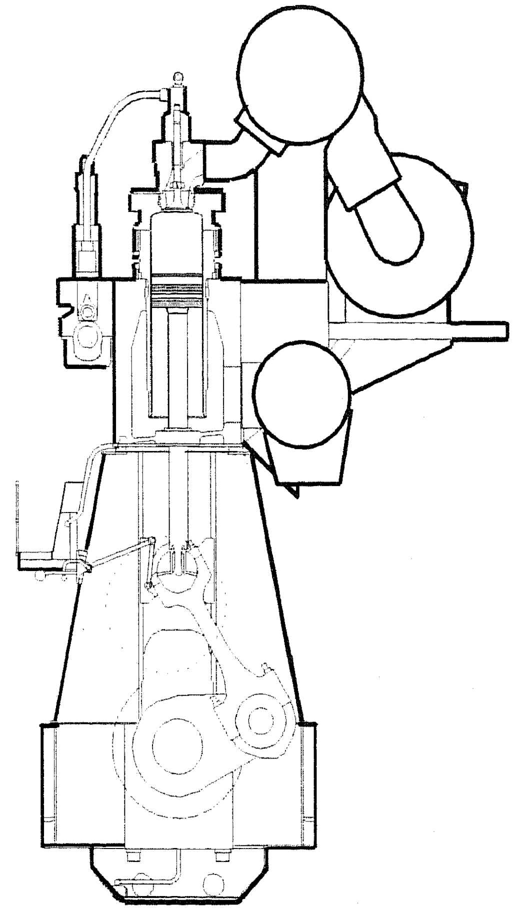
Number 15 | 1997



GUIDELINES FOR THE LUBRICATION OF TWO-STROKE CROSSHEAD DIESEL ENGINES

The International Council
on Combustion Engines

Conseil International des
Machines à Combustion

CIMAC is an international organisation, founded in 1950 by a French initiative to promote technical and scientific knowledge in the field of internal combustion engines (piston engines and gas turbines). This is achieved by the organisation of congresses and working groups.

It is supported by engine manufacturers, engine users, technical universities, research institutes, component suppliers, fuel and lubricating oil suppliers and several other interested parties.

The National Members Associations and previous CIMAC Recommendations still available are listed in the back of this publication.

This document has been elaborated by the Working Group "Lubricants" and approved by CIMAC on June, 30 1997

Le présent document a étè éleboré par le Groupe de Travail "Lubrifiants" at approuvé per CIMAC le 30 Juin 1997

FOREWORD BY THE PRESIDENT

Reliability and availability are today of paramount importance to all users of internal combustion engines. Inherent engine design reliability must be complemented by a suitable periphery and by the appropriate choice and treatment of working media such as fuel, lube oil etc.

CIMAC Working Groups have a long tradition of preparing recommendations and guidelines for the internal combustion engine industry and it users. In performing this work, CIMAC takes advantage of its wide and competent international membership.

After CIMAC issued its worldwide acknowledged heavy fuel recommendations for diesel engines, it was logical to subsequently devote attention to the lubricants and the lubrication systems.

The "Marine Lubricants" Working Group started its work in 1987 and - as a first step - dealt with the medium speed engines. Experts from the diesel engine industry, oil companies, equipment suppliers, etc. worked out a recommendation, issued in 1994 as CIMAC Recommendation No. 13 "Guidelines for the lubrication of medium speed diesel engines".

Its contents are of practical use to diesel engine users, manufacturers, shipyards, engineering companies, oil suppliers etc.

In a second step, started in 1994, the lubrication of two-stroke low speed diesels has been considered. This work was finalised in 1997, and the results are presented in the current recommendation.

I am convinced that this recommendation will be appreciated and used by the industry and engine users all over the world and will thus contribute to the reliable operation of two-stroke low speed engines.

