic representation of the two-stroke crosshead diesel engine

The sealing mechanism to separate the cylinder from the crankcase system allows two different optimized lubricants to be used in the engine.

- The cylinder lubricant is optimized for the lubrication of the piston and rings in the cylinder liner and to cope with the products of combustion.
- The system oil is optimized to lubricate the bearings, camshafts and guides in the crankcase mechanism and is kept free of major contamination from combustion residues by means of the piston rod seals. The system oil may also be used to cool the pistons and turbocharger bearings. Additionally, it may be used as a hydraulic fluid to operate the exhaust valves and in some cases the fuel injection control system.

2.2 Tribology and Lubrication Fundamentals

Tribology is the science and engineering of interacting surfaces in relative motion. Lubricants are used to prevent solid surfaces from contacting one another. There are three types of lubrication as defined by the Stribeck curve (see Figure 2).

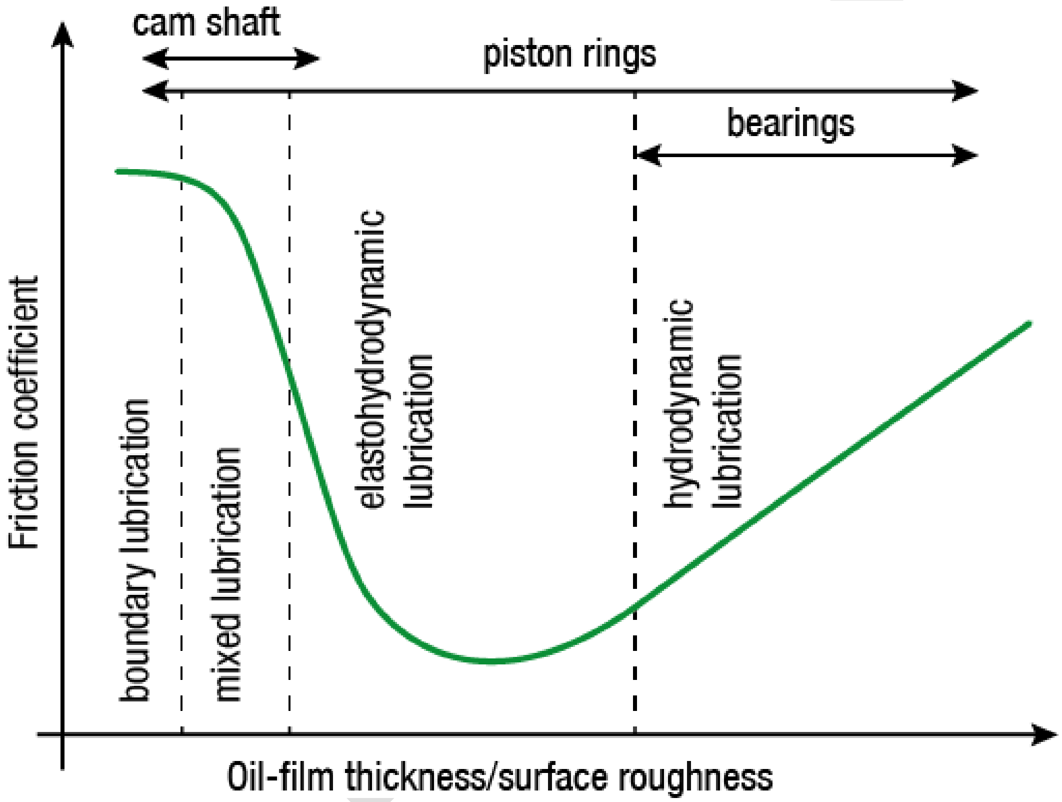


Figure 2: The Stribeck curve

The three types of lubrication depicted in the Stribeck curve and Figure 3 are:

- Boundary lubrication, characterised by a high friction coefficient and some contact of the sliding solid surface asperities, resulting in wear.
- Mixed lubrication and elastohydrodynamic lubrication, characterised by a low friction coefficient and low wear.

- Hydrodynamic lubrication, characterised by relatively low friction and virtually no wear as the solid surface asperities are kept fully apart.

The main objective of lubrication is to reduce wear to a low level, thus components and the lubricant need to be matched to achieve this goal. This is for example achieved by ensuring adequate bearing surface area for the load conditions and adequate lubricant viscosity to allow at least boundary lubrication conditions to be achieved on all interacting moving surfaces.

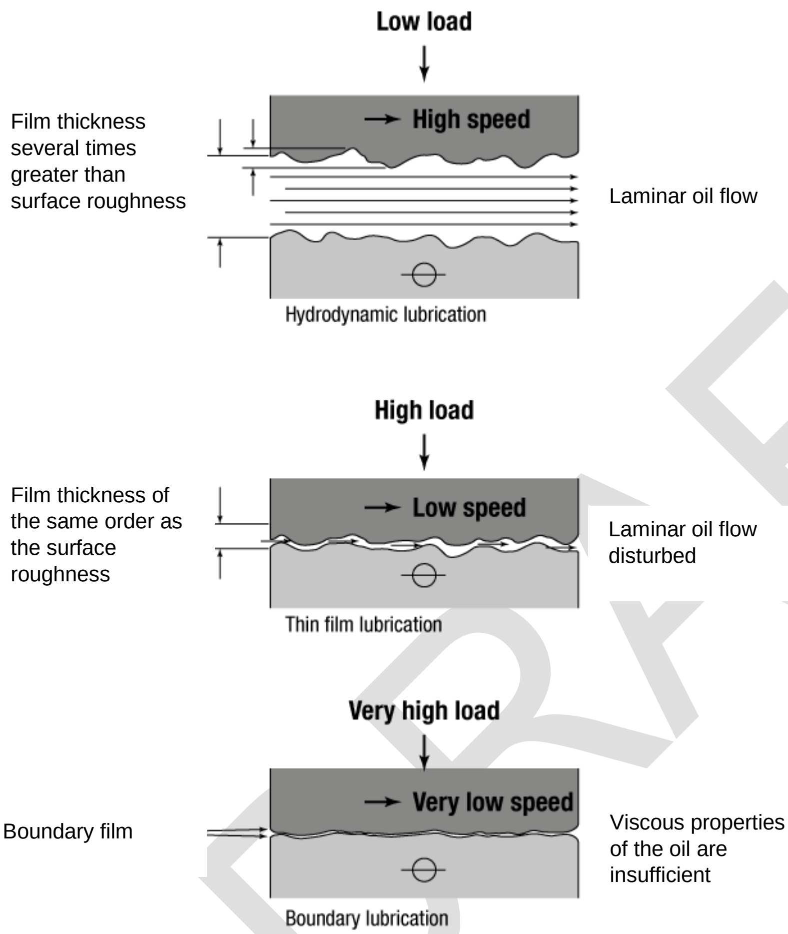


Figure 3: Schematic representation of hydrodynamic, thin film and boundary lubrication

2.3 Wear Mechanisms

Wear can be triggered by several phenomena and can have a devastating impact on engine operation. Proper understanding of the possible root causes of wear is essential to understand and eliminate unnecessary wear. Different types of wear that can occur in two-stroke engines are characterized below.

- Adhesive Wear

This phenomenon is caused by frictional contact between asperities on opposing surfaces at a high enough load, that plastic deformation or solid-phase welding occurs in the contact (Figure 4). When this results in transfer of material from one surface to another, one has adhesive wear. Wear debris can also be formed.

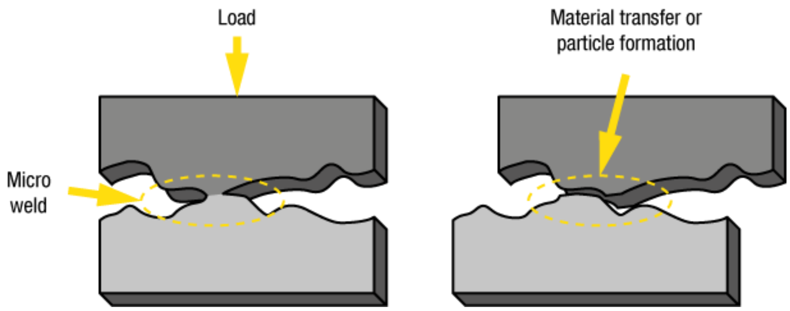


Figure 4: Schematic representation of adhesive wear

In a low speed engine this wear mechanism is generally observed when insufficient oil film is present to achieve hydrodynamic lubrication. This mechanism is often seen in bearings where insufficient oil film thickness was built up. It can also occur in the piston rings – cylinder liner interface if insufficient oil was supplied or when the liner surface roughness is unable to support a proper oil film. The first indication of this wear mechanism is the occurrence of micro welds (also called micro seizures); for example on the piston ring surface.

In two-stroke engines the term scuffing is used to describe the situation where adhesive wear has developed to surface degradation on a wider, macroscopic scale.

- Abrasive Wear

Abrasive wear occurs when a harder material is rubbing against a softer material resulting in loss of material (see Figure 5). When only two surfaces are involved and the wear is caused by asperities on the harder surface, the wear is called two body abrasion. If the wear is caused by a hard particle trapped (either free or partially embedded in one of the surfaces) between the sliding surfaces, the wear is called three body abrasion. Abrasive wear occurs when the oil film thickness allows contact and results in scratches, embedding of particles or formation of new particles.

Abrasive wear can be a result of adhesive wear, where parts are ripped out of the surfaces that can act as abrasive particles. Abrasive particles can be formed during combustion or can originate from scraped off piston deposits, soot and oil ash as well as from corrosion. Abrasive particles can however also have a foreign nature and can be introduced into the engine via the combustion air, via the fresh lubricant (for example when the lubricant was stored in previously un-cleaned tanks during transport) or via the fuel; for example in the form of catalytic fines (so-called “catfines”), which are small, worn down catalysts from a refinery process called Fluid Catalytic Cracking (FCC).

In a circulation oil system, abrasive particles are typically the result of improper purification, insufficient filtration or dirt entered during maintenance on the system.

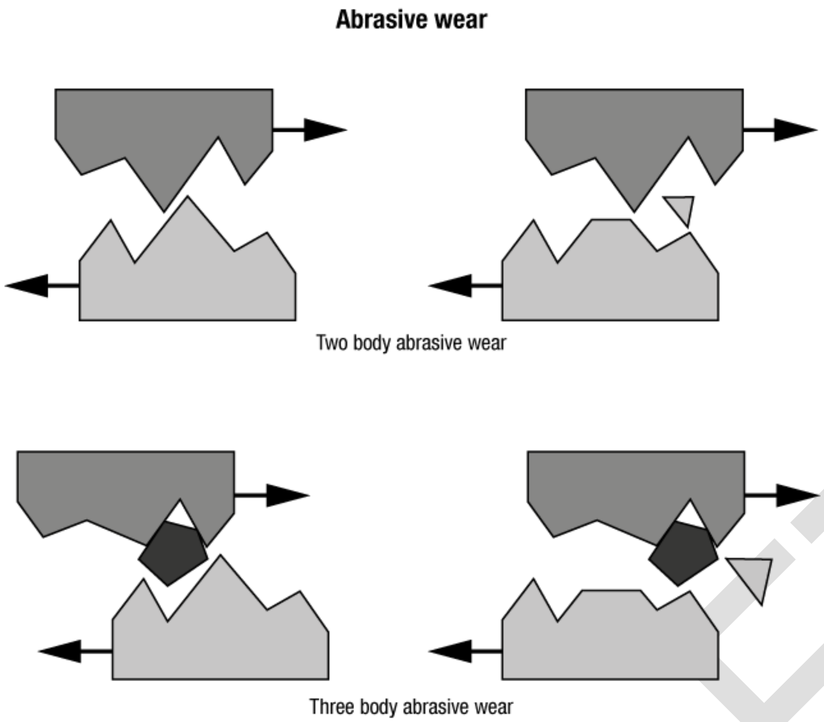
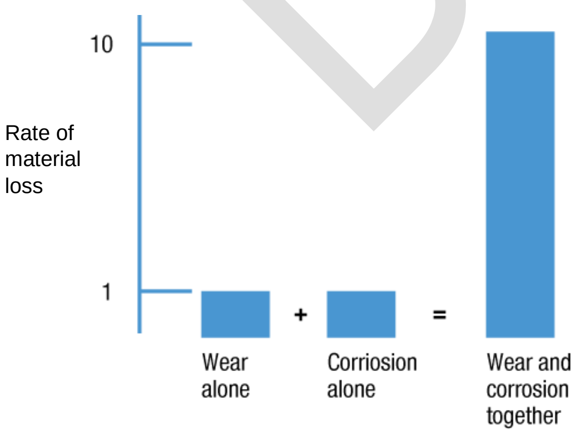


Figure 5: Schematic representation of abrasive wear

- Corrosive Wear

Corrosive wear is defined as the degradation of materials where both corrosion and wear mechanisms are involved.

Corrosive wear occurs when there is a combination of a wear situation (abrasive or adhesive) and a corrosive environment. The rate of material loss can be very high; much higher than the sum of the individual contribution of wear and corrosion (see Figure 6). This is because loose corrosion products are easily removed by wear to continually reveal fresh metal beneath, which in turn can corrode quickly (see Figure 7). Likewise, stable oxide films that would normally limit corrosion (in the absence of wear) are instantly worn away.



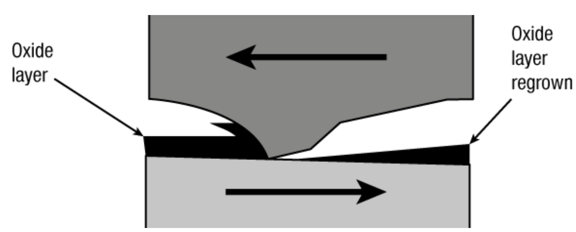


Figure 6: Illustrative example of material loss rate

Figure 7: Schematic representation of oxide layer removal – exposing the surface to corrosion

Corrosive wear may be found in the combustion chamber, and is also known as “cold corrosion”.

- Erosive wear

Erosive wear is caused by the impact of particles of solid or liquid, which remove fragments of material from the surface due to momentum effect. The impingement angle is one of the most important factors for the wear.

- Cavitation Erosion

Cavitations occurs when liquids undergo rapid changes in pressures, causing formation of small “liquid free” bubbles, containing vapour or gas or both, which implode causing local high impact pressures and temperatures, resulting in erosion of the surface, hence the name of cavitation erosion. In a lubricating oil system, cavitation can be triggered by inadequate system or component design but is often accelerated when air bubbles get entrapped via leaks on the suction side of the system or due to a too low oil level, or when water is present in the oil.

A typical occurrence of cavitation erosion can sometimes be found on the inside of high pressure fuel injection pipes due to the rapid change in fuel pressure at the end of injection.

- Fatigue Wear

Fatigue, often referred to as contact stress, occurs when a solid material is weakened by cyclic loading. Fatigue wear occurs when particles are detached by the cyclic growth of superficial or subsurface microcracks.

This type of wear is generally triggered by overloading, misalignment or inadequate lubrication. High plastic deformation can lead to crack initiation, growth and fracture after a number of cycles.

Fretting Wear

Fretting wear is a type of fatigue wear. Fretting wear occurs when fretting causes material removal of a surface. Fretting is the oscillatory relative motion of small amplitude between two surfaces.

Fretting wear often occurs on the backside of bearing shells or two surfaces connected with bolts which are put under high loads in a cyclic manner (connecting rod bolts, bearing housings).

2.4 Corrosion Mechanisms

There are different types of corrosion. Those typically found in two-stroke engines are listed below:

- Cold corrosion

Cold corrosion is caused by sulphuric acid. Marine low speed engines are often operated on high sulphur content heavy fuel oil (HFO[3]). The sulphur oxides that result from combustion of the fuel will, with the water formed during combustion and the water from the scavenge air, form sulphuric acid. When the liner temperature drops below the dew point of sulphuric acid and water, a corrosive mixture is condensed on the liner. High alkaline lubricants are used to neutralize the sulphuric acids and avoid cold corrosion of piston rings and cylinder liner surfaces. If the sulphuric acids are not neutralised the engine will experience corrosive wear (see Section 2.3 above). Cold corrosion typical takes place at temperatures below 200 °C and is called cold in contrast to hot corrosion (see below).

- Hot corrosion

High Temperature Corrosion (also called “hot corrosion”) occurs when vanadium and sodium salts melt. These liquid melts are highly corrosive and can create “burn-like” damage of metals. When High Temperature Corrosion occurs it is typically found on piston crowns, exhaust valves or in the turbocharger turbine. Vanadium is present in all crude oils and is typically present in the heavy fuel oil (HFO) as offered on the market. When delivered, HFO often contains some sodium as well; the contamination of the fuel with seawater increases this sodium content further. The melting reaction is most likely to take place when the vanadium & sodium are present in a 3 to 1 ratio and typically takes place at temperatures above 550 °C. Therefore, the introduction of sodium, for example via the fuel, the intake air or the lubricant, in the combustion space or in the presence of high temperature exhaust gasses containing vanadium must be avoided.

- Galvanic corrosion

Galvanic Corrosion is caused by an electrochemical process between two different materials in electrical contact and exposure to an electrolyte. This exposure of the materials will develop a galvanic current which will flow from one material to another, causing sacrificial material loss (anode versus cathode) also known as contact corrosion.

The typical galvanic corrosion is observed on propeller shafts and the main bearing surfaces. It must be noted that galvanic corrosion can be prevented by grounding the parts between which there is a difference in potential.

3 Cylinder Lubrication

3.1 Cylinder Lubrication Requirements

Cylinder lubricants are specially formulated to perform in the specific environment of the split lubrication two-stroke combustion chamber. The generic purposes of a cylinder lubricant are to protect the cylinder liners, pistons and piston rings from the harmful effects of combustion by-products and provide an oil film between piston rings and cylinder liners.

To achieve this, the cylinder lubricant is required to:

- Spread uniformly over the cylinder liner surface and form a stable oil film
- Provide a gas seal between the liner and the piston rings
- Neutralise acids formed from the by-products of the combustion process
- Minimise deposit formation on piston surfaces and ring grooves
- Flush out particles formed during combustion from the combustion chamber as well as wear particles
- Prevent a build-up of deposits in the piston ring grooves which can lead to ring sticking or breakage
- Prevent corrosion of the cylinder liner and other combustion chamber components while the engine is stopped
- Be compatible with the different methods used by engine manufacturers to introduce lubricant into the combustion chamber

Traditionally cylinder lubricants have been designed for heavy fuel oil (HFO) operation, but now other fuels such as distillate fuels and gas are becoming more widely used. As engine development proceeds and the range of fuels burned increases, the temperature and pressure conditions to be endured by lubricant and engine components will likely become both more severe and more varied. Cylinder lubricants will be required to maintain performance under these varying conditions.

Correct engine operation ensures that the optimum supply of the cylinder lubricant to the critical ring/liner interface is maintained. Detailed advice on oil feed rates and maintenance to ensure the necessary protection of the engine, is given in the engine manufacturers instruction manuals.

The selection of a cylinder lubricant depends on the type and quality of the fuel, the mode of engine operation and the economic criteria applied by the owner. This could result in multiple cylinder lubricants being required in the operation of the engine. It is recommended to only use cylinder lubricants that successfully underwent the engine OEM validation process (refer to OEM information).

3.2 Cylinder Lubrication System Design

The cylinders in a two-stroke, crosshead engine are lubricated by a separate system working on a once-through principle. That is, fresh lubricating oil is directly supplied to the cylinders to provide lubrication for the liners, pistons and piston rings. The used oil is partly burned and partly drained from the bottom of the cylinder liners and discharged.

The main components of such a system are the storage tanks, service tanks, lubricators delivering the oil under pressure to the cylinders, the pipe system, valves for control of flow rates and injection timing and the oil injectors. A typical arrangement of a cylinder lubricating system is shown in Figure 8.

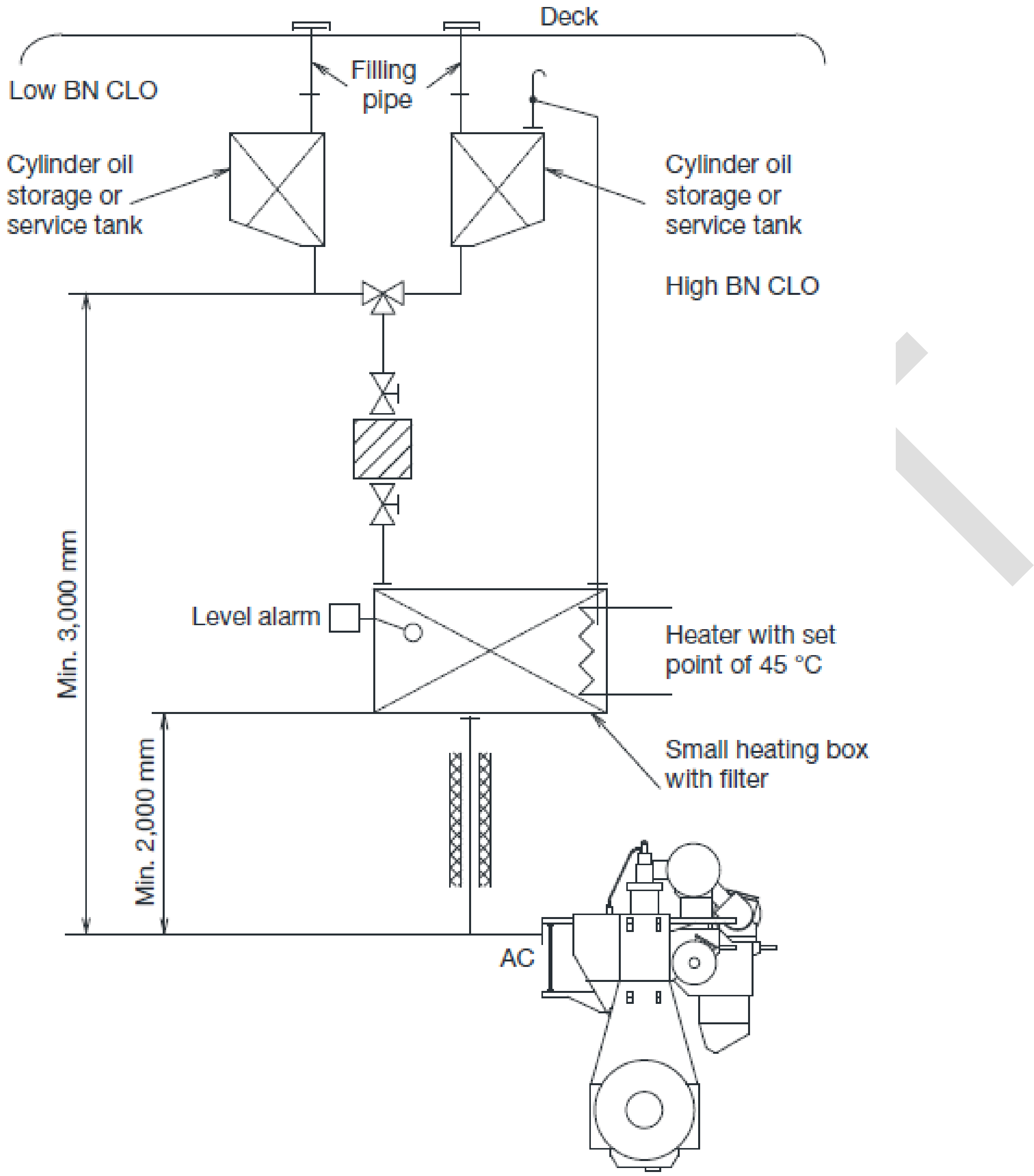


Figure 8: Typical arrangement for the cylinder lubrication system

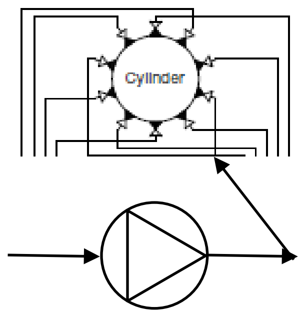


Figure 9: Schematic representation of cylinder oil supply to the cylinder liner

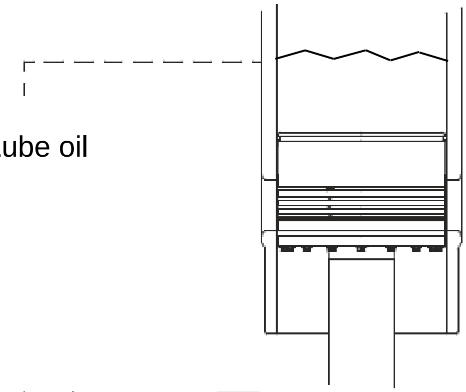


Figure 10: Schematic representation of cylinder oil supply to the oil quills

A service tank holding a supply of about 48 hours of normal cylinder oil consumption is typically located in the engine room. From the tank the oil flows by gravity to the lubricators (see Figure 8). The lubricators can be of different design piston-type pumps, either driven mechanically or, more commonly on modern engines, by a hydraulic system (see Section 3.2.2 below). The lubricators force the oil through pipe connections via non-return valves and injectors to the individual cylinders where a number of bores in the liner wall feed the oil onto the surface of the cylinder liners (see Figures 9 and 10). The bores, commonly called quills, are connected by grooves, machined into the liner surface (see Figure 11). The quills provide a uniform distribution of the oil around the liner circumference and by the movement of the piston rings the oil is spread over the running surface of the liner; enabling the oil to build up an oil film necessary for the lubrication of the cylinder.