Peter Sunn Pedersen

GUIDELINES FOR THE LUBRICATION OF TWO-STROKE CROSSHEAD DIESEL ENGINES

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GUIDELINES FOR THE LUBRICATION OF TWO-STROKE CROSSHEAD DIESEL ENGINES

1. INTRODUCTION

Fuels and lubricants are integral and intimately related to the operation and performance of low-speed diesel engines. That is why CIMAC identified the contribution of fuels and lubricants for need of better understanding.

Following the successful work of the CIMAC Working Group on "Fuels", another working group on lubricants, was formed in 1987 with the aim to develop a generally accepted user language on the lubrication of non-automotive diesel engines, giving priority to medium-speed, over two-stroke crosshead and high-speed engines respectively. The "Guidelines for the Lubrication of Medium-Speed Diesel Engines" were published in 1994.

These guidelines compile insights generated by the Group members who represent users, engine and equipment manufacturers, institutions as well as additive and lubricant suppliers, into the lubrication of two-stroke crosshead diesel engines.

The composition of the CIMAC Working Group "Lubricants" is given in Appendix 1.

The sections of these guidelines deal with:

- the engine and its lubrication
- the cylinder lubrication
- the system lubrication
- the handling of drain and waste oils
- the analysis of oils in service
- health, safety and environmental aspects
- trouble-shooting

By compiling the Working Group's conclusions on these topics the work is not over. The ultimate target, as given in the Terms of Reference, remains unchanged and is:

The Working Group trust their conclusions will provide a substantive platform on which the industry at large can operate towards optimising the lubrication of today's and future engines for a variety of existing and forthcoming fuels.

1.1 Purpose & Scope

42 The 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 the operation, servicing and fluid selection practices and to the advice available from lubricant suppliers.

Engines may be operated under test-bed conditions, in the shipyard, undergoing sea trials or 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.

43 The 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.

2. USER LANGUAGE

2.1. The Engine

Low-speed, two-stroke crosshead diesel engines are normally used as prime movers in ships, but are also used for electricity generation in land-based power plants. Generally the term low-speed is applied to engines with a rotational speed of up to 300 revolutions per minute. The output per cylinder of such engines covers a range from about 400 kW to over 6000 kW providing, in a 12 cylinder engine for example, a total output in excess of 70000 kW.

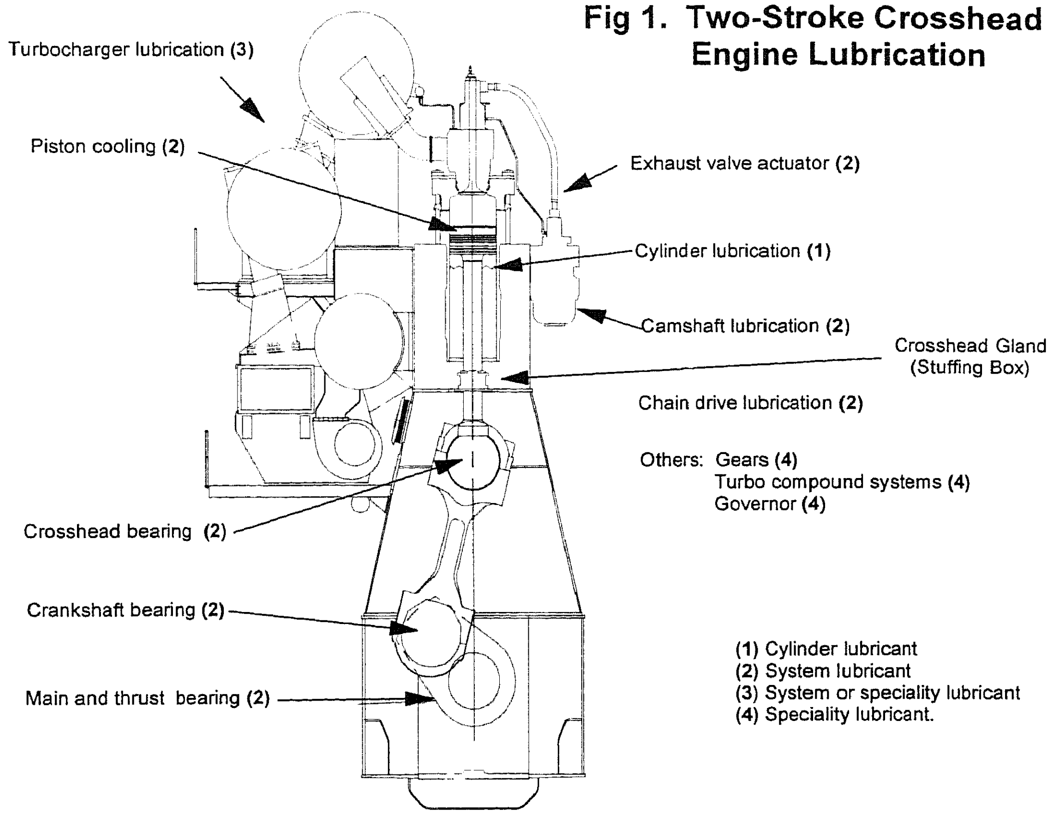
The most common crosshead engines in the 1990's are of the oil-cooled piston type, burning heavy fuel oil and having all or most of the following main features and associated parameters:

- large bore	260-980 mm
- high stroke-to-bore ratio	up to 4.2:1
- high BMEP	up to 19 bar
- maximum cylinder pressure	up to 160 bar
- mean piston speeds	approx 8.5 ms^{-1}
- combustion over wide crank angle	
- uniflow scavenge system	
- variable and controlled fuel injection timing	
- Power Take Off (PTO) and/or Power Take In (PTI) systems	
- crosshead and diaphragm to separate the cylinder from the crankcase.	

The most distinctive features are the connection between the piston and crankshaft and the separation of the cylinder from crankcase spaces. The connection is not direct but is provided by a reciprocating guide, the "crosshead", that converts the linear movement of the piston into the rotational motion of the crankshaft. The separation of spaces is achieved by a plate (or diaphragm) cast or welded on the top of the crankcase box, with provision for the linear motion of the piston rod through a stuffing box or gland. Figure 1 illustrates the principal design features of this type of engine.

This design enables the lubrication of the cylinders and crankcase components to be dealt with separately by oils optimally selected for each purpose, as illustrated in Figure 1.

Fig 1. Two-Stroke Crosshead Engine Lubrication



2.2 The Lubricant

The engine lubrication is separated into two major areas employing two or three types of lubricants respectively, ie.

- (i) cylinder lubrication, comprising the protection of piston rings, piston grooves and cylinder liners from the effects of combustion processes.
- (ii) system lubrication, encompassing bearings and camshaft lubrication, cooling of piston undercrowns and functioning as hydraulic fluid for valve actuation.
- (iii) specialised oils for hydraulic circuits, gear oils in PTO/PTI systems or for turbocharger bearing lubrication.

For the lubrication of the bearings, and for piston cooling, an alkaline lubricant of BN between 4 and 12 of SAE 30 viscosity grade is normally recommended. The system oil performs its several functions by means of a circulating supply and maintenance system and remains in service for extended periods.

For the lubrication of cylinders the oil must have sufficient viscosity at operating temperatures to maintain a hydrodynamic film to prevent metal to metal contact between piston rings and the liner walls. Also the lubricant needs good spreading characteristics to provide an oil film over the whole swept area of the liner and be able to neutralise acidic products. When high sulphur heavy fuel oils are burnt these various requirements generally are met by oils with viscosities within the SAE 50 grade and whose alkalinity, a measure of neutralising capability, is indicated by a BN of about 70 mgKOH/g.

Engines are evaluated on performance. As lubricants are an integral part of the engine and its systems, they provide an essential contribution to the total performance and reliability of the installation.

Therefore the performance criteria that accurately specify the key functions of the lubricants are:

- to "protect" the engine's components and mechanisms which - without an appropriate lubricant - would fail.
- to ensure that the lubricated engine components remain in a serviceable condition for an acceptable period.