There are variations in the arrangement of the quills, the number of oil quills, the number of quill rows, their position relative to the top dead centre position (of the piston in the liner) and the shape of the distribution grooves, representing the different engine designs of the different engine designers. A typical example of the injection into the cylinder liner via injector and oil quills can be seen in Figure 11.

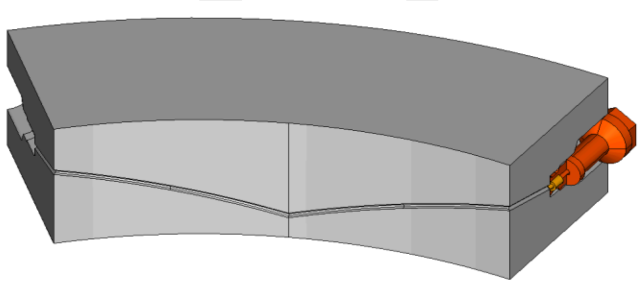


Figure 11: Typical example of the injection channel of the lubricant into the cylinder liner via oil quills

3.2.1 Cylinder Lube Oil Control Systems

As stated above, the lubricators can be of different designs, either driven mechanically or more commonly on modern engines by a hydraulic system. The hydraulic system enables electronical control. The electronically controlled systems are always found on electronically controlled engines, whereas the mechanically controlled engines may be lubricated by both the mechanically and the electronically controlled systems. The mechanically controlled systems are mainly found on older vessels and newer vessels with small engines, as this system is simpler and thereby cheaper.

Generally, the main difference is that the electronically controlled systems offer the possibility to time the injection of the lubricating oil, where the mechanically controlled systems inject the oil when the pressure in the combuster chamber is lower than the pressure in the injector. For the electronically controlled systems the injection is timed, usually during the upward passage of the piston rings (see Figure 12)

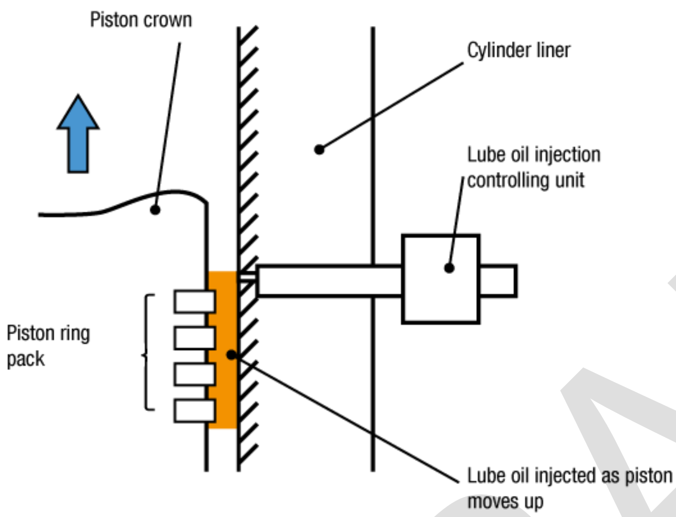


Figure 12: Injection controlled timing of cylinder lube oil

Both controlling systems can vary the cylinder oil feed rate for the individual cylinders. In the electronically controlled systems it is possible to define the feed rate very precisely, whereas for the mechanically controlled systems this process is more course.

In general, the mechanically controlled designs inject a small, controlled amount of cylinder oil every crankshaft revolution, whereas electronically controlled designs inject a constant amount of cylinder lubricating oil per pump-stroke and the feed rate is controlled by adjusting the number of engine revolutions between pump strokes.

3.2.2 Overview of Available Cylinder Lubricating System Designs

There are a number of different lubricating systems available on the market today. The electronically controlled systems are normally following the engine design from the different OEMs, but for mechanically controlled design the cylinder lube oil designs are normally made by specialized companies.

An overview of the main cylinder lube oil designs on the market (at the time of this publication) and their key features are shown in the table below.

Table 1: Main cylinder lubrication system designs

Name	Designer	Control system	Injector design	For engine types	Retrofit available
HJ Mechanical Lubricator (SIP)	Hans Jensen Lubricators	Mechanically	Timed injection SIP: Swirl Injection Principle	All mechanically controlled engines	Yes
HJ Lubtronic	Hans Jensen Lubricators	Electronically	Timed injection SIP: Swirl Injection Principle	All designs, mechanically & electronically controlled engines	Yes
ECL (Electronically Controlled Lubricating System)	Mitsubishi Heavy Industries	Electronically	Timed injection	Mitsubishi mechanically and electronically controlled engines	No
A-ECL (Advanced Electronically Controlled Lubricating system)	Mitsubishi Heavy Industries	Electronically	Timed injection	Mitsubishi mechanically and electronically controlled engines	Yes
CLU3 Lubricating system	Wärtsilä	Mechanically	Timed by cylinder pressure	Wärtsilä mechanically controlled engines	No
Pulse or CLU4 Lubricating System	Wärtsilä	Electronically	Timed injection. Pulse Jet: radial injection into the piston ring pack	Wärtsilä mechanically and electronically controlled engines	Yes
Alpha Lubricator	MAN Diesel & Turbo	Electronically	Timed injection	MAN B&W mechanically and electronically controlled engines	Yes
ME Lube	MAN Diesel &Turbo	Electronically	Timed injection	MAN B&W electronically controlled engines	No

More specific information regarding the design, lay-out and knowledge on the different systems are provided in Appendix II and we refer to OEMs and other designers for updated information.

3.3 Blending on Board Systems

Normally, the cylinder lube oil is produced and quality controlled by the oil companies and delivered to the vessels as a finished product ready for use. However, an alternative system has been developed: The Blending on Board (BoB) system. Here the cylinder oil is made on the vessel by blending a specially supplied additive package with used system oil. A schematic representation of the system can be seen in Figure 13.

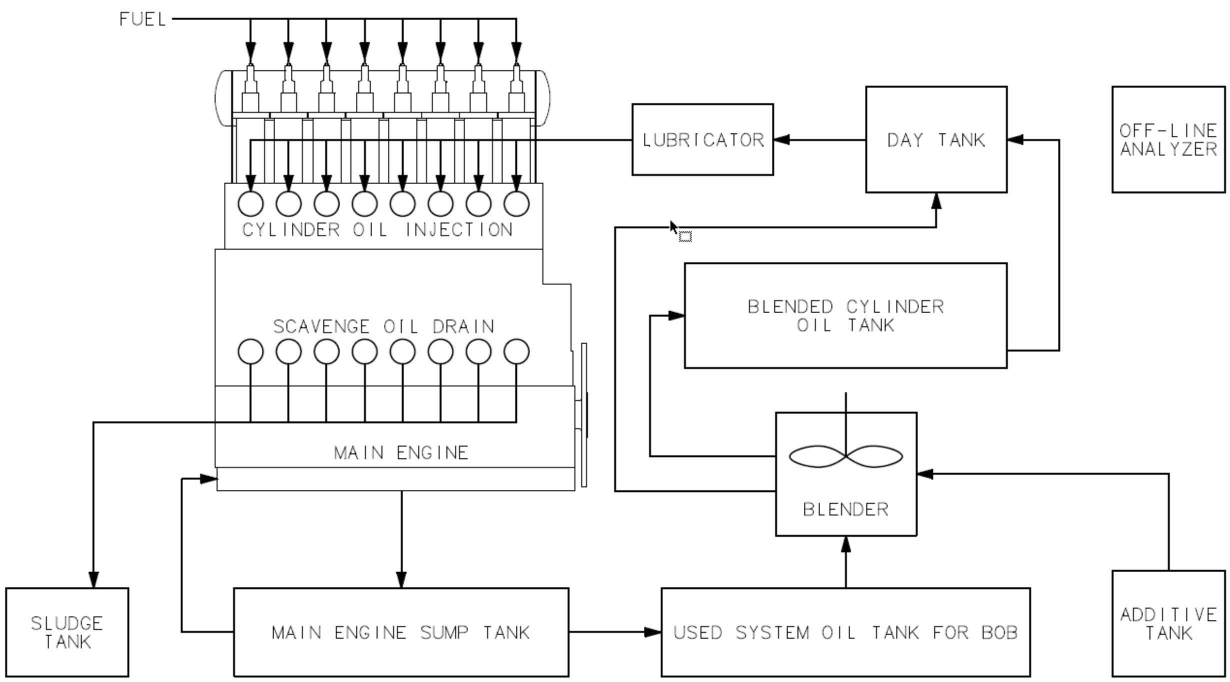


Figure 13: Schematic representation of the Blending on Board system

The BoB system can blend the cylinder lube oil to a desired alkalinity (BN) level to meet the engine's need for acid neutralisation. This enables the engine to run on fixed (low) feed rate when using residual fuel oils with different sulphur levels and when operating under varying conditions.

At the time of publication of this document there is only experience with residual fuel operation.

Since the BOB concept uses system oil to blend cylinder oil, the system oil in the engine crankcase is refreshed continuously which helps maintain key system oil properties (e.g. antiwear, detergency, anti-oxidancy etc.) close to fresh oil values.

This system provides more flexibility, but introduces extra complexity to the crew and operation on board the vessel. This results in additional responsibility and requires a higher degree of technical competency from the crew.

It should be noted that in practice the BoB system typically makes a cylinder lubricant with a viscosity in the SAE 40 grade range.

As such, the OEM should be consulted to ensure that such lubricants and operations are in line with their latest recommendations.

3.4 Cylinder Lubricant Feed Rate

3.4.1 Introduction to Cylinder Lubricant Feed Rate

The primary operational consideration for the cylinder lubricant is its feed rate to the cylinders, typically expressed in gram lubricant per engine produced energy (gram lubricant per kilowatt-hour, g/kWh). This may also be referred to as the Specific Lubricating Oil Feed Rate (SLOFR).

There are various factors that influence the amount of cylinder lubricant that is needed for safe engine operation. As lubricant feed rate recommendations vary by engine manufacturer, by operational conditions (e.g. engine load, fuel sulphur, fuel type etc), by engine model and by lubricant used, the engine manufacturers recommendations should be consulted for how the appropriate feed rate can be determined in a specific situation.

On modern engines, lubricant feed rates can readily be adjusted and can include systems that determine the appropriate feed rate for the known operational conditions. This is however not the case for older engines and automated feed rate systems may not be present on every modern engine or they may not include the ability to factor in all operational parameters. Therefore, it is important for the engine operator to understand the factors that are of influence on the required cylinder lubricant feed rate. The most important factors will be explained below, as well as to thoroughly understand the engine manufactures recommendations.

3.4.2 Factors of Influence on Cylinder Lubricant Feed Rate

The following factors are of primary influence on the amount of lubricant required for safe engine operation:

- Engine load
- Fuel sulphur content
- Engine bore and stroke
- Engine speed
- Inlet air humidity

Below some general information is given. Please refer to OEM information in specific cases.

- **Engine Load:**

Increasing load will lead to a higher cylinder liner temperature, a higher maximum pressure and therefore a higher pressure of the rings on the liner and lubricant film. It will also generally lead to a higher engine speed (depending on the propeller arrangement), more fuel to be burned and thus generally more combustion by-products to handle. Therefore, a higher engine load demands a higher performance of the cylinder lubricant. As feed rate is given per unit of energy output, the absolute amount of lubricant provided to the cylinders per unit of time increases proportionally with the engine load.

Low load – see OEM guidelines for defined values: This is an area of continuous operation that typically the engine is not designed for. At low load, there is less pressure on the piston ring pack and the temperature along sections of the liner is lower, often below the dew point of water, the presence of water from combustion and ambient air as well as the SO_3 formed during combustion enables sulphuric acid formation inside the combustion chamber. The lower the liner temperature, the more sulphuric acid can condense and corrode the piston ring and cylinder liner surfaces if it is not neutralized by the cylinder lubricant.

The majority of lubricant injection systems are designed to apply a fixed oil volume per injection; the volume has typically been optimized for operation at or near full load. Some new engine designs have variable volume cylinder oil injection equipment. At low load operation the engine operates for a number of revolutions between oil injections. The decreased sliding speeds and/or reduced pressure on the ring pack at low load make the system more sensitive to enter boundary lubrication. To ensure that there is enough oil for lubrication of the liner and piston rings as well as enough lubricant for neutralization of the sulphuric acid, the cylinder lubricant feed rate may need to be increased in low load conditions.

When an engine is used for a prolonged period in this low load area, this is often referred to as **slow steaming** or **economical speed** operation. It is possible to de-rate the engine and adjust the engine parameters to better cope with the adverse conditions.

- **Fuel sulphur content:**

Higher sulphur level in the fuel increases the potential for sulphuric acid formation. To cope with the increased presence of sulphuric acid, sufficient alkalinity has to be introduced to neutralize the acids before it can corrode critical engine parts. This alkalinity is defined by the base number (BN) of the cylinder lubricant as determined through the ASTM D2896 standard. Increasing alkalinity can be achieved by increasing the cylinder oil feed rate or selecting a higher base number lubricant.

Lower sulphur level in the fuel decreases the potential for sulphuric acid formation. It is however still important to match the fuel sulphur level with the lubricant alkalinity introduced. The calcium carbonate present in the cylinder oil may form hard abrasive deposits when there is not sufficient sulphuric acid present to react with. These hard deposits generally accumulate on the piston crown land and can disturb the oil film when they rub against the liner surface. In such cases the lubricant feed rate needs to be lowered or a lower base number lubricant needs to be selected.

- **Engine bore & stroke:**

Theoretically, the larger the bore and stroke, the bigger the surface area that needs lubrication. The longer the stroke of the engine, the more challenging it becomes to equally spread the oil film over the liner surface and bring sufficient lubricant into the areas which need most protection against wear and corrosion.

There is a mechanically needed minimum quantity of lubricant to ensure hydrodynamic lubrication and gas sealing between ring and liner surface. Modern lubricators account for that and in addition control the amount of cylinder oil in relation to the produced engine power.

- **Engine speed:**

To achieve a proper hydrodynamic oil film, adequate piston speed and pressure on the ring pack are essential to avoid areas of boundary lubrication. Boundary lubrication results in a metal to metal contact between the piston rings and liner and can initiate seizures and scuffing on piston rings and cylinder liners.

With a fixed propeller, low load operation is achieved by lowering the engine speed. This results in lower piston speeds. It is generally sufficient to cope with this operation by increasing the oil feed rate to strengthen the oil film.

With controllable pitch propellers (CPP), engines are often operated at high engine speeds and low power output. This results in little pressure on the ring pack and creates more difficult conditions for the formation of a hydrodynamic oil film. Consult OEM recommendations for specific information regarding the feed rate to be used with CPP’s.

- **Inlet Air Humidity:**

High inlet air humidity can increase cylinder liner and piston ring corrosion by introducing more water. Although increasing the lubricant feed rate can help it is more important to ensure that the charge air coolers are in good and clean condition and that there are no water leaks.

3.4.3 Running-in Operation

The main purpose of the running-in procedure in a two-stroke engine is to achieve the bedding-in of the piston rings on the liner surface as quickly as possible. A new liner with insufficiently bedded-in piston rings cannot endure full power. Therefore, the engine load can only be gradually increased during the running-in process to give the rings the opportunity to adapt to the increasing combustion pressure. The running-in process removes the high asperities on fresh metal surfaces to leave uniform contacting surfaces. This ensures the formation of a good gas seal between the piston rings and the liner. This prevents blow-by of hot combustion gases, which may destroy the oil film between rings and liner and thereby promote excessive wear.

The engine requires extra attention and extra lubrication during this process.

The purpose of the extra lubricating oil during the running-in period is to:

- Help flush away wear particles
- Quickly build-up a uniform oil film in a not yet run in cylinder

The engine designers have their specific recommendations for running-in that may vary from a single step in lubricant feed rate during a short period (e.g. 200 hours) to more than 10 steps during several thousands of operating hours; some general advice is provided below.

A typical running-in procedure starts with a very high lubricant feed rate which is reduced in several steps towards a feed rate that is recommended for normal operation (see the engine designer recommendations and Figure 14). It is always recommended to do frequent scavenge port inspections and drain oil analysis during the running-in period.

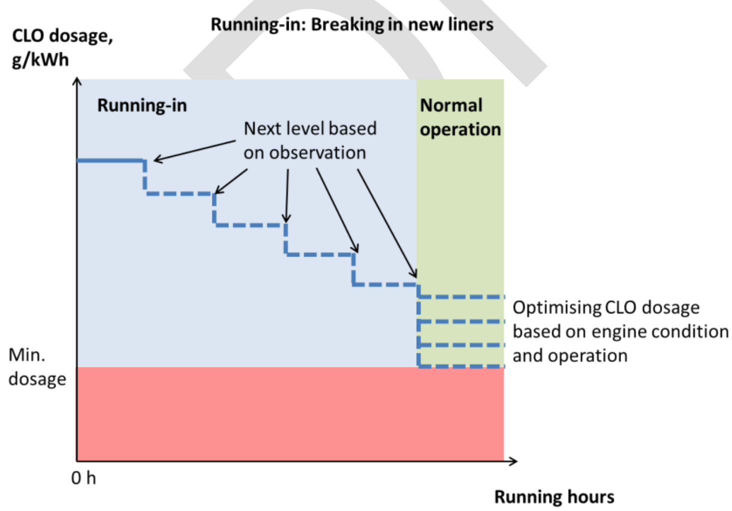


Figure 14: Illustration showing cylinder lube oil feed rate during running-in of new liners. Note that optimizing the feed rate may only be done based on advised decisions *e.g.* port inspections and drain oil analysis.

Normally, it is not recommended to lower the oil feed rate and proceed with the next step in the running-in procedure, before the cylinder condition is evaluated and found in good condition.

There are no special fuel recommendations for running-in operation.

All engine designers recommend the use of normal lubricant during running-in. However, the cylinder oil must be of the appropriate alkalinity (BN) for the fuel sulphur content in use during running-in.

Some piston rings have a running-in coating to reduce the running-in time by more smooth bedding-in compared to normal piston rings. Some piston rings are lapped after such coating procedure and consequently need only a short running-in time.

If, during the running-in process, irregularities in the cylinder condition are observed (e.g. micro seizures or corrosion on the rings, see Figure 15 and 16) it is normally recommended to increase the lubrication feed rate. In case scuffing (heavy metal-to-metal contact, adhesion), sticking piston rings or high liner temperature fluctuations are observed, it is normally recommended to increase the cylinder lubricant feed rate and lower the pressure in the actual cylinder(s) in which such phenomena are found. In all these cases, it is recommended to continue to follow the situation carefully by scavenge port inspections and return the lubrication feed rate and pressure to normal when the cylinder condition has returned to acceptable levels.

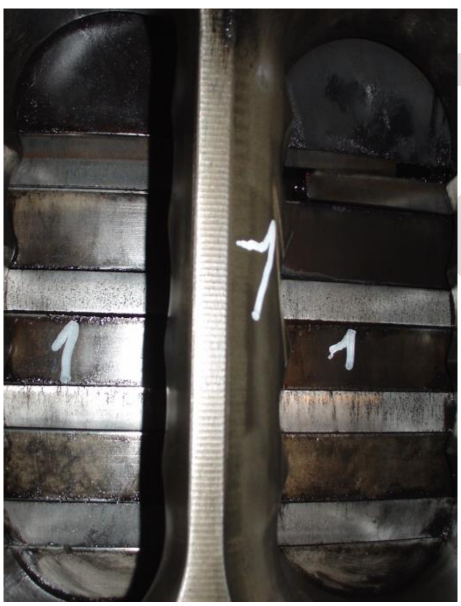


Figure 15: Piston ring microseizures

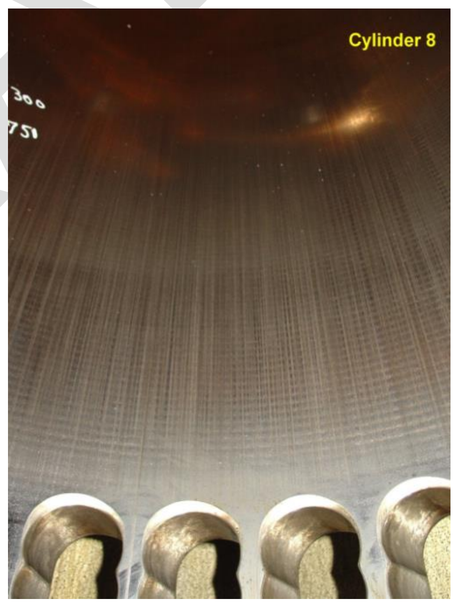


Figure 16: Cylinder liner scuffing

3.5 Performance Features of Cylinder Lubricants

The features of the cylinder lubricant that enable it to provide protection to the piston rings, cylinder liners and exhaust systems are detailed below. Information on the proper performance of the cylinder lubricant can be obtained via inspections through the scavenge air ports of the cylinder liner (see Appendix III).

3.5.1 Distribution on the Liner Surface

The ability of the cylinder lubricant to spread out over the whole swept area of the liner depends upon:

- viscosity at the temperature of the liner wall
- capability to wet the metal surface
- capability to adhere to the surface
- capability to form a stable film covering the swept surface
- piston ring profile

In order to fulfil these requirements, the cylinder lubricant must be formulated to balance its viscometric properties with the appropriate surface activity derived from the performance enhancing additives. Cylinder lubricants have traditionally been SAE 50 viscosity grade. This does not define quality, but determines oil viscometric characteristics, the most important being oil film thickness.