The details of cylinder and system lubrication are discussed in the following two chapters.

3. THE CYLINDER LUBRICATION

3.1 <u>Principles of Cylinder Lubrication</u>

The purpose of cylinder lubrication is to:

- Provide a hydrodynamic film between rings and liners. [Lubrication]
- Provide a gas seal between rings and liners. [Sealing]
- Protect the liners, pistons and piston rings from the harmful effects of the combustion of heavy fuel oils. [Detergency]
- Provide an effective fluid to neutralise acidic components. [Alkalinity]
- Minimise deposit formation to allow free movement of piston rings. [Detergency, dispersancy]

Cylinder lubricants are specially formulated to perform in the specific environment of the combustion chamber. As engine development proceeds the temperature and pressure conditions to be endured by lubricant and engine components alike become ever more severe.

The correct engine operation ensures that the optimum provision of the cylinder lubricant to the critical ring/liner interface is maintained. Detailed advice on cylinder liner temperature distributions, oil feed rates, oil injection timings and maintenance to ensure the necessary protection is given in the engine manufacturers' instruction manuals.

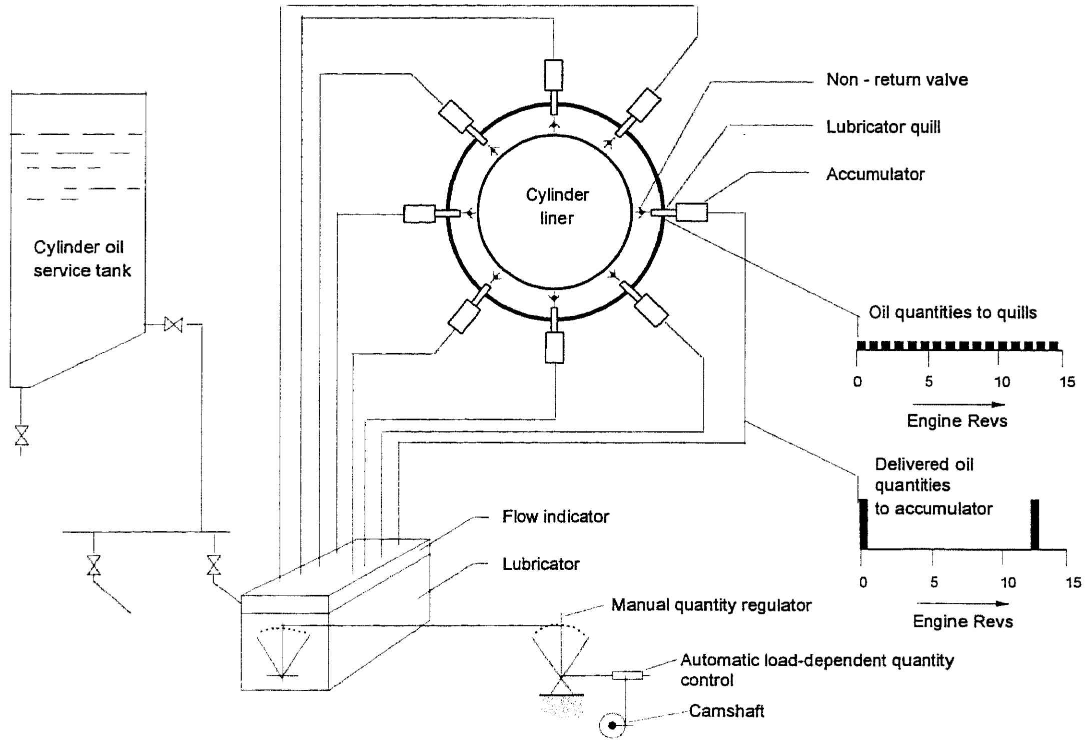
The selection of a lubricant depends upon the quality of the fuel, the mode of engine operation and the economic criteria applied by the owner. This could result in a wide range of different lubricants being required in the operation of the engine. To simplify the choice certain principles are applicable as described in the following paragraphs.