3.5.2 Wear Control

Once the cylinder oil has been distributed across the liner surface, it has to ensure that the running surfaces of both liner and piston rings are protected against wear processes. Sulphuric acid is produced in the combustion chamber when burning high sulphur fuels like the Heavy Fuel Oil (HFO) that is typically used. Therefore, the principal mechanism of wear is typically corrosive wear (see Section 2.3 – wear mechanisms). This is counteracted by the inclusion in the lubricant of neutralizing additives. Typically, highly overbased detergent additives are employed that include inorganic base, for example carbonates and hydroxides.

Given the pressures between piston rings and cylinder liners, the oil film also has to provide sufficient load carrying capacity to resist the adhesive wear arising from metal to metal contact. This feature may be enhanced, for example by ensuring a thick oil film even at the highest values of the liner wall temperature or by incorporating specially selected anti-wear additives.

In addition to corrosive and adhesive wear processes, particles, formed during engine operation (e.g. fragmented piston deposits) or introduced into the engine via incoming streams such as the fuel (e.g. refining catalyst fines), can give rise to abrasive wear. There is only a minimal role for the lubricant in this instance since the oil film thickness may be less than the nominal average size of the particles. Such particles may promote wear, depending upon their origin and composition. Particularly damaging particles are the catalyst fines, also known as “cat fines”, that can be found in heavy fuel oils; these particles should be removed by the fuel centrifuge and filters prior to use of the fuel. As damage from cat fines can be rapid and catastrophic it is very important that OEM requirements for the fuel at engine inlet are met.

3.5.3 Deposit Control

The continuing optimal operation of the two-stroke crosshead diesel engine depends substantially upon the correct behaviour of the piston rings. Given adequate protection from wear processes, the rings and piston grooves need to retain a sufficiently clean state at all times. This may be achieved by way of the anti-fouling performance of the cylinder oil. In turn this depends upon the detergency and dispersancy imparted to the oil and its ability to protect the metal surfaces from deposit forming precursors generated by fuel combustion and thermo-oxidative changes to the lubricant itself.

Detergency, dispersancy and protection against thermal degradation and oxidation are provided by the addition of various lubricant additives and can furthermore be influenced by the selection of the baseoils used.

Figure 17: Poor piston cleanliness caused by lubricant chemistry – broken, stuck & collapsed piston rings

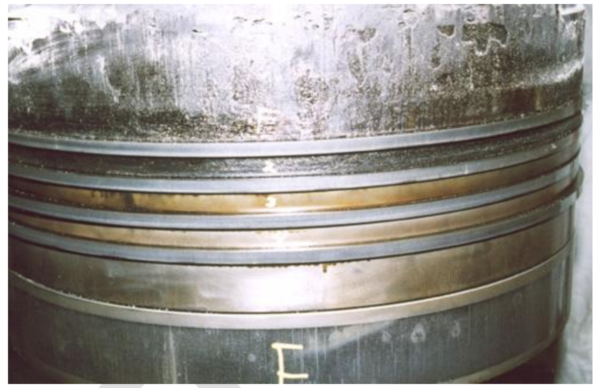


Figure 18: Good piston cleanliness obtained through the right lubricant chemistry

Excessive ring groove deposits can cause excessive pressure to be applied on the ring that can lead to high ring and liner wear and in some cases ring breakage (see Figure 19). Such deposit levels can also cause the ring to stick leading to blow-by of the combustion gasses. This blow-by can result in high liner wear and the resulting high temperature can cause the piston rings to lose their tension (and thus their ability to seal) and can also be the root cause for cylinder liner cracking.

Figure 19: Heavy deposits in the piston ring groove – seen after removal of the piston ring

Excessive top land deposits can disturb the oil film on the cylinder liner and can lead to excessive wear and scuffing (see Figure 20 and 21).

An excessive cylinder oil feed rate or a mismatch of the oil alkalinity with the fuel sulphur level can in some cases lead to excessive deposit formation both on the piston (see Figure 22) as well as, in isolated cases, areas outside of the combustion space; see also section 3.4 on cylinder lubricant feed rate.

Figure 20: Excessive top land deposits

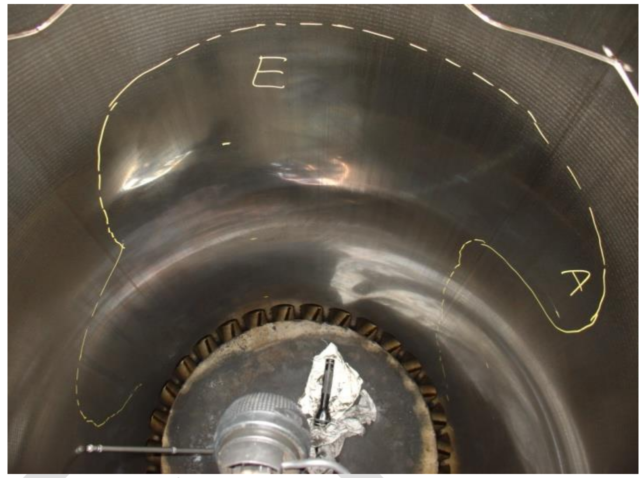


Figure 21: Bore polish of the cylinder liner by excessive top land deposits

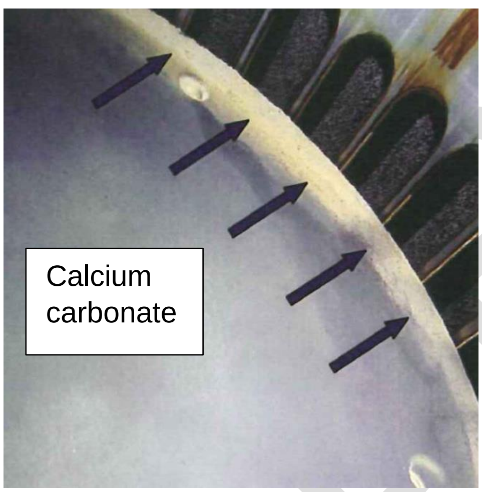


Figure 22: Calcium Carbonate on the top of the poston crown.

3.5.4 Lubricating Oil Influence on the Catalyst System for Emission Control

If Selective Catalytic Reduction (SCR) is used for NO_x emission control, fouling of the catalyst channels by Ammonium bisulphate (ABS) and alkaline metal species may occur. This may result in an increased pressure drop and an uneven flow distribution over the catalyst. Fouling may be minimised by choosing a catalyst with the appropriate catalyst geometry or by installing cleaning devices.

If oxidation catalysts are used (this is typical for Marine engines) to reduce hydrocarbons, ammonia and/or carbon monoxide emissions, chemical deactivation ("poisoning") of the catalyst is possible.

Some catalyst types, especially those containing precious metals, are quite sensitive to phosphorus. As some cylinder lubricants may contain phosphorus, this should be taken into account by seeking the advice of the catalyst manufacturer. It should be noted however that precious metal containing catalysts are typically also very sensitive to sulphur and therefore these oxidation catalysts are typically not applied for two-stroke engines operating on high sulphur fuels such as Heavy Fuel Oil (HFO).

Some OEMs recommend that the SCR be installed in front of the turbocharger to avoid $CaSO_4$ deposit build-up from burning high sulphur HFO.

New technologies for reducing emissions, such as Exhaust Gas Recirculation (EGR) may also introduce new considerations for cylinder oils in the future.

3.6 Selection Criteria for Cylinder Lubricants

Several key features of engine operation and installation need to be specified in order to determine the type of cylinder oil to be selected. The following factors have to be taken into account:

- Fuel in use
- Operational conditions
- Engine type & configuration
- Wear and economics of cylinder lubrication

3.6.1 Fuel in Use

At the time of publication of this document, the vast majority of two-stroke diesel engines operate on Heavy Fuel Oil (HFO) with a sulphur content of over 1.5 mass% for most of the time. For the typically short operation in Emission Control Areas (ECAs) and in ports (see section 1.2 and Appendix I) lower sulphur HFO (below 1 mass%) or distillate fuel, which can have a sulphur content as low as 10 ppm mass, is most often used.

Two-stroke diesel engines have also been designed in the recent past for dual fuel use, meaning both operation on gaseous and liquid fuel is possible.

A list of current specifications on fuels for large bore two-stroke crosshead diesel engines is:

- ISO 8217 standard[3]
- Legislative or statutory requirements
- Engine manufacturer’s requirements

The following general guidelines can be given regarding cylinder oil selection in relationship to the various fuels:

- **High sulphur Heavy Fuel Oil (>1.5 mass% sulphur):**

Of the cylinder oil requirements listed in section 3.1, it is most important that the alkalinity provided to the cylinder liner and piston rings is sufficient to neutralize the acids formed from the products of combustion. This can be achieved by an appropriate combination of lubricant feed rate and lubricant neutralization capability; the latter expressed by the base number “BN” of the lubricant (as measured by ASTM D2896). Typically, higher alkalinity cylinder lubricants are preferred for high sulphur HFO to keep lubricant feed rates relatively low. Please also see the below paragraph on “Cylinder Lubricant Approach” and section 3.6.3 below.

- **Low sulphur Heavy Fuel Oil (≤1.5 mass% sulphur):**

Under some operating conditions, and for some engine types, excess alkalinity in combination with a low sulphur fuel can lead to deposit formation on the piston crown land that can disrupt the oil film between the piston rings and the cylinder liner, hence increasing the risk of metal-to-metal contact, seizures and scuffing. As less alkalinity is needed due to the lower sulphur content of the fuel, typically lower alkalinity cylinder lubricants are used for this fuel. Please also see the below paragraph on “Cylinder Lubricant Approach”.

- **Distillate fuel**:

Distillate fuel can have a low sulphur content (<1.5 mass% sulphur) but more typically has a very low sulphur content (<0.1 mass% sulphur). At the time of publication of this document, there is very limited experience with prolonged operation of two-stroke engines on distillate fuel. Generically it is recommended to operate on a low BN cylinder oil and frequently evaluate the engine’s actual cylinder condition by means of visual inspections through the scavenge port as well as timely analysis of drain oil samples.

- **Gaseous fuel & dual fuel operation**:

At the time of publication of this document there are no two-stroke crosshead diesel engines for these types of fuel in service yet. The cylinder oil requirements for this fuel have not yet been sufficiently determined and the engine builder should be consulted for recommendations regarding cylinder oil choice. However, it is expected that operation on LNG (Liquified Natural Gas) will require low BN oils.

3.6.2 Cylinder Lubricant Approaches

There are basically two approaches among commercial cylinder lube oils available today:

1. The cylinder lube oils are optimized for the amount of alkalinity required in certain operation modes – in particular in relation to the fuel sulphur level:
   High BN oils must be used for high sulphur fuel, and low BN oils for low sulphur fuel.
   Thereby, the oil must be switched when the fuel is switched. This approach is generally recommended by the OEMs.
2. The cylinder lube oils are based on a “single-cylinder-lube-oil” approach. The cylinder lube oil is formulated to meet the demands of both high and low sulphur fuels, and thereby the crew does not need to switch lube oil when the fuel type is switched. This approach is also accepted by the OEMs in some cases.

In both cases, OEM requirements must be strictly adhered to and it is recommended to follow the cylinder condition for wear and deposit build-up by scavenge port inspections and drain oil analysis. OEM lubricant recommendations must be followed. For distillate fuel with sulphur less than 0.5 mass% special care must be taken to select an appropriate BN cylinder oil, especially if running-in feed rates are applied

A general overview of how to select a suitable cylinder lube oil can be found in Figure 23.

- **New low BN oils (<40 BN)** have recently been introduced to the market. They are specifically designed for operation on very low Sulphur fuel (<0.1 mass% Sulphur).
- **New high BN oils (>70 BN)** have recently been introduced to the market. They are specifically designed for highly corrosive conditions, and are for example found as 100 BN oils. See also Section 3.6.3 below.

3.6.3 Operational Conditions

Aside from fuel, the engine operation and operational circumstances also have a major impact on the conditions to which the cylinder lubricant is exposed (see section 3.4).

The following guidelines can be given regarding cylinder oil selection in relationship to the operational circumstances:

- **Running-in**: running in is normally done on a standard cylinder lubricant appropriate for the fuel sulphur but at a higher specific lubricating oil feed rate. Therefore, if running-in is required for a low sulphur fuel (<1.5 mass% S), a low BN cylinder oil must be selected.

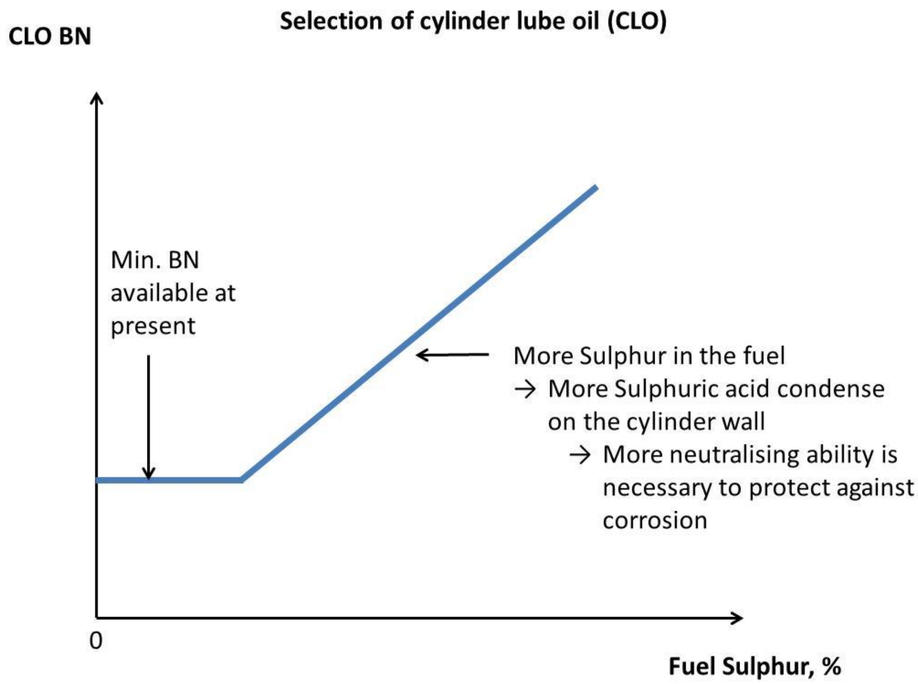


Figure 23: General recommendation for selection of cylinder lube oil depending on fuel sulphur content

- **Low load operation - refer to OEM guidelines for defined values, also known as "slow steaming" or "economical speed"):** low load operation may change the conditions in the engine such that more sulphuric acid can form and condense in the combustion space compared to higher engine loads. Therefore, it is recommended to use a high alkalinity (BN) cylinder oil in combination with an appropriate feed rate for low load operation. Frequent scavenge space inspections and scavenge drain oil analysis is recommended to ensure satisfactory engine operation with low corrosion and wear rates.

3.6.4 Engine Type and Configuration

Some engine types and engine configurations may be more susceptible to cold corrosion than others. Therefore, consult the OEM recommendations regarding cylinder oil selection for the applicable engine type and/or engine configuration. It should be stressed that nowadays there are many different configurations and operating patterns in use. As such, selection of the right cylinder lubricant at the right feedrate is a complex matter that is more and more specific to the specific engine, configuration and operation.

For many new engine types operating on higher sulphur residual fuel the engine manufacturers recommend the use of >70 BN oils, such as 100 BN cylinder lubricants. General experience has shown that an increased amount of cylinder lubricant or a cylinder lubricant with higher neutralising capacity (higher base number, BN) can protect against excessive corrosion. The wear rate is thereby stabilized to normal levels. Experience has shown that an insufficient amount of cylinder lubricant or the use of lubricants with less neutralising capacity (lower BN) cannot protect every engine against excessive corrosion and will result in increased wear rates.

3.6.5 Wear and Economics of Cylinder Lubrication

As discussed in detail in the above sections, engine design, fuel in use and operational parameters play an important role in the conditions under which the cylinder lubricant has to perform. It strongly depends on these circumstances what lubrication approach is most economical for the engine operator.

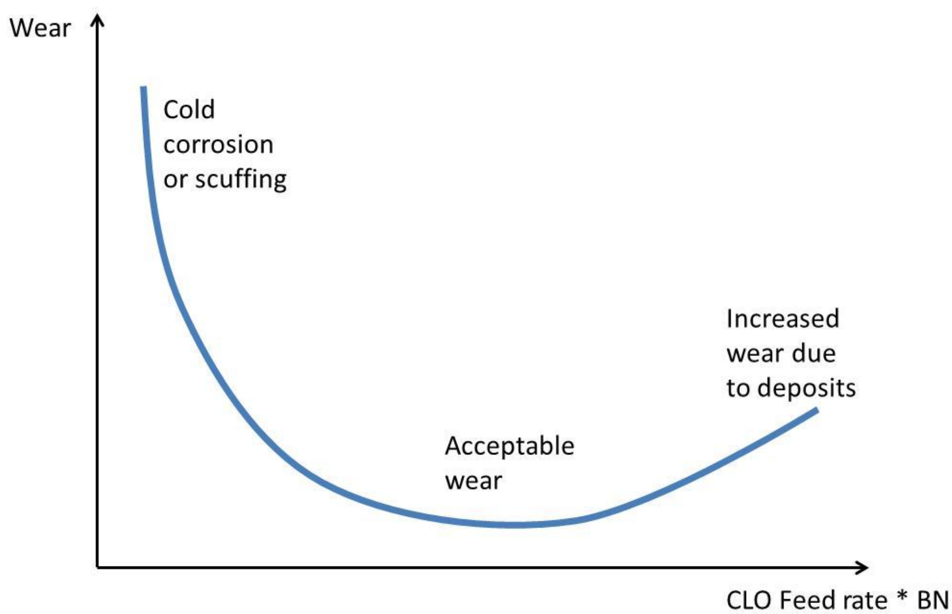


Figure 24: Generic correlation between wear and amount and type of cylinder oil (CLO)

Minimising operational costs is a balance between acceptable wear rates (see Figure 24) of cylinder liners and piston rings (and thus the time between overhauls) and the amount, type and cost of cylinder oil consumed; the latter being influenced by cylinder oil logistics (see Figure 24).

4 System Lubrication

4.1 Introduction to System Lubrication

The purpose of the system lubricant is to:

a. provide lubrication to the main bearings, crosshead pin bearings, crank pin bearings, gears or chain, camshaft, crosshead guide shoes, ancillary drives (e.g. power-take-off) and, if applicable, the turbocharger;
b. provide cooling to pistons (except for old designs with water cooled pistons);
c. function as a hydraulic fluid for valve actuation (exhaust valve and fuel injection systems), camshaft shifting and other control systems;
d. support the functioning of vibration damping systems
e. perform the above functions for extended periods of time.

For system lubrication a low alkaline lubricant (typically between 5 and 8 BN, though in some cases up to 12 BN may be allowed by the OEMs) of SAE 30 viscosity grade is normally recommended. A SAE 40 viscosity grade version may be recommended for land based engines. The system lubricant performs its several functions by means of a circulating supply and maintenance system, remains in service for extended periods of time and is formulated to meet a widely ranging load and other lubrication requirements.

Under normal operation, the system oil charge remains in the sump with regular fresh oil top-up to compensate for lubricant consumption and loss. A partial drain & replacement is sometimes needed to prevent the oil exceeding condemning limits (e.g. viscosity, BN). A complete drain & replacement of the system oil is typically only needed when encountering abnormal contamination by fuel oil or scavenge drain oil. Water leakage contamination can normally be removed by the lubricating oil purifier.

Cleaning the system lubricant is continuously done with a dedicated treatment system. It is very important that the lubricant treatment system is adequately designed and operated to prevent engine damage.

With a system oil consumption of 0.1 to 0.2 g/kWh and a system content of typically 0.5 to 1.5 kg/kW (dependent on the engine design) the time to replenish the entire volume in the crankcase system, via top-up with fresh oil and engine consumption of the system lubricant, is approximately 7500 hours.

To obtain the maximum life of the system lubricant it is necessary to achieve a balance between replenishment and cleaning. Failure to achieve the correct balance could result in the lubricant becoming unfit for further service and necessitate a partial or complete system oil change.

Achieving the most efficient balance is dependent upon the capacity and operation of the lubricant maintenance system (e.g. centrifuges and heaters, filters, used oil analysis, equipment maintenance, tank system etc); this is further detailed in sections 4.3 and 4.4.

In addition, knowledge of the key performance characteristics of the fresh oil and the oil in service is required. Details listed on the Technical Data Sheet for a fresh system oil should inform the user on what the user has ordered and can confirm the product is meeting the engine manufacturer's specifications; it will however not give complete information on the performance to be expected in an individual engine under individual conditions.

Systems which use the system oil and add cylinder oil additives in a dedicated on board blending facility (“Blending on Board”) to make variable BN cylinder oil dependent on engine operating conditions are available on the market (see section 3.3).

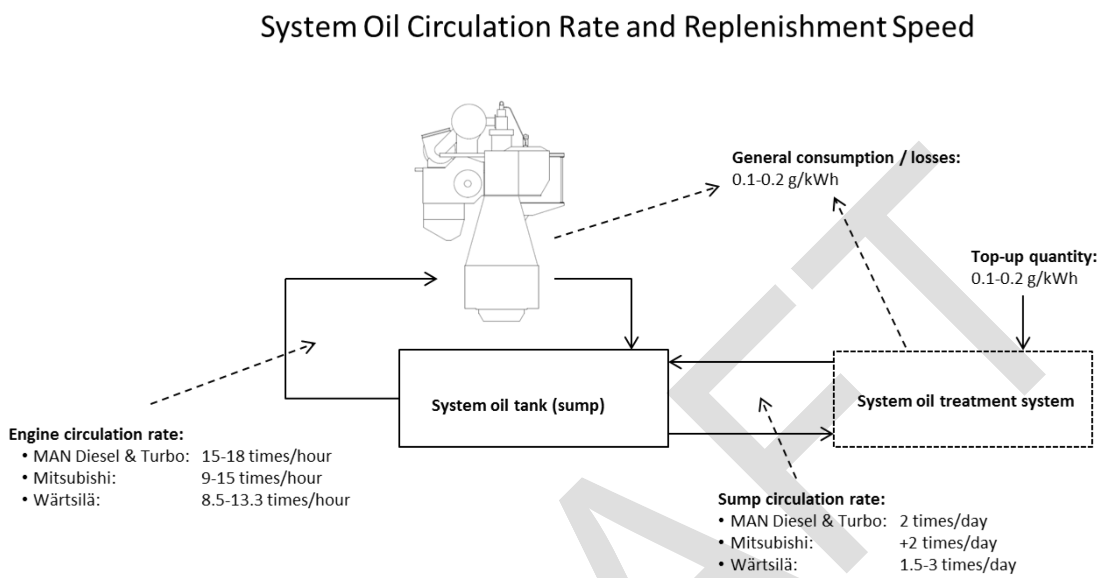


Figure 25: System oil circulation rate and oil consumption

4.2 System Lubricant Requirements

The system lubricant serves the purpose described in Chapter 4.1 by meeting the following requirements.

4.2.1 Adequate Lubrication of Bearings, Crosshead Shoe & Drive Gear/Chain

The engine's system lubrication equipment supplies oil to the engine bearings, crosshead shoe, gear/chain drive, moreover, all parts within the crankcase needing lubrication. For the vast majority of two-stroke crosshead engines today, piston cooling oil and camshaft lubricant are supplied from the same system.

For this application in the crosshead assembly, the lubricant must ensure good sliding characteristics for which lubrication properties, such as acceptable viscosity, spreadability and reliable adhesion to metal surfaces are important.

When the oil enters the engine and operates in the engine journals and bearings, there must be an oil film of suitable thickness. To achieve this, the viscosity grade is defined by the engine designer, taking into account the engine characteristics and temperature conditions.

4.2.2 Sufficient Piston Cooling

The oil enters the piston rod to reach the piston undercrown space where it is used as a coolant medium. For that purpose, the oil must show good resistance against degradation in the presence of air and high temperatures. Oxidation stability is more important here than in the crankcase application mentioned above. Other important properties required in this application are thermal stability, high temperature detergency, dispersancy, water separation efficiency and anti-foaming.

4.2.3 Adequate Lubrication of Various Components

a) The Camshaft: Some engine designs have a dedicated lubrication system and some use the lubricant taken from the crankcase system. Wherever the lubricant film is insufficient or temporarily interrupted, the metallic surfaces have to be protected by anti-wear (AW) and extreme pressure (EP) properties of the lubricant. Although such properties are advantageous for camshaft lubrication, they are also critical in engine and Power Take Off/Power Take In (PTO/PTI) gear systems where high specific load carrying capability is essential. Therefore, system oil that is properly designed for PTO/PTI systems will readily meet the AW & EP requirements for the camshaft.

b) Engine gear train and PTO/PTI (Power Take Off/Power Take In) systems: For lubrication of the engine gear train and PTO/PTI drive gears there may be a minimum "load carrying" requirement as measured by an AW and EP gear test (Performance in the “FZG test”, see section 4.5.13). Note: The system oil application here should not be confused with the hydraulic oil lubrication for the constant speed gear drives for PTOs which may require a separate lubricant with a higher FZG and specific hydraulic oil performance.

c) Exhaust Valve, fuel system control and cylinder lubrication pumps: Some engines use the system oil for these hydraulic functions. In the function of a hydraulic oil, the foaming, air release, load carrying, and water tolerance properties are relevant.

d) Turbocharger Bearing Lubrication (applies to some engine designs): Lubricant requirements for this case are: lubricity, oxidation stability, thermal stability and anti-foaming. Some engine designs have turbochargers with a separate dedicated oil charge that need a special lubricant.

Other parts of the engine that have separate dedicated lubricant systems that utilize special lubricants are:

1. The Turning Gear: It has its own separate oil system and is typically filled with an ISO VG 220 industrial transmission lubricant and uses a dry lubricant on the open gear drive.
2. The Hydraulic Governor: A lubricant of suitable viscosity at the typical operating temperature would normally be specified by the equipment manufacturer. The lubricant needs to have rust and oxidation inhibition and good anti-foam and air release properties. Depending on the equipment manufacturer, a suitable lubricant (e.g. turbine oil, hydraulic oil) of an appropriate viscosity is normally acceptable, but sometimes system oil may be approved if its viscosity falls within the application requirement.

4.2.4 Adequately Function as a Hydraulic or Dampening Fluid

The system oil is sometimes also used as hydraulic fluid for operating the cylinder oil pump and in some cases the fuel injection control systems; it can also be used in hydraulic dampers. In order to operate effectively as a hydraulic fluid, the system oil should have a high viscosity index to maintain the viscosity over a wide temperature range, good anti wear and anti-oxidation properties and must be clean. Normally NAS or ISO particle count standards are applied to ensure that the oil is clean enough for these applications.

4.3 Design of the System Lubrication System

The efficiency of the lubricating oil system is crucial for the performance and safe operation of the engine. Much attention therefore, has to be paid to its design and construction.

4.3.1 Overall System Layout

This system consists of two major parts -the lube oil service system and the treatment system. They are shown in Figure 26. The lube oil service system is supplying the system oil to the engine in the correct temperature range, while the treatment system is cleaning the lube oil continuously in the sump.

The crosshead stuffing box drain system is also of importance for system lubrication and is described further below. The system oil line is equipped with a pump, a cooler and filters to provide a constant and uninterrupted flow of cooled and filtered lubricant to the bearings, cams, oil cooled pistons etc. as well as to the drive of the exhaust valve and fuel injection hydraulic system if fitted. An additional safety filter may be fitted before the crosshead system.

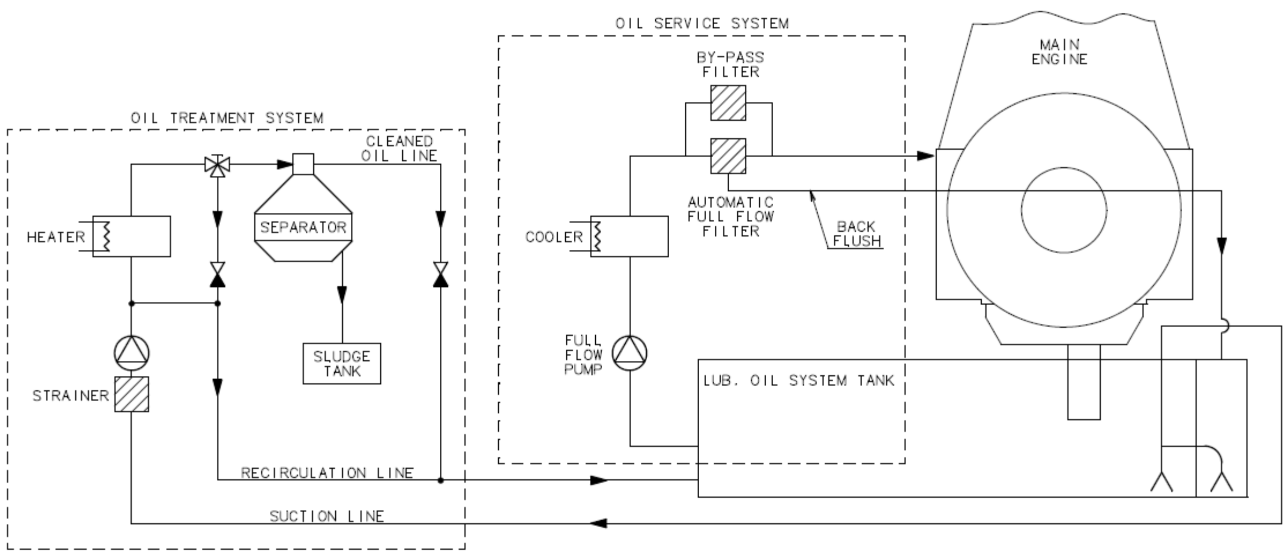


Figure 26: Typical layout of the lubricating oil service system and treatment system

A purifier with a lubricating oil heater are fitted to help clean the system oil in the engine oil tank. The treatment system can also be used to clean system oil in the storage, settling and renovating tanks. The purifier can also be used to fill the engine with new oil, thus removing particle contamination that typically occurs.

A stuffing box is fitted to separate the crankcase from the underside of the cylinder to prevent contamination of the crankcase oil system by used cylinder oil. Consequences of this contamination can be seen in Table 2 below. More detail is provided in section 4.5.6.

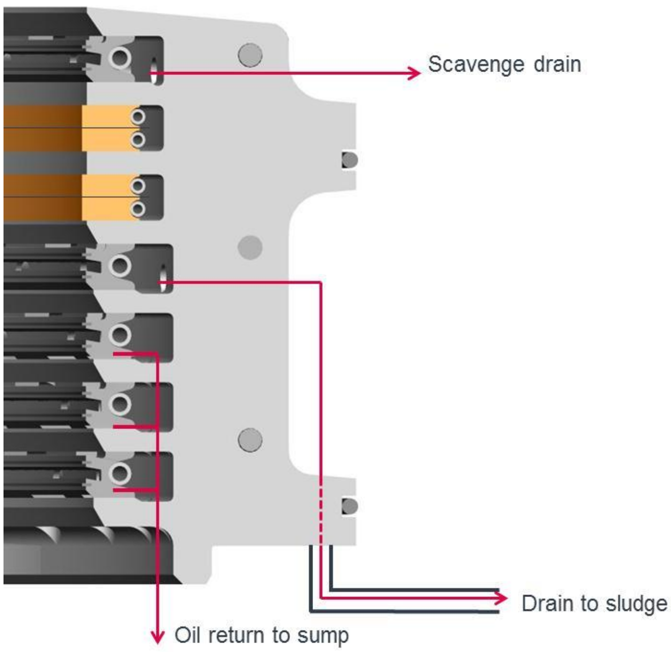


Figure 27: The stuffing box drain arrangement

It should be noted that scavenge drain oil and stuffing box drain oil should never be added to the system oil charge as make-up oil.

4.3.2 The System Lubricant Treatment System

In crosshead engines, a piston rod stuffing box separates the combustion chamber and the scavenge air space from the crankcase. The cylinder is lubricated by a high BN (normally SAE 50 viscosity grade) cylinder lubricant and the crankcase is lubricated by a low BN (typically SAE 30 viscosity grade) system oil, which is also used to cool the piston – except for some older designs which use water for pison cooling. The sytem oil is treated and re-used, whereas the cylinder lubricating oil is a once-through product.

A mixture of used cylinder oil, wear debris and a small extent of partly unburnt fuel accumulate in the scavenge air space under the liner and above the stuffing box.

For safe and satisfactory engine performance, contamination of the system oil has to be kept to a minimum. Careful attention is necessary to prevent combustion products, unburned fuel, used cylinder oil and scavenging air impurities to contaminate the system oil. Additionally, the system oil used for piston cooling can be subjected to oxidation on the hot piston undercrown, giving rise to further degradation of the system oil.

Table 2 lists the types of contaminants, their possible origin and their likely influence.

Table 2: Source and consequences of contamination of system oil

Contaminants in the system oil	Sources of the contaminants	Origin of contaminants	Consequences in the engine
Combustion products	Combustion	Combustion chamber → Stuffing box	• Deposit formation • Black colouration • Increase in viscosity • Increase in insolubles
Soot	Poor combustion of the fuel		
Oxidated and deteriorated cylinder oil	Used cylinder oil		• Increase in viscosity and BN • Increase in lacquer and sludge • Corrosion if acidic compounds are not taken care of
Calcium salts (Calcium Sulphate and Calcium Carbonate)	• Cylinder oil • Products from reaction between cylinder oil and sulphuric acid		• Deposit formation • Wear
Fuel	• Incomplete combustion • Blow-by gas • Poor fuel atomisation		• Dilution with - Diesel: Decreased viscosity - Heavy fuel oil: Increased viscosity • Oil mist generation • Low oil stability • Deposit
	Leaking seals	Leak from fuel pump	
• Dust • Sand • Atmospheric contamination	Fuel	See above	
	Scavenge air	Insufficiently working air filter	• Wear • Filter plugging
• Water • Salt • Scales		• Leak from cooling system • Blow-by moisture condensate • Incorrect operation of the system oil purifier	• Corrosion • Oil emulsification • Deposits • Scales • Microbial growth • Impact on cleaning systems
Metallic debris	• Engine parts wear	Engine parts	• Wear • Deposit formation • Filter plugging
	• Corrosion	The engine and cleaning system	
	• Scales	Lack of cleaning after welding etc.	

Particles	New system oil	Topping up new system oil	• Wear

The removal of particles and sludge from the oil can be done by centrifugal separators and is backed up by filters.

The centrifugal separators separate the particulate matter from the system lubricant using the density difference between particles and oil. The separator has a large sludge handling capability and can remove particles down to a few microns. The separator can also remove large volumes of water from the oil.

The filter separates the particles from the oil by retaining particles on the filter mesh. Filters are, however, limited in their sludge and water removal capability.

Whilst the filters for engine protection are installed as full flow filters, the cleaning by the separator is done in a by-pass circuit where only a small quantity of the oil is treated at a time. If the system oil is used as a hydraulic fluid, fine filters (below 10 micron) are applied in a by-pass system. A by-pass system is optimized to remove as much as possible of the contaminants per time unit rather than per pass over the separator.

Efficient cleaning of the oil with separators is critical to support the function of the full flow filter in the protection system. For more detailed design information see Appendix IV on System Oil System Design.

4.4 Operation of the System Lubricant System

4.4.1 System Lubricant Storage and Handling

Because correct lubrication is vital to the operation of diesel engines, lubricants must be given the same meticulous care as is common practice for engine spare parts. It cannot be over-emphasised that even high quality lubricants can cause difficulties in service, when stored or handled inadequately.

Contamination with other lubricants aboard a vessel must be avoided. It is essential that freshly bunkered lubricants are taken into the correct tank and kept clean and that no sea water enters the tanks. If there is any doubt, the fresh oil should be subjected to a quick analysis to verify that it is clean and uncontaminated.

When an engine is switched to another lubricant brand it is recommended not to mix the different oil into the storage tanks. If only one storage tank is available, the mix should be kept at a minimum. However, for the oil in use it is usually undesirable to replace an oil bath considering the oil is usually still in good shape. The majority of system oils available from the major lubricant companies are compatible and mixable. Issues with mixing of different brands are generally not compatibility related, but usually related to the difference in performance level of the different brands (e.g. cleaning-up effect of crankcase walls, causing filter blocking). In case of doubt it is recommended to contact your oil supplier and/or submit samples for compatibility testing.

A storage tank, before being filled for the first time, should always be inspected to ensure that it is clean and free from rust, dirt, and other contaminants. The filling pipe, the venting pipe and the breather should also be inspected. When already in service, the filling pipe should be drained to ensure that it is free from other liquids.

As it cannot always be guaranteed that the new oil is free from particles when taken on board, a once-through fine filtration is highly recommended. Preferably, this is done before the oil gets to the oil storage tank.

After filling the storage tank, deck filling connector caps and valves are to be closed.

Where only a small quantity of a particular grade is stocked in drums, these should be held in a protected storage and in a horizontal position.

If for any reason it is necessary to add oil to the system in service, this should be done via the lube oil purifier or filter. New system oils often have a higher particle count than the system oil in service in engines which are operated correctly. This is particularly true for engines fitted with fine mesh size filters for the hydraulic operation of fuel and oil injection systems and for exhaust valve operation. Accordingly, it is important to ensure that new system oil entering the engine system is clean and passed through the purifier and filter before entering the system oil sump.

4.4.2 Particle size and count

Particle size analysis can provide a useful insight into wear in an engine. Abrasive particles in the oil can cause wear, thus the requirements should be closely followed. OEMs define whether particle size limits apply to their engines and for which parts of the engine they are relevant. For electronically controlled engines, the engine manufacturers will typically have a higher cleanliness requirement than for mechanically controlled engines due to the use of system oil as a hydraulic fluid.

Table 3: ISO 4406 particle count and size classes

Number of particles per 100 ml		
More than	**Up to and including**	**Class**
250,000,000	—	>28
130,000,000	250,000,000	28
64,000,000	130,000,000	27
32,000,000	64,000,000	26
16,000,000	32,000,000	25
8,000,000	16,000,000	24
4,000,000	8,000,000	23
2,000,000	4,000,000	22
1,000,000	2,000,000	21
500,000	1,000,000	20
250,000	500,000	19
130,000	250,000	18
64,000	130,000	17
32,000	64,000	16
16,000	32,000	15

8000	16,000	14
4000	8000	13
2000	4000	12
1000	2000	11
500	1000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5
8	16	4
4	8	3
2	4	2
1	2	1
0	1	0

The ISO 4406 particle count system operates with 3 size classes based on a 100 ml oil sample, which are:

- R4 = Number of particles equal to or larger than 4 µm
- R6 = Number of particles equal to or larger than 6 µm
- R14 = Number of particles equal to or larger than 14 µm

If it is found that the particle count is exceeded, the coarse and fine filters must be checked to ensure that all the filter elements, gaskets and seals are intact and not damaged. If high particle counts persist and the filters are in order, then there is probably an area of excessive wear in the engine generating an excessive number of particles. Excessive numbers of particles can also enter the system oil if the piston rod gland boxes are not sealing correctly and used cylinder oil is getting into the system oil. The purifier also removes particles, and care must be taken to ensure that it is operated at the correct temperature according to the manufacturers recommendations and that the throughput is adjusted to suit optimum operation.

4.4.3 Recommendations for Normal Operation

The lubricant separator should be in continuous operation when the engine is running in order to remove the contaminants as they occur. In addition, when the engine is shut down, separator operation should if possible be continued in order to further reduce the level of contaminants.

The cleaning efficiency of the separator mainly depends on:

- the interface position between oil and water in the separator;
- the throughput;
- the separation temperature;
- the "agitation" of the oil (extensive mechanical agitation, pumping and throttling in valves, etc., can cause emulsion and dispersion of fine particles);

- the lubricating oil properties.

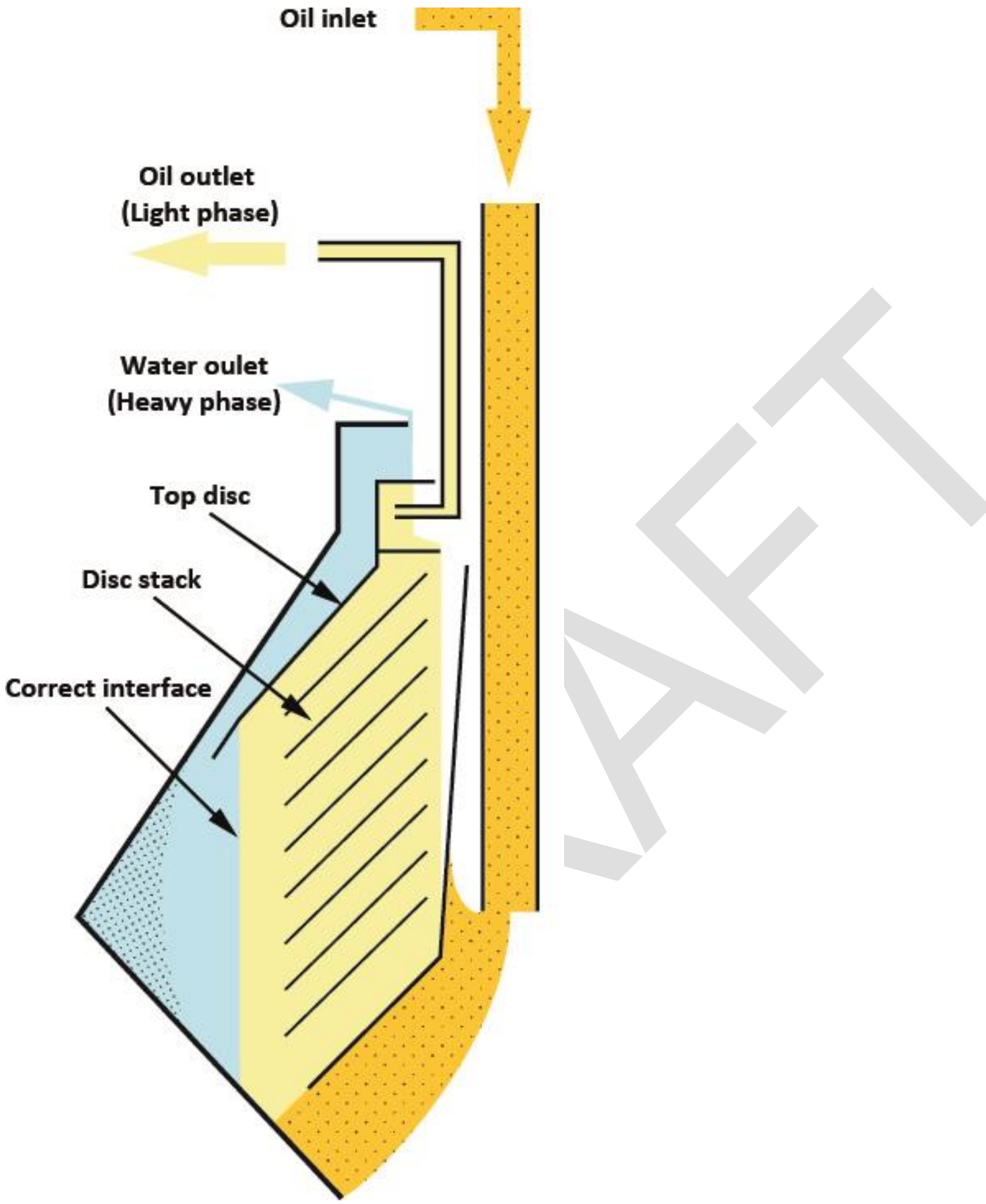


Figure 28: Correct Oil/Water interface position in a purifier

The correct interface position between oil and water should be outside the disc stack but inside the top disc (see Figure 28). If the interface is allowed to go into the disc stack the separation efficiency will decrease. Traditional separators (purifiers) are equipped with a gravity disc, in order to maintain the hydraulic balance between oil and water. The gravity disc sets the position of the interface.

During the operation the interface is inevitably affected by variations in flow and temperature. Therefore, it is of the utmost importance to ensure that these parameters are kept as stable as possible. The most

commonly used type of separators today, however automatically adjusts the interface without the need of any gravity disc, thereby relieving the crew to select the correct one.
With help of a sensor, the separator controller will open and close the water outlet valve and position the interface correctly.
In the case both the engine and separator have been stopped, it is recommended that, before the engine is restarted, the separator is run for sufficient time to ensure that the temperature of the oil in the drain tank is as required for correct engine start. A minimum of one pass of the volume of the drain tank should be passed through the separator.

Purifier Throughput

Throughput has a significant impact on the purifier efficiency; a lower throughput leads to better separation. Throughput can also affect the temperature, depending on heater capacity in the system as designed, and as explained below that is another major factor in purifier efficiency. A very low throughput leads to better separation, but only a small portion of the sump will be cleaned per day. Therefore there is an optimum range for the throughput. OEM guidelines should be consulted and we also refer to CIMAC Recommendation 24: Treatment of the system oil in medium speed and crosshead diesel engine installations. [4]

Separation Temperature

Separation as applied in a system oil separator is an accelerated form of sedimentation. The sedimentation theory is therefore outlined below to explain the importance of separation temperature.

Generally, the sedimentation rate is dependent on physical parameters: density, viscosity and particle size according to the following formula as derived from Stoke's Law:

$$\mathrm{Vg} = \frac{d^2(\rho p - \rho e)\mathrm{g}}{18n}$$

Vg = Sedimentation rate (m/s)

ρe = Density of continuous phase (kg/m^3)

d = Particle diameter (m)

g = Gravitational acceleration (9.81 m/s^2 - for sedimentation)

ρp = Particle density (kg/m^3)

n = Viscosity of the continuous phase (kg/m·s)

Both density and viscosity of the lube oil decrease when the temperature rises, thereby increasing the sedimentation rate and the efficiency with which particles are separated. The effect of temperature on oil viscosity (VI = Viscosity Index) is of special importance.

The higher the separation temperature, the better the separation. A temperature reduction from 85 °C to 70 °C will result in a 40% reduction in separation efficiency. Normally a 90 °C oil inlet temperature for a SAE 30 viscosity grade oil and 95 °C oil inlet temperature for a SAE 40 viscosity grade oil gives satisfactory separation.

System Oil Top Up

For topping-up of the system oil no more than 10% and preferably less than 5% of the total content should be added at a time if possible. This is recommended to keep an equilibrium and thereby avoid potential risks of sludge precipitation and to prevent difficulties in interpreting used oil analytical data when samples are taken. Larger topping up amounts could also affect the balance of the used oil characteristics.

Feed Pump Arrangements

All flow regulation by throttling of valves should be avoided as this can cause an emulsion to form whenever water is present. There is also a risk that sludge agglomerates are broken up and finely dispersed which reduces the cleaning efficiency.

Oil Pre-heater

The heater must always be started after the oil feed pump is operated and stopped before the oil feed pump is switched off in order to prevent blockages caused by oil coking.

4.4.4 Recommendations for Intermittent Operation

It has been noticed that during engine shut-down, intrusion of contaminants, mainly condensation or leaking water, into the lubricating oil system may occur. As a consequence, it is the recommendation of separator manufacturers to circulate the total oil volume through the separator before the engine is started.

In general, crosshead engines require a minimum separator turnover rate of 2 to 3 times in 24 hours. Thus, separation should take place for a period of 8-12 hours before the engine is started.

Accordingly, there is no reason to stop separation during engine shut-down periods which are shorter than the turnover time of the separator, normally 8 hours.

Maintaining separation for some time after the engine has been shut down facilitates removal of water condensate and of particles which have not yet settled to the bottom of the tank. This in consequence improves the cleanliness of the lubricating oil.

4.4.5 Cleaning Contaminated System Lubricant Using the Renovating Oil Tank

For treatment of an excessively contaminated system lubricant, the complete system oil should be pumped to the renovating tank, heated and allowed to settle for as long as possible. The main engine crankcase and oil tank can then be cleaned, if necessary.

If contamination is excessive, the oil should be circulated via the separator and regularly analyzed during treatment to ensure the oil is within the engine manufacturer's used oil limits, before returning it to the engine system.

After settling, the oil should be returned to the main engine oil tank via the separators, set at the lowest possible feed rate.

4.4.6 Recommendations for New / Repaired Installations or Complete Oil Change

When an engine, the systems or the connecting pipe system have been installed or opened for repair or an overhaul, particulate contamination will occur. It is essential for the engine's operating safety and performance that such particles are removed.

To prevent external contamination, all openings in the lubricant system should be blanked off during installation, maintenance, repairs, and modifications to the engine, the piping and/or parts of the lubrication system.

If a complete oil change is necessary, the sump and all tanks must be cleaned manually and inspected before refilling them with the new charge. In such cases it is also important to circulate and purify the new oil before the engine is started up. Alternatively, a small quantity of the new oil can be circulated for flushing and consequently drained.

Flushing the System

The following recommendations are given for flushing:

- Develop a flushing diagram and procedure.
- All flushing is to be executed in one direction only.
- Close attention must be given to flushing of pipe ends.
- All tanks must be inspected before filling them with oil.
- Oils must be added into the system through a filter and/or a purifier.
- The oil flow must be turbulent (Reynolds Number above 3000).
- Oil temperature should ideally be 65 °C but no less than 55 °C.
- Pipe vibrators or shock facilities must be fitted.
- A flushing filter, with a mesh finer than the original system filter must be fitted during the flushing process.
- The purifier is to be in service.

The flushing has to be continued until the pre-determined cleanliness level of the system and the lubricant is achieved. The engine manufacturers recommendations must be followed and ideally check-back of the filters and a particle count of the fluch oil should be employed. When the cleanliness of the pipes is acceptable, the lubricating oil system should be converted back to the original status. This must include the cleaning of main filters and pipes between filters and engine inlet.

Running-in filters are occasionally deployed and they can be fitted early and be in use when commencing the flushing phase.

It is essential that all pumps and the lube oil maintenance system are started and kept running as long as possible before starting the engine. This helps to remove a maximum of particles still inside the engine before it is started for the first time.

Normal practice is to use the service lube oil as the flushing medium. However, a thin flushing oil, typically SAE 20, compatible with the system oil can also be used.

4.4.7 Recommendations for Running-in Operations

It is well known that many contaminants are released during the running-in period of piston rings and cylinder liners. It is therefore an advantage to remove the contaminants as soon as possible by keeping the flushing filter in the system during the running-in period.

4.5 Performance Features of System Lubricants

The lubricating oils used must be designed to meet all the requirements necessary as specified by the engine designers/builders (see section 4.2).

In particular lubricating oil properties required for satisfactory lubrication of the various components within the crankcase are:

4.5.1 Dispersancy

The dispersancy defines the ability of the oil to maintain in suspension all contaminants, e.g. used cylinder oil draining, passing through the stuffing box. All the impurities must be transported by the oil to the purifier and filters (if installed), where most are removed. The dispersancy is also very important when the oil returns to the oil tank. It helps prevent the settling out of impurities which could lead to sludge in the bottom of the tank.

4.5.2 Corrosion Protection

This property is necessary to protect surfaces of bearings and other sensitive engine components from corrosion, especially in the presence of water contamination and acidic combustion products.

4.5.3 Water Tolerance

The oil must be water tolerant, while still providing basic lubrication even when contaminated with some water. Persistent and prolonged water contamination is conducive to microbiological attack which can lead to filter blockage and corrosion of engine parts.

4.5.4 Filterability

Filterability must be especially safeguarded in the event of water contamination. The lubricant should also be tolerant to used cylinder oil drain contaminants and have adequate dispersancy to transport solid contaminants to the centrifuge and fine filters (if fitted) for removal. Good maintenance, good "house-keeping" and a well planned system design also help to keep stagnant areas in the oil circuit to a minimum and free from deposits. In adverse conditions, (e.g. in rough seas), deposits can get agitated and "overload" the filters. Section 4.4.3 also recommends a planned oil top-up practice to avoid destabilising the system oil charge leading to sludge precipitation and filter blockage.

4.5.5 Anti-Foaming/Air Entrainment

The oil is circulated through the engine, at approximately 12 to 15 times per hour. During this circulation, air and oil are mixed intensively. Thus, the oil must be able to control foaming and air entrainment because both can lead to adverse lubrication conditions. Anti-foaming characteristics need to be carefully balanced with the air release properties.

4.5.6 Handling Cylinder Scavenge Drain Oil Contamination

Contamination from used piston underside cylinder oil is possible via the stuffing box. Compatibility of the system oil with used cylinder oil is important to avoid deposits settling out and to maintain all entrained solid contaminants in suspension for removal in the purifier and fine filter (if fitted). Cylinder oil contamination can also impair the water tolerance/demulsifying properties of the system oil. Contamination should be reduced to a minimum by design and maintenance efforts. Some operators require that both the cylinder oil and system oil are from the same lubricant manufacturer to ensure compatibility.

4.5.7 Compatibility with Tank Coating Paint

Consideration needs to be given to "lubricant tank coating" compatibility to avoid adverse chemical reaction with the paint surface. The latter can result in removal of the paint from the tank surfaces and the debris blocking the oil ways and causing oil starvation of the lubricated areas. Only paints compatible with mineral oil based lubricants should be used.

4.5.8 Viscosity and Viscosity Index

To ensure optimal hydrodynamic lubrication, it is essential to have a stable and sufficiently viscous lubricant in the bearing. Viscosity Index (VI) is an indicator of oil viscosity change with temperature and is therefore an important parameter. However in practice, specified minimum viscosity at 100 °C and maximum viscosity at 40 °C seem more appropriate. Note that in practice the viscosity is often also affected by contamination -hence the engine needs to be designed with acceptable viscosity tolerance.

4.5.9 Thermal Stability

The oil is exposed to high temperatures during its passage through the engine, especially when cooling the piston undercrown which may be at a temperature of typically up to 230 °C. Adequate thermal stability is thus essential to control piston cooling bore deposit formation. If excessive deposits form in the bores, the piston cooling is impaired and this can result in piston overheating and consequently cylinder lubrication failure. This could lead to excessive deposit accumulation on piston crowns, the back of piston rings and in the piston ring grooves.

4.5.10 Detergency

In engines with oil cooled pistons, the oil has to keep the piston undercrown clean from oxidized and thermally degraded products as well as contaminants (e.g. used cylinder oil drainings through the stuffing box). This property of the lubricant is called high temperature detergency.

The same oil is circulated to the crankcase where it is acting as a cleaning agent to remove deposits from crankcase walls and from engine components in motion such as the piston rod, crankshaft, counterweights, etc. This cleaning effect is called the low temperature detergency.

As the working area of the oil system is separated from the combustion area (i.e. the piston and liner), the detergency property of the system oil is less stressed than that of a cylinder lubricant or medium speed engine lubricant.

4.5.11 Alkalinity

This property indicates enhanced anti-oxidant and anti-rust characteristics of the system oil compared to a premium mineral oil. It is not provided in the context of prevention of corrosive wear, as is the case of cylinder oils. The alkalinity is defined by the base number (BN) according to ASTM D2896.

4.5.12 Oxidation Stability

Good oxidation stability is required as the lubricant is in contact with air at high temperature within the engine, for example in the piston cooling bores.

4.5.13 Extreme Pressure and Anti-Wear Performance

This is specified by the engine manufacturer in terms of the FZG minimum 'failure load stage' (FLS) (CEC- L-94 A.3/90) requirement, which is typically minimum FZG FLS 10 or 11 for fresh oil. The engine designer must be consulted for the exact requirement. This is required because the system oil is typically used to lubricate cams, followers and the gear drive train as well as power-take-off and power-take-in systems and fuel injection pump systems. This is an important performance aspect of system oils and is becoming more critical as fuel injection pressures rise to meet emission and fuel consumption requirements. This in turn places a higher load on camshafts and followers, and consequently on the gears driving these systems.

Another important aspect of FZG performance is the retention of performance level of used oil in service. If the anti-wear and anti-scuffing performance falls off rapidly in service, components may be damaged even if they were well protected while the system oil was new.

There is also a risk that when new gears, camshafts and followers are fitted to old engines, damage may occur due to the inadequate anti-wear and anti-scuffing performance of the old system oil. In such cases a major part, at least 50%, of the system oil may have to be replaced to provide adequate protection.

Table 4 summarizes engine requirements using the terminology developed.

Table 4: Required lubricant properties for system lubrication

Engine Component		**Stress / Risk**	**Required Lubricant Properties**
Component	**Detail**	**Problems**	
Bearing	Surface	• Wear: Corrosive & abrasive • Deposits	• Corrosion inhibitor, oil viscosity • Oxidation inhibitors
Crankcase	Surface	• Deposits	• Dispersant / Detergents
Piston undercrown	Surface	• Deposits	• Dispersant / Detergents • Thermal stability • Oxidation inhibitors
Maintenance system	• Centrifuge, filter • Oil coolers • Heaters	• Fluid and solid contaminants • Deposits • Deposits	• Low dispersancy, Water tolerance • High dispersancy • Compatibility with fuel
Camshafts / Gears	Surface	• Wear: Corrosive, abrasive & adhesive	• Corrosion inhibitor, anti-wear / EP additives, oil viscosity
Crosshead	Surface	• Wear: Corrosive, abrasive	• Corrosion inhibitor • Oil viscosity • Cohesion / spreadability

Hydraulic system	Surface	• Wear: Abrasive	• Cleanliness
	Performance, Efficiency	• Loss in efficiency	• Anti foam / air release • Anti-wear / EP additives • Tolerant to water contamination
PTO / PTI units	Surface	• Wear: Adhesive, abrasive	• Anti-wear / EP additives • Oil viscosity

4.6 Selection Criteria for System Lubricants

It is the responsibility of the lubricant supplier, who, in close co-operation with the engine manufacturer, must specify the preferred type and grade of lubricant aboard a vessel. The system oil must be of the rust and oxidation inhibited type of oil of typically SAE 30 viscosity grade.

In order to keep the crankcase and piston cooling spaces clean of deposits, the oil should have adequate dispersion and detergent properties. Alkaline system oils with 5-12 BN generally meet this requirement. The oil in-use also has to provide a certain minimum FZG anti-wear and anti-scuffing performance. All fresh system oils in use today must meet at least the minimum FZG requirement as specified by the engine manufacturer. Furthermore, the in service retention of FZG performance is an important consideration. Please see recommendations for specific oils in the OEM’s recommendations.

5 Lubricant Analysis

The two lubricants in a two-stroke engine serve different purposes. Therefore, the analysis requirements are different. The cylinder lubricant is a once-through product that is lost after use. The system oil typically stays in the engine for years, while gradually deteriorating and being replenished by fresh oil to make up for oil consumption. Regular analysis of the system oil is therefore required to ensure that the system oil fulfils the requirements.

Scavenge drain oil analysis (also known as scrapedown oil analysis) can be used to monitor the engine condition provided that analysis is performed regularly and that other key information is also gathered.

For detailed information about lubricant analysis, please refer to CIMAC recommendation no 30[5] “Used engine oil analysis – user interpretation guide”.

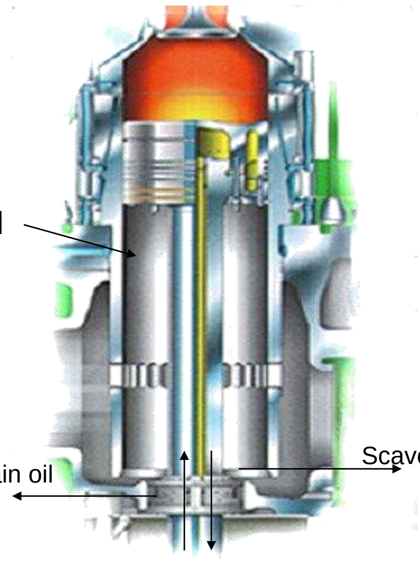


Figure 29: Drain oil location

5.1 Cylinder Lubricant Analysis

Cylinder lubrication of two-stroke crosshead diesel engines is done by a specifically formulated, non-recyclable, once-through product. Fresh cylinder lubricants are quality controlled by the lubricant provider and therefore routine analysis of cylinder oil prior to use is not required.

5.2 System Lubricant Analysis

System oil is continuously recycled and centrifuged and topped-up, as required, with fresh system oil. Therefore, it will typically stay in the engine for years. The continuous and multiple functional use causes the lubricant to deteriorate and it is therefore necessary to regularly monitor the system oil condition to confirm adequate lubricant properties.

Scavenge drain oil will typically over time leak into the system oil carrying cylinder oil, combustion products, water etc. The system oil is refreshed by topping up and only on rare occasions will it be necessary to replace the entire sump.

Regular system oil analysis provides important information about:

- System oil condition - do the lubricant properties fulfil the requirements
- Engine condition - e.g. through monitoring of wear particles

Furthermore, system oil analysis can also provide important information when trouble shooting engine issues such as in high wear situations.

The below table from CIMAC Recommendation 30[5] sets guiding limits for system oil in use. For specific limits, the OEM recommendations must also be checked. It should be noted that for system oil viscosity limits, most OEMs evaluate the % increase at 40 °C rather than at 100 °C.

Table 5: Guiding limits for system oil in use[5]

PROPERTY	METHOD	UNIT	MANDATORY ACTION
Viscosity @ 100 °C	ISO 3104	mm^2s^{-1}	max. 3.0 mm^2s^{-1} decrease
			max. 3.5 mm^2s^{-1} increase
Acid Number	ASTM D664	mg KOH/g	max. 2.0 mg KOH/g increase
Base Number	ISO 3771 / ASTM D2896	mg KOH/g	min. 3.0
			max. 30
Water Content	ISO 3733 / ASTM D1744	% v/v	max. 0.2
Flash Point	ISO 2719 / ASTM D3828	° C	min. 180
n-pentane and toluene insolubles	ASTM D893B	% m/m	max. 1.5

5.3 Scavenge Drain Oil Analysis

In the scavenge space on top of the stuffing box, a mix of used cylinder oil, combustion products, wear particles and system oil is formed. As the stuffing box does not completely seal off the crankcase from the cylinder, some of the scavenge drain oil will leak into the system oil and some of the system oil will pass through the stuffing box into the scavenge space.

It is possible to gain information about the engine condition by monitoring metal content and physical & chemical properties (e.g. BN and viscosity) of the scavenge drain oil. It should however be emphasized that there is a significant potential for misinterpretation as many factors e.g. lube oil feed rate, lube oil BN, and system oil leakage, will influence the scavenge drain oil composition.

OEM guidelines for scavenge drain oil analysis and follow-up action must be followed; generic advice on the interpretation of scavenge drain oil analysis data can be found in the below Figure 30. It should be noted that in determining residual BN, it should be corrected for system oil dilution which can affect values significantly.

Note that the below figure is for high sulphur fuel operation; there is not enough experience yet with prolonged operation on distillate and gaseous fuels to provide generic guidelines.

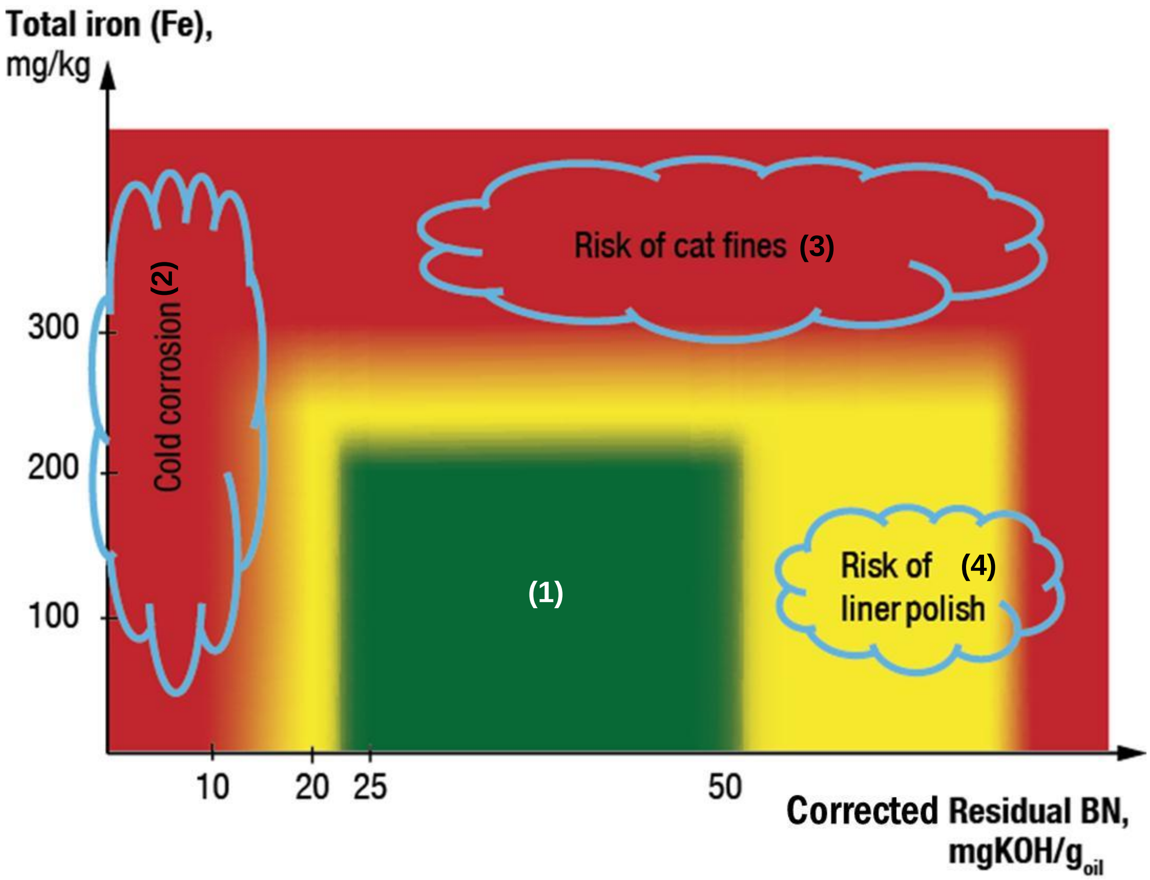


Figure 30: Scavenge Drain Oil analysis interpretation: (1) green area: keep current operation procedures; (2) "Cold Corrosion": increase cylinder oil feed rate and/or switch to a higher BN cylinder oil; (3) "Risk of Cat fines": check fuel centrifuge operation and cleanliness of the fuel; (4) "Risk of liner polish": consider to reduce cylinder lube feed rate or switch to a lower BN cylinder oil

Scavenge drain oil analysis is a trending tool. A single result will not hold much value as data has to be compared to previous data to give information about the current status of the engine.

Various onboard test equipment systems are available with the benefit of providing instant results and frequent sampling. However most of the on-board systems perform iron measurements only and more comprehensive results are obtained from lab analysis. Some onboard test kits will for example only measure iron adhesive and abrasive wear particles and not iron originating from corrosive wear.

Stuffing box oil

Oil is scraped off the piston rod when the piston moves through the stuffing box thereby generating stuffing box drain oil. According to the major engine designers, as much as 80% of the stuffing box drain oil consists of system oil.

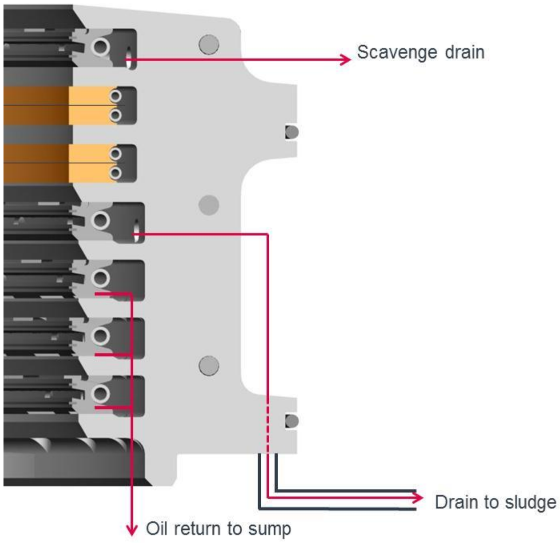


Figure 31: Stuffing box drain arrangement

Whereas the recent stuffing box designs aims at a low stuffing box drain amount, older designs resulted in a significant drain amount. Due to the high concentration of system oil, some installations returned the stuffing box drain to the sump after suitable treatment. This is not recommended as the stuffing box contains not only system oil. A significant amount of the stuffing box oil consists of scavenge drain oil which is not beneficial to the system oil properties.

5.4 Online Condition Monitoring

During recent years, development in sensor technologies has made online measurements of various oil parameters possible[5].

Online water sensors are an example of how it is possible to continuously monitor the water content of system oil. As system oil analysis is usually done 3-4 times per year, sudden water ingress will not be detected unless the system oil sample is taken at the time of the contamination. By continuously measuring the water, the incident may be discovered soon after the occurrence. Rapid detection may prevent engine damage if timely and appropriate action is taken.

When choosing an online sensor system, consideration should be given to measurement range, reliability and alarm configuration to avoid false alarms.

6 Troubleshooting Guide

In this section typical causes are listed for operational issues that can occur in two-stroke engines.

6.1 Combustion Space / Cylinder Oil Related Issues

Piston Ring Breakage

1. Continuous overload operation.
2. Continuous low load operation
3. Distorted pistons or cylinders.
4. Worn piston ring grooves. Worn chromium layers in piston ring groove(s).
5. Worn piston rings or those that have lost tension (ring collapse).
6. Insufficient piston ring side clearance.
7. Bad combustion.
8. Excessive blow-by.
9. Use of piston ring of the wrong dimensions.
10. Insufficient spreadability, detergency of oils, and thermal degradation.
11. Overstressing piston ring material during installation
12. Wear ridges not removed after overhaul

Piston Ring Sticking

1. Continuous overload operation.
2. Continuous low load operation
3. Distorted pistons or cylinders.
4. Insufficient piston ring side clearance.
5. Bad combustion.
6. Excessive blow-by.
7. Use of piston ring of wrong dimensions.
8. Insufficient spreadability, detergency of oils, and thermal degradation.
9. Overstressing piston ring material during installation

Excessive Ring and Cylinder Liner Wear

1. Improper filtration of air, fuel, and/or lube oil resulting in presence of particles.
2. Corrosive wear from fuel sulphur & operating conditions:
   a. The alkalinity reserve & nature of wear can be determined by scavenge drain oil analysis (piston underside / scape down analysis).
   b. Running at too low alkalinity reserve is reflected in:
      - Tendency to form black patches on the liner surface
      - Ring corrosion
      - Ring land deposit formation (can have other causes)
3. Low oil viscosity.
4. Insufficient oil feed/distribution to cylinders.
5. Low cooling water temperature.
6. Excess of drain water condensed at air inter cooler.

7. Excessive blow-by.
8. Pistons or cylinders distorted by mechanical force and/or thermal expansion (too fast loading-up).
9. Frequent cold start.
10. Excessive piston ring clearance.
11. Improper running-in.
12. Inadequate liner surface condition.
13. Unsuitable cylinder liner material, unsuitable piston ring coating
14. Overloading of the engine.
15. Adverse combustion properties (long combustion time) of fuel.
16. Excessive high content of carbon residue in fuel.
17. Excessive temperature due to insufficient air by blockage of air cooler/exhaust gas economiser.
18. Heavy deposit on piston undercrown.
19. Insufficient piston cooling.
20. Excessive FCC fines in fuel.

Piston Crown top (fire-side) & topland Deposits

1. Improper air filtration.
2. Wet or corrosive gas in dual fuel engine.
3. Improper fuel filtration.
4. Improper combustion.
5. Too high cylinder oil feed rate.
6. Too high alkalinity (BN) oil in use
7. Worn piston rings or those that have lost tension.
8. Continuous overload operation.
9. Continuous low load operation
10. Excessive ash (vanadium and/or sodium) content in fuel.
11. Under crown deposits causing insufficient piston underside cooling.
12. Faulty / leaking injectors.
13. Leaking of piston o-rings.
14. Cracks in the piston crown.

Piston lands & piston groove deposits

1. Improper air filtration.
2. Wet or corrosive gas in dual fuel engine.
3. Improper fuel filtration.
4. Improper combustion.
5. Too low cylinder oil feed rate.
6. Too low alkalinity (BN) oil in use
7. Worn piston rings or those that have lost tension.
8. Continuous overload operation.
9. Continuous low load operation

10. Excessive ash (vanadium and/or sodium) content in fuel.
11. Under crown deposits causing insufficient piston underside cooling.
12. Faulty / leaking injectors
13. Insufficient spreadability, detergency of oils, and thermal degradation.
14. Worn piston ring grooves.

6.2 Crankcase / System Oil Related Issues

Excessive Ring and Cylinder Liner Wear

1. Heavy deposit on piston under crown / cooling gallery caused by:
    a. Too high insoluble content system oil.
    b. Excessive piston crown burn off.
    c. HFO contamination in system oil (asphaltenes).
    d. Insufficient thermal & oxidative stability of system oil
2. Insufficient piston (oil) cooling.

Crankcase Deposits

1. Improper oil filtration/purification
2. Insufficient capacity/operation of the purifier
3. Neglected replacement / Cleaning of filter element.
4. High oil temperature.
5. Low oil temperature.
6. Water in oil.
7. Too low oil consumption.
8. Clogged crankcase breather air vent.
9. High insolubles content.
10. Improper suction pipe line design of purifier.
11. Ingress of cylinder oil and unburnt fuel via the stuffing box (or fuel via leaking fuel pumps).
12. Micro organisms / bacteriological contamination (only possible when water is present)
13. Oil condition outside OEM recommended condition.

Excessive bearing wear or bearing failure

1. Excessive bearing clearance.
2. Insufficient bearing clearance.
3. Misaligned bearings.
4. Distorted crankshaft.
5. Insufficient oil feed to bearings.
6. Oil viscosity too high or too low.
7. Contaminated system oil.
8. Corrosive oil (high Acid Number (AN) or presence of strong acids).
9. Water in oil.
10. Defective bearing construction.
11. Insufficient removal of contaminants in oil by purifier/filter.
    a. Insufficient capacity/operation of the purifier.

b. Neglected replacement / Cleaning of filter element.

12. Vibration of engine (when not running) caused by external source.
13. Wear due to migrating electric currents (micro welding) caused by insufficient earthing / grounding of engine. Especially occurring with shaft generator installed.
14. Incorrect bearing metallurgy.
15. Insufficient oil feed into bearings before engine is started.
16. Insufficient length/diameter of bearings to support combustion pressure and/or centrifugal force.
17. Inadequate oil groove design in bearing shells (insufficient minimum oil film thickness in bearings).

Wear of Crankshaft

1. Wear due to migrating electric currents (micro welding) caused by insufficient earthing / grounding of engine. Especially occurring with shaft generator installed.
2. Hard particles in oil being embedded in bearing overlay surfaces.

Deterioration of system oil

1. Water contamination caused by:
   a. Lube oil cooler leakage.
   b. Purifier water solenoid failure.
   c. Seawater ingress in storage tank / sump tank.
   d. Water cooled pistons: telescopic pipes leakage.
   e. Water condensation due to insufficient / blocked crankcase venting.
2. Significant Increase of Viscosity caused by:
   a. Increase of insolubles in used oil.
   b. Insufficient capacity of lube oil purifier.
   c. No oil consumption because of cylinder drain leakage into crankcase.
   d. Ingress with higher viscosity cylinder drain oil.
   e. Faulty operation of lube oil purifier.
   f. Oil filter element not cleaned / replaced.
   g. Insufficient capacity of oil filter.
3. Worn / leaking stuffing box sealing causing system oil to:
   a. Increase in insolubles level.
   b. Increase in oil viscosity.
   c. Increase in Base Number (BN).
4. Wrong fitting of stuffing box rings (e.g. upside down).
5. Insufficient removal of contaminants in oil by purifier/filter.
   a. Insufficient capacity/operation of the purifier.
   b. Neglected replacement / cleaning of filter element.
6. High oil temperature.
   a. Cooler dirty.
   b. Wrong temperature adjustment.
   c. Insufficient system design.
7. High volatility of system oil.
8. Excessive foaming of oil.

    a. Faulty design of oil return pipes above oil surface in sump tank.
    b. Ingress of air into lubricating system.
    c. Contamination with grease and/or rust preventives (Complete replacement of oil recommended).
9. Excessive back flushing of filters back in crankcase (dirty oil).
10. Exposure to excessive pressures of common rail system.

High Oil Temperature

1. Clogged oil cooler.
2. Clogged oil lines.
3. Crankcase sludge.
4. Continuous overload operation.
5. Insufficient water cooling.
6. Overheated bearings.
7. Incorrect oil viscosity.
8. Insufficient oil in sump or crankcase.
9. Insufficient oil circulation.
10. Faulty thermostat or controller.
11. Wrong temperature adjustment.
12. Inadequate system design.

Camshaft actuated exhaust valve issues - Fouling of Roller Cam, Actuator and/or Air Spring (Exhaust valve insufficient opening)

1. Insufficient hydraulic oil supply.
2. Contamination of hydraulic oil with fuel oil.
3. Worn cam/roller for actuator pump due to lack of lubricating oil feed.
4. Sticking of exhaust valve stem by lack of lubricating oil supply.
5. Worn/clogging of throttling orifices in exhaust valve upper housing.
6. Leakage of hydraulic oil.
7. Leakage of spring air.

6.3 Non-oil Related Issues

Exhaust Valve Failure

1. Improper cooling.
2. Material failure.
3. Faulty valve adjustment.
4. Trouble with valve rotator.
5. Hot corrosion (Na, V in fuel).
6. Excessive fouling due to slow steaming (low load operation).
7. Poor alignment of valve seat to seat ring causing leakages

Lack of Power

1. Improper combustion.

2. Insufficient air supply.
3. High exhaust back pressure.
4. Low fuel energy content.
5. Low fuel viscosity (leakages over fuel pump barrel and plunger); insufficient fuel injected to achieve full power output.
6. Heavy blow-by over piston rings.
7. Low compression pressure.
8. Leaking exhaust valves.
9. Sticking, leaking or plugged injectors.
10. Incorrect injection timing.

Improper/Bad Combustion

1. Unbalanced cylinder load.
2. Sticking, leaking or plugged injectors.
3. Unsuitable fuel (due to improper fuel heating temperature and bad combustion properties of fuel).
4. Low injection pressure.
5. Incorrect injection timing.
6. Insufficient air supply.
7. Blockage exhaust gas boiler / economizer
8. High exhaust back pressure.
9. Low compression pressure.
10. Leaking or sticking exhaust valve.
11. Low load operation (without TC cutout or auxiliary blower)

Turbocharger Deposits

1. Prolonged low load operation.
2. Poor combustion.
3. Use of fuel with high ash content.
4. Excessive use of cylinder lubricant.
5. Salt water in the fuel and/or air.
6. High Sodium/Vanadium content in the fuel

7 References

[1] www.imo.org

[2] Improved modelling of ship SO2 emissions—a fuel-based approach. Øyvind Endresen;

[3] ISO 8217:2012 Petroleum products – Fuels (class F) – Specification of marine fuels;

[4] CIMAC Recommendation 24: Treatment of the System Oil in Medium Speed and Crosshead Diesel Engine Installations, 2005;

[5] CIMAC Recommendation 30: Used Engine Oil Analysis - User Interpretation Guide, 2011;

APPENDIX I

EMISSION LEGISLATION REFERENCES

1. www.imo.org
2. www.ec.europa.eu/environment/air/transport/ships.htm
3. http://www.egcsa.com/

APPENDIX II

CYLINDER LUBRICATION SYSTEMS

Wärtsilä and Winterthur Gas and Diesel Specific Lubrication Systems (Engine OEM System)

1. The CLU3 Lubrication System

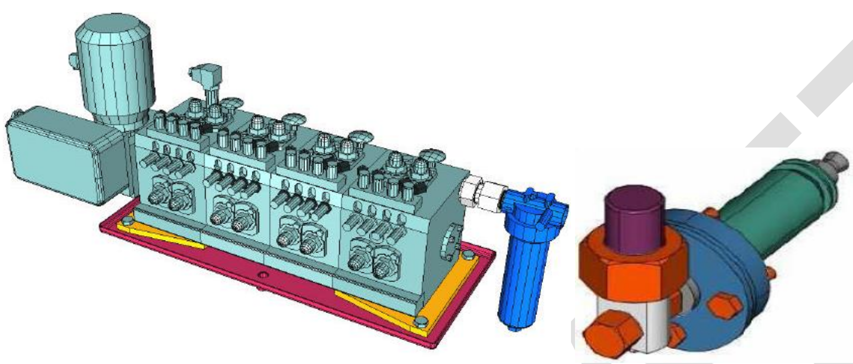


Figure A1: Oil pump and quill of the CLU3 cylinder oil injection system.

The cylinder liners have two rows of lubricating quills. For instance, a 96 cm bore engine will have two rows of eight quills each.

The Cylinder Lubrication Unit CLU3 lubrication system consists of a multi-element pump unit driven by an electric motor, and a progressive distributor for each cylinder unit with a number of quills with a small spring loaded membrane accumulator (see Figure A1). The pump unit supplies the cylinder lubricating oil to the progressive distributors, ensuring equal distribution of the oil to each individual quill. The CLU3 system releases a small amount of oil to the cylinder liner in each engine cycle.

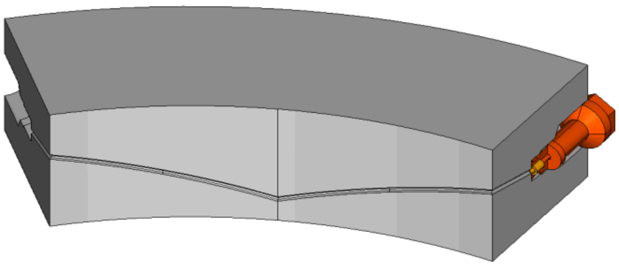
The oil supplied by the lubricating pump to the eight lubricating points located in the upper part of the cylinder liner first reaches the accumulator of the lubricating quills.

Through this, the spring loaded piston is pushed upwards and a pressure starts to build up in the lubricating quills that is slightly higher than the scavenge pressure. If the pressure in the cylinder at the lubricating points drops below the pressure in the lubricating quills, then the oil is supplied to the cylinder liner running surface. That allows to feed oil above and below the piston. Circumferential distribution and the mixing of fresh and used oil is secured by the inclined lube oil grooves.

The same operation as above occurs for the lower quills.

The feed rate is controlled by disc settings in the multi-element pump unit, and by varying the rotational speed of the driving electric motor.

2. The Pulse Lubrication System



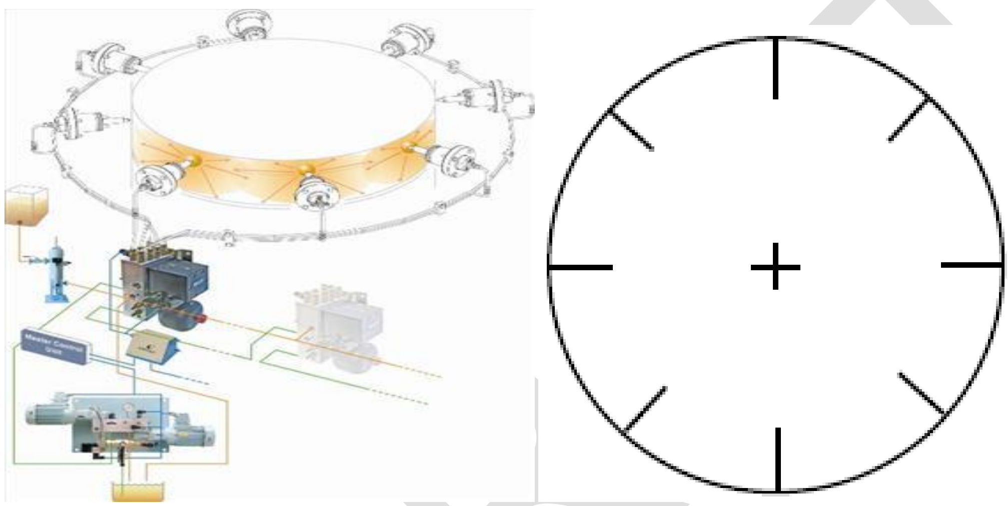


Figure A2: Layout of the CLU4 Pulse Feed and Pulse Jet cylinder oil lubrication system

The Pulse Lubricating System is a timed lubricating system. It distributes cylinder lubricating oil in pressurized pulses precisely into the piston ring package, where it is evenly distributed around the circumference of the liner by the help of lubrication grooves. These grooves secure the refreshment of the oil film covering the running surface.

The CLU4 pump and Pulse Lubricating System (PLS) comprises one CLU4 pump and six to eight quills per cylinder unit. It further comprises a 50 bar servo oil system, which actuates the CLU4 pumps, and a control system. The CLU4 pump is a hydraulic, positive displacement device, with a number of independent cylinder lubricating oil outlets corresponding to the number of quills in the cylinder liner (see Figure A2).

The pump piston is driven by servo oil, which is pressurized to 50 bar. When the solenoid valve is activated, the pump piston delivers a fixed, predefined amount of cylinder lubricating oil to each quill in the cylinder liner. When the solenoid valve is deactivated, the pump piston returns to its starting point, the cylinder lubricating oil chambers are then refilled from the gravity tank, and the pump is on stand-by for the next delivery stroke.

This PLS can also be retrofitted to existing Wärtsilä mechanically controlled RTA and electronically controlled RT-flex type engines. In such cases the lubrication system is known as RPLS.

3. The Pulse Jet Lubrication System

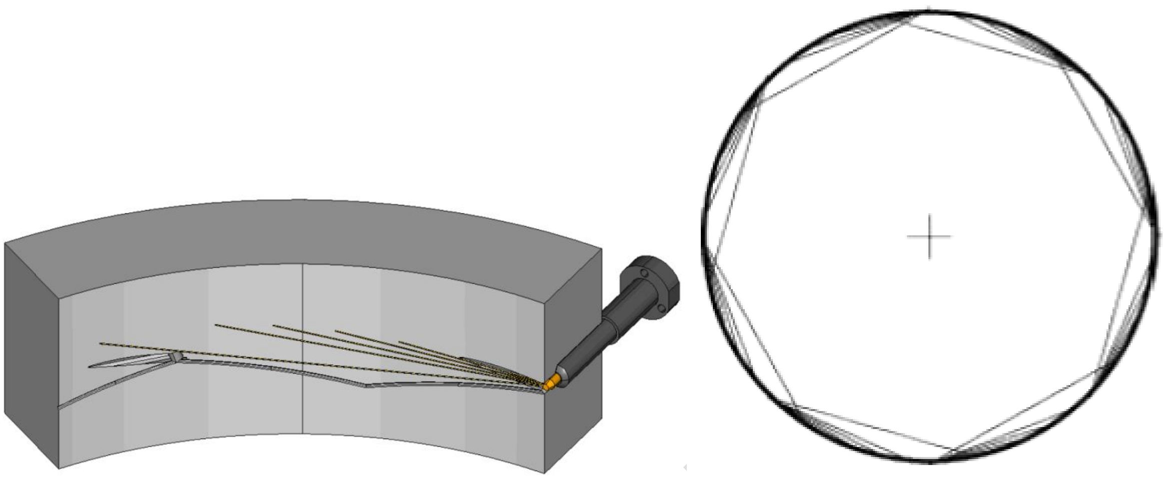


Figure A3: The Pulse jet oil injection system introduces oil tangentially into the cylinder liner

The Pulse Jet Lubricating System is also a timed lubricating system. It utilizes Pulse Jet quills which generate high speed – but not atomized – “jets” of cylinder oil. Pressurized pulses distribute cylinder lubricant oil *tangentially* to the surface of the liner (see Figure A3).

Bore dependent up to 5 lubrication points are therefore covered by each quill around the circumference of the liner.

The refreshment of the oil film on the running surface is secured by the inclined lube oil grooves.

MAN Diesel & Turbo Specific Lubrication Systems (Engine OEM System)

1. Alpha Lubricator system (Alpha Lube mark I)

The Alpha Lubricator system (Alpha Lube) controls the cylinder oil dosage to each cylinder (see Figure A4). This enables dosing the cylinder oil according to the actual power output of the engine and proportional to the Sulphur content in the fuel.

The Alpha Lube supplies the cylinder oil evenly around the liner circumference. See Figure A4-A5. It pumps the cylinder lube into the liner in pressurized pulses when the piston rings pass the lubricating nozzles during the upward stroke. See Figure A5-A6. The piston rings will then distribute the cylinder lube to the entire liner surface.

The Alpha Lube is designed to supply cylinder oil every 2-15 engine revolutions. It delivers a constant amount of cylinder lube oil per pump-stroke. The lube oil feed rate is governed by the engine power:

- High load → High feed rate → Fewer engine revolutions between every pump-stroke.
- Low load → Low feed rate → More engine revolutions between every pump-stroke.

The Alpha Lubricator is designed for the MAN B&W mechanically controlled engines: Engines types: MC and MC-C. It can be retrofitted to existing engines.

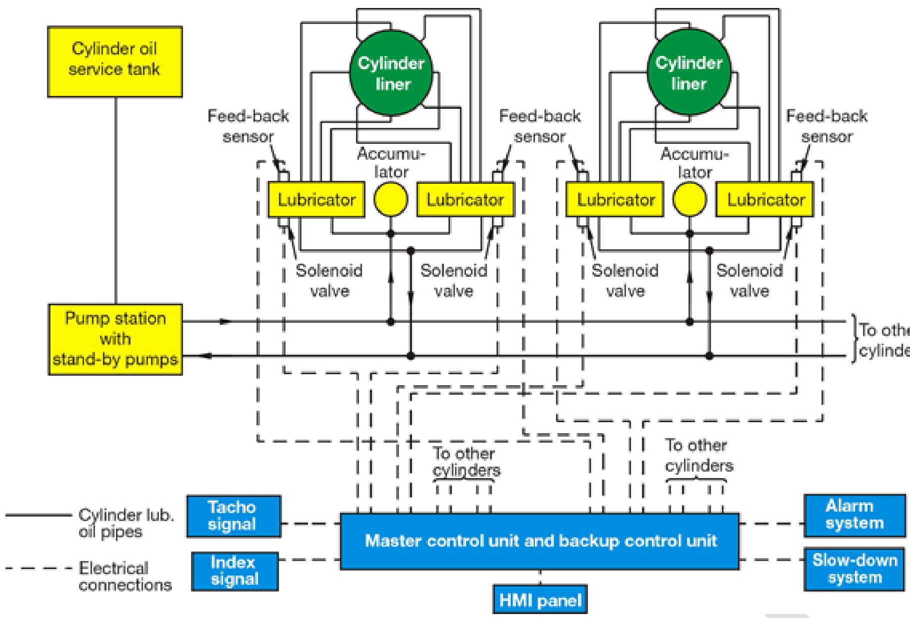
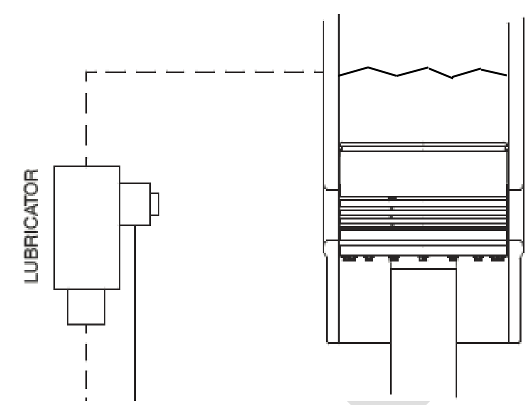


Figure A4: Principle of the Alpha Lubricator System (Alpha Lube)



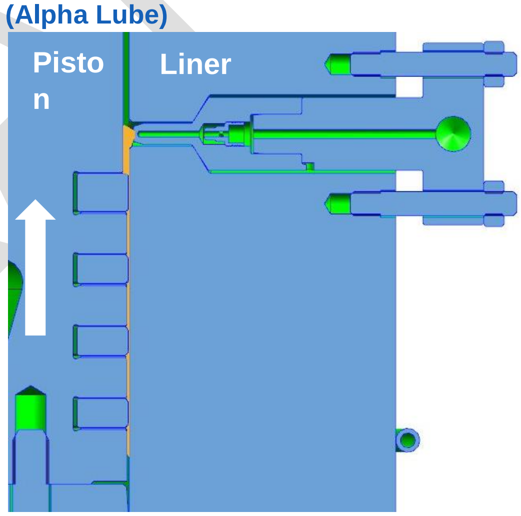


Figure A5: Schematic of cylinder oil supply to oil quills.

Figure A6: Oil injection into piston ring pack.

2. ME Lube

The ME Lube uses the same principles as the Alpha Lube mark I, and it is basically an upgrade of the Alpha Lube for the MAN B&W electronical controlled engines. The Alpha Lube mark I is described in the previous Section 1. Based on keyed in information in the ECS-MOP (Engine Controlling System Manual Operating Panel) on Sulphur content of the fuel and the Feed Rate Factor experienced for the engine, the ME Lube delivers the programmed feed rate to protect the engine at the actual condition.

The ME Lube is designed for the MAN B&W electronically controlled engines: Engine types: ME, ME-B, ME-C, ME-GI (burning gas+fuel) and ME-LGI (burning Methanol+fuel).

3. Alpha Mark II

The Alpha Mark II lubricating system is an upgrade of the ME Lube where the new design and control system enables it to inject cylinder lube in small amount at every stroke of the engine. ME Lube is described in the previous Section 2.

The Alpha Mark II is designed for the MAN B&W electronically controlled engines: Selected engine types of the ME-C engine type.

4. ACOS (Automated Cylinder Oil Switch) System

The ACOS (Automated Cylinder Oil Switch) system facilitates and optimises the lubrication automatically. It is the present standard for MAN B&W gas engines.

The ACOS system is designed to switch between low-BN and high-BN cylinder lube oils depending on the sulphur content of the fuel actually combusted in the engine (sulphur equivalent, S_e). A schematic illustration is shown in Figure A7.

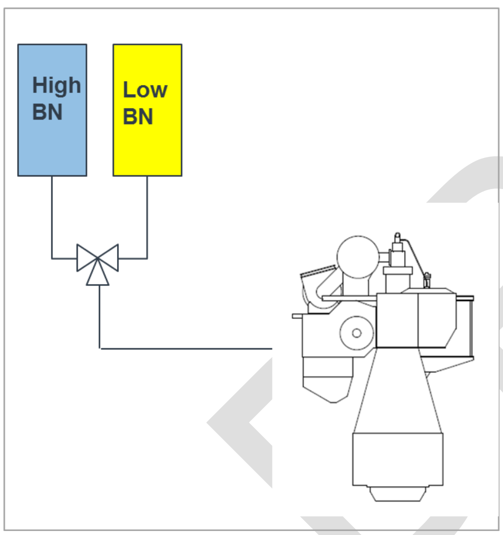


Figure A7:Schematics of the ACOS (Automated Cylinder Oil Switching) system.

The S_e will be calculated by the ME ECS (Engine Control System) system by using the:

1. Sulphur content of the liquid fuel
2. Sulphur content of the gas
3. Fraction of the two fuels currently used

The fuel fractions depend on the chosen operational mode, the available amount of gas, and the engine load.

The sulphur content of the fuels in use must be entered on the Main Operating Panel (MOP) together with the feed rate factors experienced for the low-BN and high-BN cylinder lube oil. The system will then automatically change between low-BN and high-BN oil, and deliver the correct feed rate at different S_e as the percentage of gas and fuel oil are changed by the operation.

If the ACOS system should fail, a three-way valve switches mechanically to "failsafe" position, which is set to the high-BN oil.

5. ACOM (Automated Cylinder Oil Mixing) System

The newly developed ACOM (automated cylinder oil mixing) system mixes fully-formulated cylinder lube oils to the BN (base number) required to match the sulphur content of the fuel (see Figure A8). This enables the operator to use a low cylinder lube oil feed rate and, at the same time, keep the cylinder oil BN at the optimum for the engine.

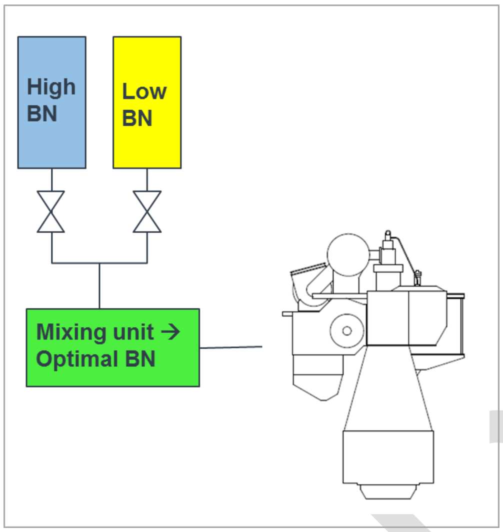


Figure A8: Schematics of the ACOM (Automated Cylinder Oil Mixing) system.

Matching the actual sulphur content to the right lube oil according to the engine type and operating pattern is a key factor in achieving efficient lubrication. Furthermore, by mixing two fully-formulated cylinder lube oils, detergency and dispersancy are always at the highest level, while viscosity is kept at the recommended level.

The ACOM system is a stand-alone system for the mechanical engine types: MC and MC-C. It is integrated into the engine controlling system (ECS) for the electronic controlled engines types. The integration into the ECS will enable the operator to control both cylinder oil BN and feed rate from the control room using the ECS-MOP (Engine Controlling System Manual Operating Panel). Based on keyed in information on Sulphur content of the fuel and Feed Rate Factors experienced for the engine, the ACOM system fully automatic mixes the optimal BN for the cylinder oil at the actual condition of the engine.

MHI Specific Lubrication Systems (Engine OEM system)

1. The Advanced Electronically Controlled Lubricating System (A-ECL)

The conventional mechanical cylinder lubrication system for two stroke marine diesel engines injects a fixed quantity of oil at a fixed injection timing. The injection timing is set before the piston rings pass the quills under piston upward process and/or after piston ring passing.

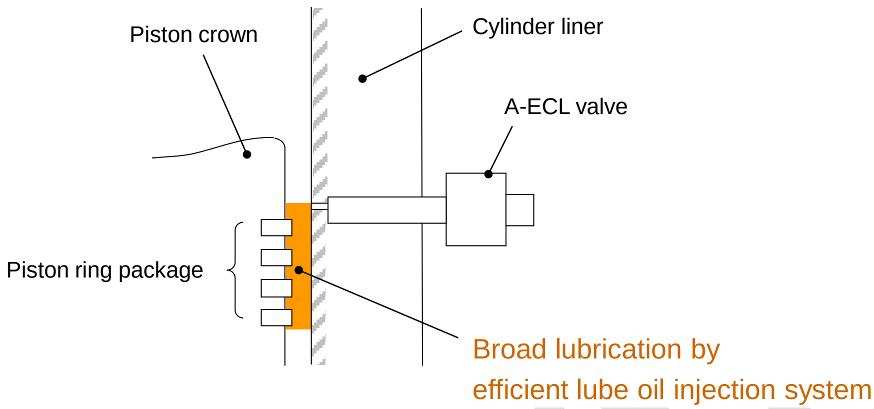


Figure A9: A-ECL System

System outline

On the A-ECL system, the cylinder oil is fed to the cylinder through the A-ECL valves by the small plungers in the lubricator (Figure A9). The plungers are actuated by the cylinder oil which is pressurized by pump on supply unit and the timing of actuating the plungers is controlled by solenoid valve which is controlled by A-ECL controller.

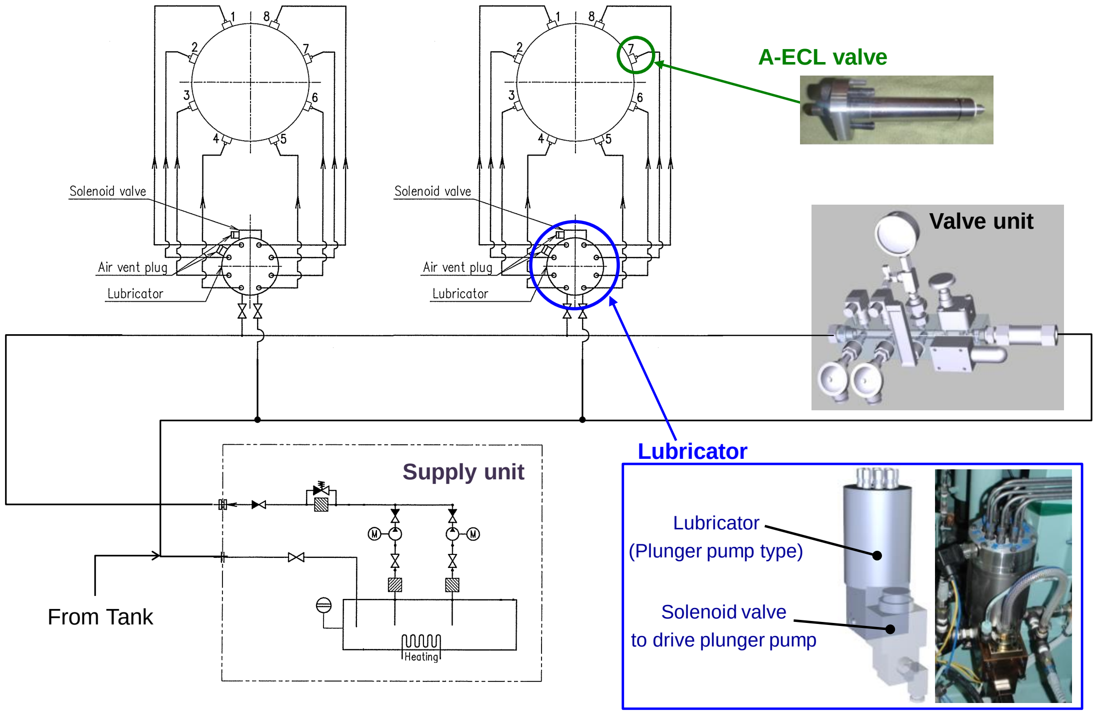


Figure A10: A-ECL System outline

Control of feed rate

The Mitsubishi A-ECL system controls the cylinder oil feed rate by frequency of injection. The mode of feed rate corresponding to the engine load can be chosen from the followings settings by selection, according to the operator needs.

1) Proportion to main engine speed
2) Proportion to main engine BMEP
3) Proportion to main engine output

Control of cylinder oil injection timing

The A-ECL lubricating system can control the injection timing flexibly and freely by the benefit of the electronically controlled system. Therefore, the injection timing can be set at the most suitable for utilizing cylinder oil effectively over the load range from low load (speed) to high load (speed).

Stability of control system

The A-ECL control system is based on the developed system of Mitsubishi UEC-Eco Engine (full electronically controlled engine). The crank angle detection method and injection timing control system etc. of UEC-Eco Engine are applied to the A-ECL control system. The durability test for each control system including the solenoid valves and distributers was carried out by 3×10^8 cycles durability test.

And the reliability of the controller is based on many service experiences of the ECL system developed previously.

Furthermore, the A-ECL has a complete dual control system. If any issue should occur on the control system, the other control system will provide back up control automatically.

Retrofit of the A-ECL lubrication system

In the case of retrofitting a conventional mechanical cylinder lubricator, the retrofit work should be executed during dry docking because of relatively large scale construction work (including the physical restriction of lubricator unit and driving unit setting position).

The A-ECL lubrication system does not have the above restriction and it is therefore making the retrofit installation work simpler, and the installation work period also can be shortened compared to the above scenario.

Hans Jensen Lubrication Systems (Retrofit System)

The Hans Jensen (HJ) SIP cylinder lubrication system is designed to apply the cylinder lube oil directly on the liner wall, instead of on the ring pack. This is done by spraying the cylinder oil into the cylinder and utilizing the scavenge air swirl to distribute across the entire surface (see Figure A11).

The lubrication system consists of lubricators **(1)**, HJ SIP valves **(2)**, pressure pipes **(3)**, return pipes **(4)** and an oil filtering system **(5)**.

The procedure is to have smaller amounts of cylinder oil supplied with **every** piston stroke, and distributed above the piston in the upwards moving direction.

The lubricators **(1)** are installed according to engine builder specifications as far as the alignment is concerned and are connected to the engine's rotating mechanical drive or another similar drive that ensures synchronization with the crank shaft movement thereby allowing timed injection of the cylinder lube oil.

The lubricator **(1)** pumps lube oil through the pressure pipe **(3)** to the HJ SIP valves **(2)** placed in the cylinder liner **(6)**. The HJ SIP valves inject the oil into the cylinder liner **(6)**. New valves have an internal oil leak of 20±10 ml/h which is led back to the lubricator by a return pipe **(4)**.

The oil is injected in atomized form and is distributed on the cylinder wall utilizing the centrifugal force of the scavenging air swirl.

After injection, the oil film covers a large area of the upper part of the cylinder liner prior to the passing of the piston and the piston rings. During the movement of the piston/piston rings the oil is distributed to the rest of the running surface of the cylinder liner **(6)**.

HJ SIP is an injection and distribution principle which can be used with all types of lubricators – mechanical and electronic.

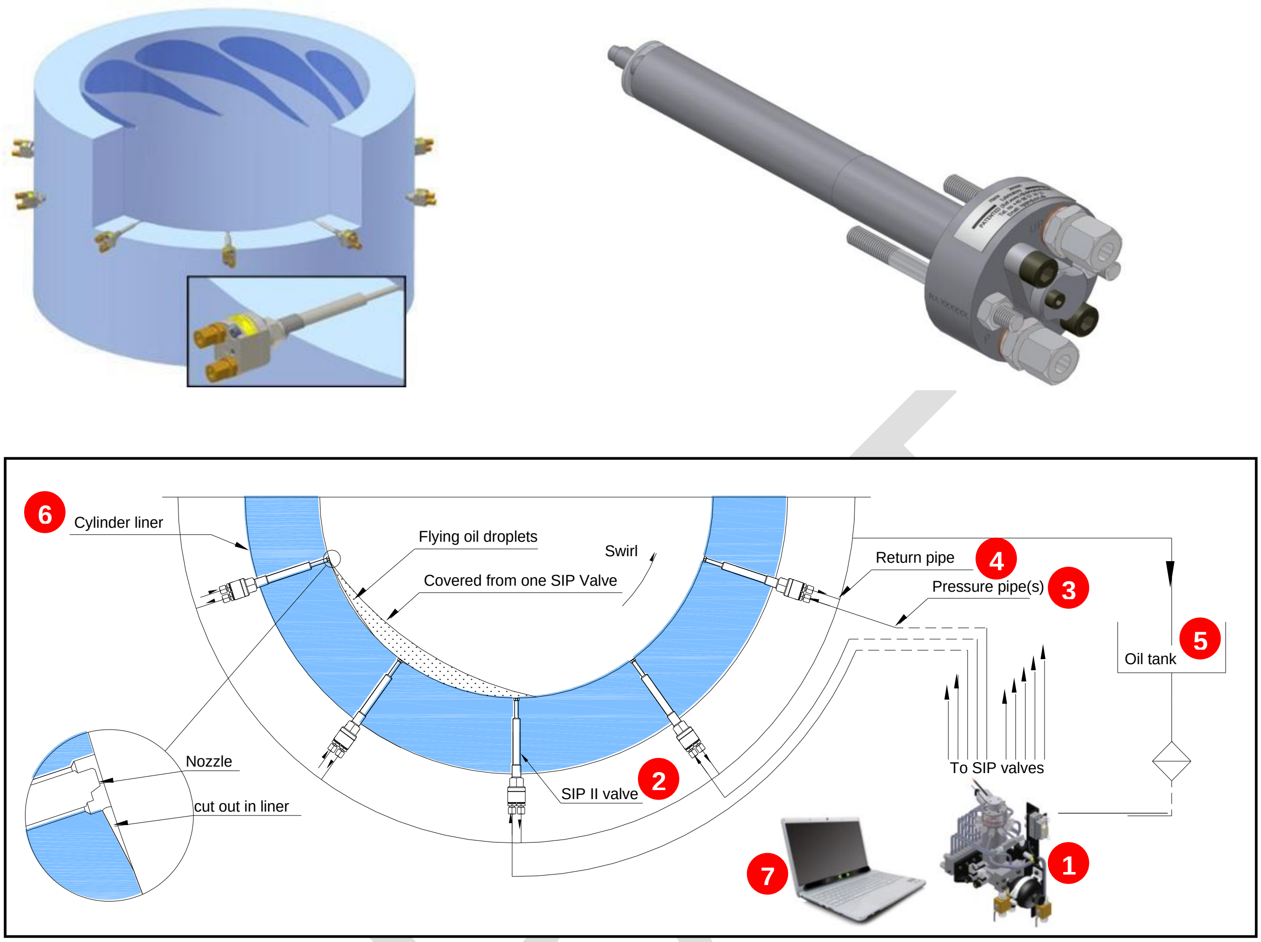


Figure A11: Hans Jensen lubrication system.

HJ Mechanical Lubricators

Development of the Hans Jensen conventional mechanical lubricators (see Figure A12) started as far back as 1923, and this type of lubricator is therefore installed on numerous vessels.

This type of lubricator can be combined with either HJ SIP valves or traditional non-return valves.

The mechanical lubricators from Hans Jensen Lubricators offer RPM dependent cylinder lubrication by nature, but can be combined with load regulations in either mechanical or electronic form (note: the electronic control system is a seperate dedicated HJ system). This is a way to ensure that cylinder oil consumption will be automatically adjusted according to engine load, and thus a vital feature when slow steaming or operating at varying load.

Like all other cylinder lubrication solutions, also the mechanical lubricator can deliver fresh cylinder oil with every piston stroke.

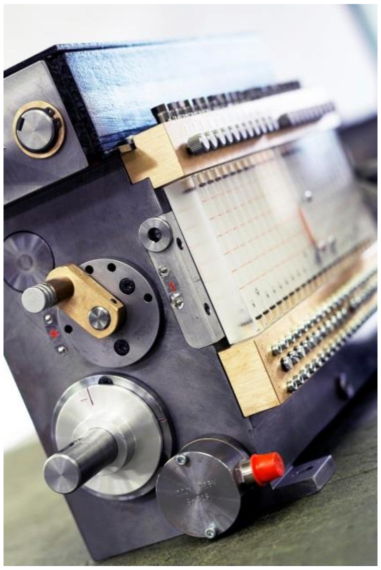


Figure A12: HJ Mechanical Lubricator

HJ Lubtronic Lubrication system

HJ Lubtronic allows timed lubrication, and regulation according to various parameters such as for instance MEP, BHP or user-specified algorithms. It can also be installed on engines where no mechanical drive is available.

The HJ Lubtronic system (Figure A13) is in short a hydraulically driven and electronically controlled lubrication system. It should be noted that the electronic control system is a seperate dedicated HJ system.

The HJ Lubtronic system consists of:

- HJ Lubtronic control system
- T155 lubricator arrangement
- Hydraulic piping arrangement

HJ Lubtronic can be combined with both traditional non-return valves and HJ SIP valves.

Timed lubrication is necessary in order to take full advantage of the HJ SIP Lubrication. With HJ SIP Lubrication, the oil is delivered to the cylinder running surface above the piston at every engine revolution.

Timed lubrication is necessary in order to take full advantage of the HJ Non-return valve lubrication. With HJ Non-return valve Lubrication, the oil is delivered to the cylinder running surface between the piston rings at every engine revolution.

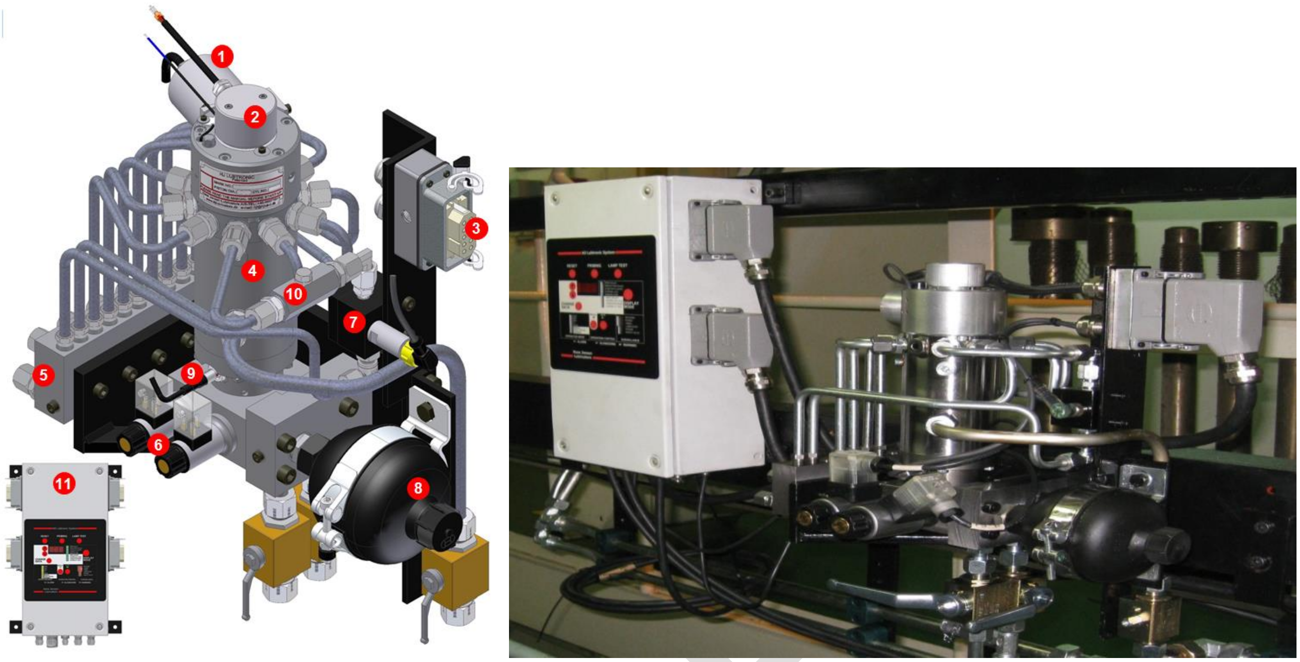


Figure A13: Hans Jensen Lubtronic Lubrication System. Schematic representation (left) and example of setup (right)

(1) DC motor

(2) Potentiometer

(3) 'Harting' terminal for connection with CLC box **(11)**

(4) HJ T155 lubricator

(5) Manifold

(6) Magnetic valves (one primary, one back-up)

(7) Flow meter

(8) Hydraulic accumulator

(9) Proximity switch

(10) Magnet filter w/ possibility for strainer inserts

(11) CLC control box (one per lubricator)

Other Retrofit Lubricating Systems

Other retrofit lubricating systems are available such as: Winterthur Gas & Diesel – Pulse Feed and Pulse Jet systems, MAN Diesel & Turbo: Alpha Lubricator system, MHI: A-ECL system, SKF lube oil pumps, Wärtsilä electronic converson of mechanical pumps, Tekomar electronic conversion of mechanical pumps (Figure A14) and others.

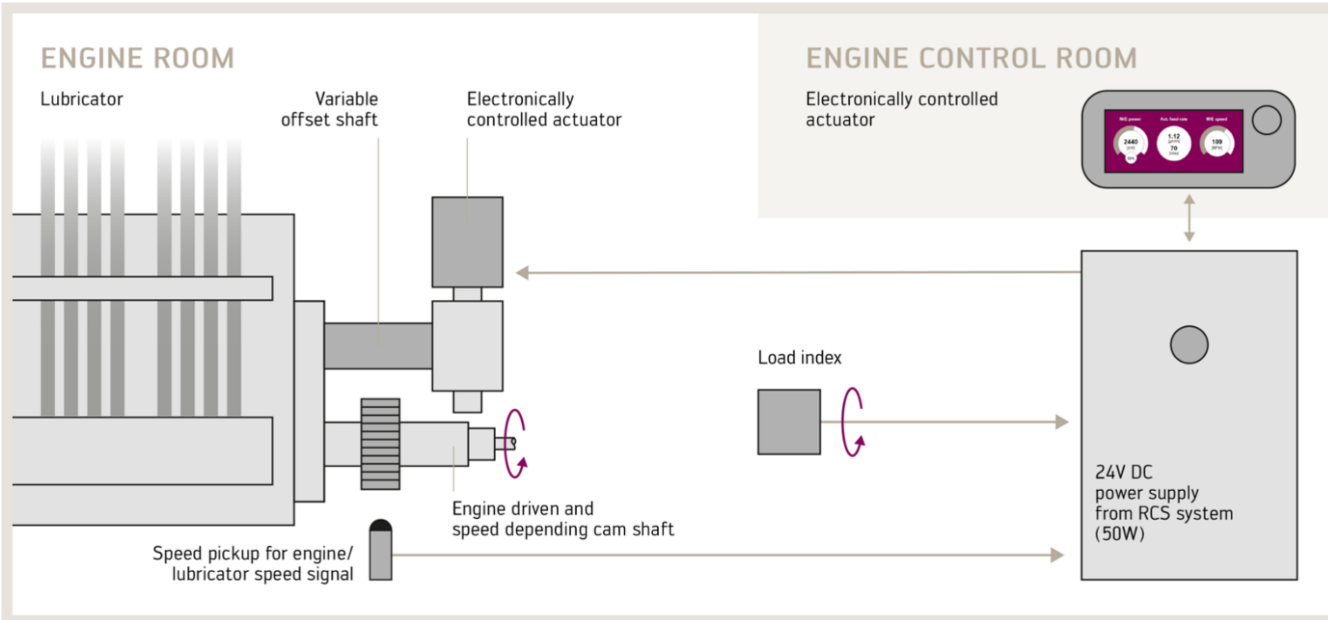


Figure A14: Schematic representation of Tekomar CYLUBE retrofit lubricating system.

APPENDIX III

SCAVENGE PORT INSPECTION

Performing scavenge port inspections is essential to ensure reliable operation and achieve maximum time between overhauls. To evaluate the piston running behaviour, focus is put in following areas during such inspection:

Piston

Piston ring condition

Piston rings are often covered in oil or unburned fuel, which is usually built up during manoeuvring of the vessel. This does not always provide a representative view on the performance of the cylinder unit. Therefore, before evaluating the condition of the piston rings, the ring surface has to be cleaned. First of all, the unit is checked for broken rings. To check the piston ring tension, a wooden stick is typically used to tap on the surface.

To observe if a piston ring is running properly, it is important to know the ring type technology applied. Chromium ceramic piston rings for example can show some cracks in the surface; this is considered a normal condition. Often piston rings are manufactured with running in coatings, which slowly disappear during the initial use of the rings.

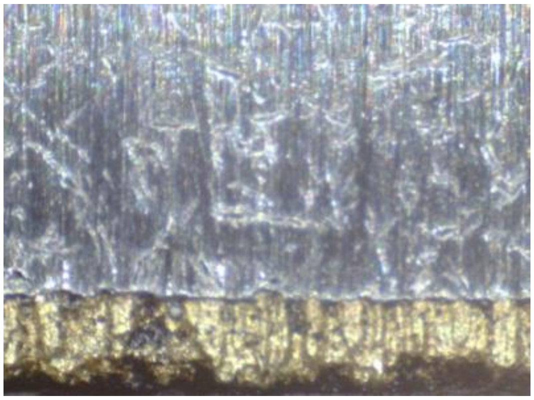
When looking at piston rings in use, it is important to look for signs of insufficient hydrodynamic lubrication, corrosion or abrasion.

When there is no sufficient hydrodynamic lubrication, typically (micro)seizures appear on the piston ring running surface. This distortion of the oil film can be caused by a too low oil feed rate or improper condition of the liner surface to obtain a proper oil film.

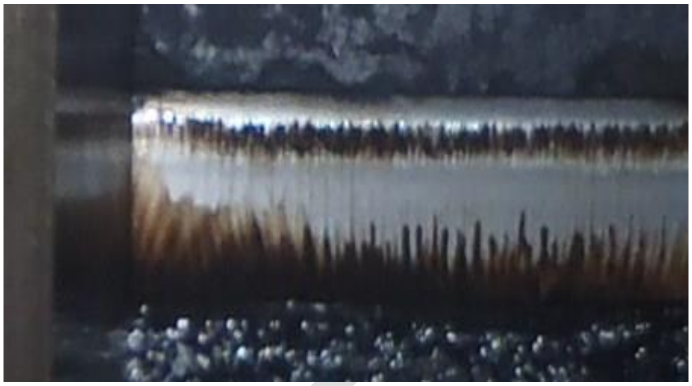
When corrosion occurs, this typically is noticeable at the edges of the rings surface, where the sulfuric acid – cylinder oil mix is accumulated during the movement of the piston. This phenomenon can be caused by a too low oil feed rate, a too low BN cylinder oil or when the oil cannot reach the area which need protection. Below pictures show the impact of corrosion on regular (cast iron) versus Chrome Ceramic piston rings.

Abrasion on the piston ring surface typically shows deep scratches. The most common source of abrasive wear in this area are catfines (fines from refinery catalyst that can occur in HFO (residual fuel oil). Catfines typically also trigger excessive piston ring clearance and can rapidly lead to scuffing and ring breakage (sometimes within less than a day of operation).

Excessive deposits behind the piston rings can lead to ring sticking. This can be very detrimental as the deposits can push the ring against the liner with excessive force and can possibly lead to scuffing. Deposits behind the ring can sometimes be observed through the ring gap during a port inspection. This however depends on the system configuration and the type of piston ring used.



Example: Ring corrosion cast iron piston ring



Example: Ring corrosion chrome ceramic piston ring

Example: Broken piston ring

Example: Micro seizures of the piston ring

Figure A15: Piston ring conditions

During the inspection of the piston units, it is recommended to regularly check piston ring clearance which can be easily done with feeler gauges. Also the thickness of the piston ring coatings can be measured in place; this however requires specialized equipment.

Piston (top) land condition

Excessive deposit formation on the piston lands, especially on the top land, can in certain situations polish the liner surface, which can eventually disturb the oil film formation and lead to piston ring scuffing. Such deposit formation can be caused by applying too high oil feed rates or running on too high BN oils.

Deposit formation between the ring lands is usually caused due to improper sealing between the piston and liner causing the lubricant to burn. However, this phenomenon can also be caused by a lack of detergency of the cylinder oil. Occurrence of such deposits does not necessarily mean the oil quality is insufficient, it can also indicate a too low oil feed rate or that a too low BN cylinder oil is applied or can be caused by the oil not reaching the area which need protection.

Skirt condition

Damage on the piston skirt can cause damage to the liner surface and disturb the oil film.

Liner

When observing the liner condition via a scavenge port inspection, only the lower part of the liner can be observed properly. In most cases this is sufficient to spot local polishing or rubbing marks or abnormal wear patterns. When some degree of corrosion is present this is typically reflected in white or black spots formed on the liner surface. These spots are not necessarily considered harmful; however, caution is needed when operating long time under these conditions.

Figure A16: Example of bore polishing

It is always recommended to perform drip oil analysis as a tool to help understand the observations made during the port inspections. This will help to judge the degree of over or underfeeding with alkalinity, severity of high wear on certain units and running in condition of new units.

APPENDIX IV

SYSTEM OIL SYSTEM DESIGN

Guidelines for the Treatment System Design

The major components of the oil cleaning system are the feed pump, the pre-heater and the centrifugal separator (see Figure A17). The oil is pumped from the oil tank, heated up to the appropriate separation temperature, typically 95 °C, by the pre-heater and finally cleaned in the separator before being pumped back to the oil tank. The oil temperature in the purifier should be selected and maintained in accordance with the manufacturer's recommendations.

The suction line for the feed pump should be installed in the lowest section of the system lubricant tank and should be installed in a section with low fluid turbulence.

The system oil return line should lead into the sump opposite the oil suction point of the feed pump. This is to ensure proper oil circulation when the engine is not in operation.

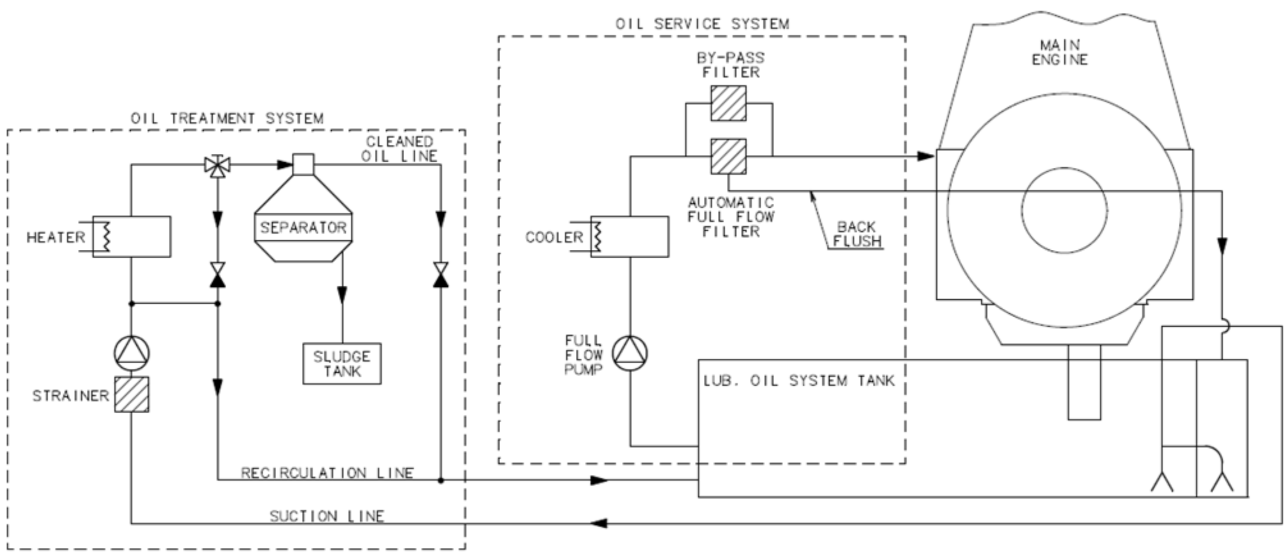


Figure A17: Schematic representation of oil cleaning system – note the oil treatment system.

The following recommendations are made for the design & selection of the treatment system components.

(a) Separator:

Conventional separators with gravity discs and modem types without gravity discs are available. With the modern types many of the operational problems, such as selection of the gravity disc and breaking of water seals, are avoided.

Self-cleaning equipment is normally recommended to increase the time between services

The centrifugal separator should be equipped with a fail-safe water supply arrangement. Malfunction of components must never result in accidental water addition to the lubricating oil system.

Due to the importance of the correct functioning of centrifugal separators each unit should be equipped with its own monitoring/alarm system. Any failure of a component should trigger an alarm.

(b) Feed Pump:

A separate, positive displacement type pump, operating at constant capacity, should be installed in close proximity to the oil tank so that suction lines can be as short as possible. By using this arrangement, a constant feed rate is maintained, which is important to obtain good separation efficiency.

(c) Oil Pre-heater:

Pre-heater dimensioning should not only take into account the temperature of the system oil during engine operation but also the lower temperature of the oil in the oil tank when, for example, the engine is not in operation.

To avoid deposits and coking on the heating surfaces the following design requirements should be considered for all types of heaters:

- Turbulent oil flow for optimum thermal efficiency and to avoid coking.
- No dead zones in which cracking of the oil can occur.
- The heater should be designed to exclude a potential "short circuit" of the oil flow.
- Short retention time of the oil in the heater.
- Low surface temperature.

Keeping temperatures constant maintains separation efficiency and reduces the need of manual adjustments to the cleaning system.

Temperature variations influence the interface position in the separator which can result in poor separation and/or broken water seals. A collapse of the water seal creates operational problems and may be caused by selecting too small a gravity disc. This results in poor separation. The primary cause, however, can be too small a heater and/or inadequate temperature control.

(d) Lube Oil Renovating or Settling Tank:

Many ships are equipped with a lube oil renovating or settling tank, which should be of sufficient capacity to hold one complete main engine system oil charge.

The renovating tank is an important part of the oil treatment system and is particularly useful in cases of gross contamination of the system oil, either by water ingress or excessive insolubles.

The advantage of the renovating tank is that it allows the complete oil charge to be passed through the separator, whereas normally the oil is being cleaned on a by-pass basis.

Dimensioning of the System Lubricant Separator

The required capacity of the system oil separator depends on several factors such as:

- engine output
- type of fuel oil
- type of lubricating oil
- type of service
- lubricating oil volume
- oil change intervals

The calculations should always be based on the output of the engine Maximum Continuous Rating (MCR) and not on the actual oil tank volume.

Normally one separator per engine should be installed in order to ensure continuous cleaning. If this is not possible the dimensioning of the cleaning system should be based on the total installed output of all engines.

The required flow rate Q [l/h] of a lube oil cleaning system is to be calculated as follows:

$$Q = p \times z \times n \times t$$

p = engine output MCR [hp or kW]

z = "conversion factor": 1 for l/hp or 1.36 for l/kW

n = number of turnovers per day of a theoretical oil volume corresponding to 1 l/hp. n = 3 is recommended in standard case.

t = actual operating time of the separator per day. Recommendations:

t = 24 hr for partial de-sludging systems (continuous feeding of oil during de-sludging)

t = 23.5 hr for total de-sludging systems (supply of oil is stopped during de-sludging)

Hence, the appropriate separator is to be selected from the capacity tables issued by the separator manufacturers. In such tables the different dispersancy levels of the lube oils normally are taken into consideration. Therefore, non dispersant system oils for crosshead engines are cleaned with a higher percentage of the nominal throughput than trunk piston engine system oils. It is recommended that system oils are cleaned at no more than 35% of the nominal throughput.

System Lubricant Filters

When the oil is pumped into the engine there is a need to prevent abrasive particles from reaching it. These particles might have been picked up by the oil anywhere in the system. As the separator is treating the oil in a by-pass system with much lower throughput than the full flow there is always a risk that the particles are not removed immediately by the separator.

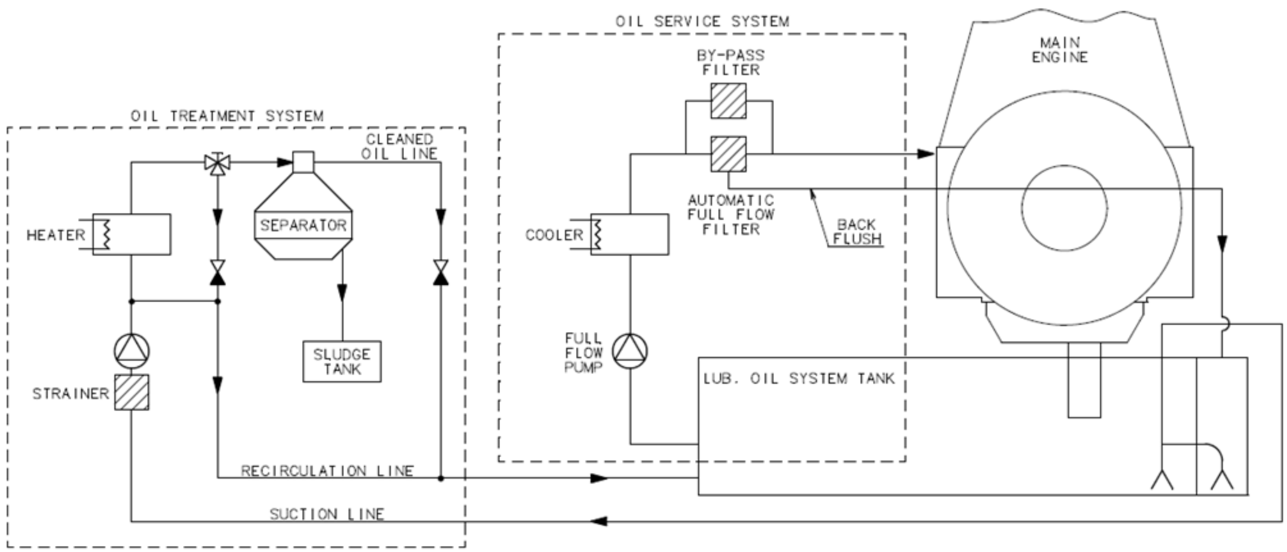


Figure A18: Schematic representation of oil cleaning system – note the position of the full flow filter before the engine.

This protection of the engine is ensured by the full flow filter placed just before the engine (see Figure A18). The filter should always be placed as close as possible to the engine.

There are manually cleaned and automatic backflushing filters.

The filters must provide good protection for the engine. For this the following is needed:

- a mechanically reliable design and construction of the filter element,
- a filter area large enough to handle the envisaged sludge amount thus achieving a low specific filter load,
- a well functioning backflushing mechanism to limit sludge build up on the filter with an independent monitoring/alarm system setting off a "group alarm" at the engine control position in the event of:
  - an electric motor fault
  - maximum differential pressure
  - excessive backflushing frequency
  - flushing-oil cartridge saturation if flushing-oil processing is provided.
- With the aim to reduce losses, the backflushed oil should be returned to the system close to the suction pipe of the purifier. A typical filter installation for an engine operating on heavy fuel oil (HFO) consists of:
- One automatic backflushing filter as the main filter. The filter mesh is typically 34 to 50 micron absolute.
  - If a double filter (duplex) is installed it should have sufficient capacity to allow the specified full amount of oil to flow through each side of the filter at a given working temperature and with a pressure drop across the filter of no more than 0.2 bar for a clean filter and up to 0.5 bar for a dirty filter.

    - When back flushing filters (manual or automatic) are fitted the main lubricating oil pump capacity must be such that it is capable of providing the additional flow rate and the increased pressure needed for backflushing.
- A manual duplex safety filter (optional).
    - The safety filter size is usually 80 to 100 micron absolute. The purpose of this filter is to act as a safety device in case the filter screen of the main filter is damaged. In this case the safety filter will be clogging rapidly thereby giving an indication to the operator. This type of filter is more commonly found on trunk piston engines. If the engine has separate camshaft lubrication, then in some installations a 30 micron filter is fitted in the filling system.

Filter mesh size

There are several definitions for filter mesh size in use:

- Absolute mesh (sphere passing mesh). One definition of absolute mesh size is the square opening as shown in Figure A19.
- Nominal mesh. The nominal mesh is a practical definition. It indicates that about 85-90% of the particles bigger than the nominal mesh are retained by the filters.

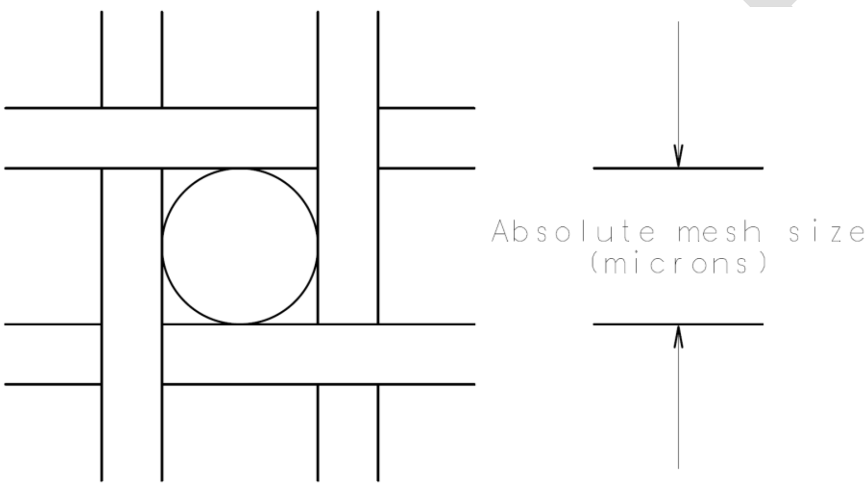


Figure A19: Definition of absolute mesh size

Experience shows that the nominal mesh figure is approximately 30-40% smaller than the corresponding absolute mesh figure. The removal characteristics of the surface filter is such that it removes particles bigger than the specified mesh size with a high efficiency, but smaller particles with a lower efficiency.

In order to avoid misunderstandings, it should always be defined whether "maximum sphere passing mesh" (absolute mesh size) or "nominal mesh" is meant.

Filter Efficiency

The filter's removal efficiency is sometimes presented as the "Beta value". This Beta value is defined as "number of particles bigger than a specified size before filter divided by the number of particles bigger than the specified size after filter". A dedicated filter test, namely the "Multi-Pass test", is detailed in ISO 4572.

Guidelines for Piping Design & Construction

The following is recommended for the design and construction for the piping in the system lubrication system:

- **a)** Pipe dimensions have to be in accordance with requirements of the classification society.
- **b)** The shortest possible piping design with a minimum of bends is to be used.
- **c)** All welds have to be accessible for mechanical cleaning and grinding.
- **d)** Use of a minimum number of flanges, preferably of the spigot type, is recommended. All flanged connections, flanges and valve lengths should comply with recognised international standards.
- **e)** Clip fitting is to be used to prevent vibration.
- **f)** Piping layouts must permit absorption of expansion and contraction.
- **g)** Flexible fittings should preferentially be used.
- **h)** Piping in the neighbourhood of pumps and heat exchangers in general is to be arranged such that it permits the overhaul of the units with a minimum dismantling of the piping system required.
- **i)** Care must be taken to minimise the number of pockets in pipe lines. Where pockets do occur, they must be fitted with drain cocks or valves.
- **j)** Piping should be installed for stress-free mating with the flanges of the engine and all its auxiliaries (coolers, filters, heaters, thermostatic valves etc.)
- **k)** Sampling cocks must be installed according to CEC M-12-T-91.
- **l)** Pipe vibrators or shock facilities are to be considered for flushing application.
- **m)** Flow velocities of oil to must be related to the inside diameters of the pipes.

During the production of the pipe system, the following procedures are essential. Note that they form only part of a wider flushing procedure which has to be followed.

- Grind all welding inside the pipes and elsewhere to remove welding burrs.
- Clean all pipes with acid before fitting.
- Neutralize the cleaned pipes after acid cleaning.
- Flush all inside surfaces very carefully.
- Ensure the pipe system is sealed after flushing or filled with the lubricating oil to be used.

Guidelines for the Oil Cooling Circuit Design

It is essential that the lubricating oil inlet temperature meets the specification of the engine manufacturer (normally 40-50°C at the engine inlet). The lubricating oil cooler capacity must be sized accordingly.

The lubricating oil cooler can be cooled by fresh water or sea water.

The following information is necessary for calculating the size of the cooler:

- heat dissipation at 110% engine load,
- lubricating oil flow, maximum pressure drop on oil side (0.5 bar typical),
- lubricating oil outlet temperature (45°C typical),

- sea water inlet temperature (32°C typical) or
- fresh water inlet temperature (36°C typical)
- fouling margin (+15%).

Required System Design Information

It is common practice to allow for a system oil quantity of between 0.5 to 1.5 kg/kW (depending on engine design) for the total oil charge. In order to assure that the engine's requirements are met, the engine manufacturers provide the following guidelines to the system lubricant system designer (typically a shipyard):

a) A principal diagram, showing all components. The oil circuit and the oil cleaning circuit should be included. The oil type to be used and a tolerable cleanliness level should be specified.
b) The filter type to be installed. A filter mesh size of 30 to 50 micron (absolute) is a typical recommendation for the inlet of system lubricant to the engine. Some engines, and in particular those with electronic control, have a fine filter of down to 6 micron absolute mesh size for the system oil used to power and/or control fuel and oil injection systems. Typically, the main filter is dimensioned according to the nominal oil flow rate and to the design pressure drop

c) The required full and bypass flow rates.

d) The required lubricating oil pressure at the engine inlet.

e) The required lubricating oil inlet & outlet temperatures.

f) The maximum allowable pressure drop in the lubricating oil coolers.

g) Cooling capacity requirements.

h) A list of all alarms and shut down criteria.

i) The cleanliness level required before commissioning.

Safe and reliable operation of the engine is very much dependent on meeting all the above requirements.

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CIMAC Central Secretariat
c/o VDMA e. V.
Lyoner Strasse 18
60528 Frankfurt, Germany
Phone +49 69 6603-1355
Fax +49 69 6603-2355
E-mail: info@cimac.com

President: Klaus M. Heim
Secretary General: Peter Müller-Baum

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