3.2 Cylinder Lubrication System

The cylinders in a crosshead engine are lubricated by a separate system working on a once-through principle, i.e. fresh lubricating oil is directly supplied to the cylinders to provide lubrication for the liners, pistons and piston rings. The main components of such a system are the storage tanks, lubricators delivering the oil under pressure to the individual cylinders, the necessary pipe system and a control device securing and adjusting the necessary flow rates and timing.

A typical arrangement of a cylinder lubricating system is shown in Figure 2.

Fig. 2 Typical Arrangement of Cylinder Lubrication System



A service tank holding a supply of about 48 hours of normal consumption is typically located in the engine room. From this tank the oil flows by gravity to the lubricators. The lubricators can be of different design piston-type pumps, either driven mechanically or more commonly on modern engines by a hydraulic system. The lubricators force the oil through pipe connections via check valves to the individual cylinders where a number of bores in the liner wall feed the oil onto the surface of the cylinder liners. The bores called quills are connected by grooves, machined in the liner surface. The quills provide an effective distribution of the oil around the liner and to the piston and piston rings. Thus, by the circumferential arrangement of the quills and by the movement of the piston the oil supplied by the lubricators is spread over the surface of the liner enabling the oil to build up a film necessary for the lubrication of the cylinder.

There are variations in the arrangement of the quills, the number of the oil quill rows, their positions relative to the top dead centre and the shape of the distribution grooves, representing the different designs of the individual engine builders.

3.3 Performance Features of Cylinder Lubricants

The requisite features of the cylinder lubricant that enable it to provide protection to piston rings/liners and exhaust systems are detailed below.

3.3.1 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,
to adhere to it,
and to form a coherent film on the surface.

In order to achieve this the cylinder lubricant must be formulated to balance its rheological or viscometric properties with the appropriate surface activity derived from the active, performance enhancing additives.

3.3.2 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 induced within the combustion chamber. The principal mechanism of wear is corrosive which is counteracted by the inclusion in the lubricant of corrosion inhibitors typically a high alkalinity, inorganic base. This component is derived from stable, colloidal dispersed carbonates, hydroxides or acetates. Highly overbased detergents are typically employed.

Given the pressures between rings and 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 wall temperature or by incorporating specially selected anti-wear additives.

In addition to corrosive and adhesive wear processes, the ingress of particulates from combustion gases may 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 catalyst fines found in heavy fuel oils.

3.3.3 Deposit Control

The continuing optimal operation of the two-stroke crosshead diesel engine depends substantially upon the correct behaviour of piston rings. Given adequate protection from wear processes, the rings and piston grooves need to retain their initial clean state for as long as possible. 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 during fuel combustion and by thermo-oxidative changes to the lubricant itself.

Since the cylinder oil is used on a "once-through" basis, the risks of exhaust duct fouling and turbocharger deposits must be minimised by careful selection of oil components. If deposits derived from the combustion of oil stick to the turbocharger blades and nozzle ring then surging can occur. In more extreme cases burning of oil mists may lead to turbocharger overspeeding or even explosions. Good maintenance, regular cleaning and adequate but not excessive cylinder oil feed rates will minimise deposit formation. Additionally the ability to prevent fouling of scavenge spaces represents an important area for oil performance.

3.3.4 Lubricating Oil Influence on the Catalyst System for Emission Control

If selective catalytic reduction is used for NOx emission control, fouling of the catalyst channels by calcium sulphate 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 to reduce hydrocarbons and carbon monoxide emissions, poisoning of the catalyst is possible. Some catalyst types, mainly precious metals, are quite sensitive to zinc and phosphorus. As some cylinder lubricants may contain zinc and phosphorus, this should be taken into account by seeking the advice of the catalyst manufacturer.

3.4 <u>Oil Feed Rates</u>

To perform the lubricating functions a certain quantity of oil must be delivered to the cylinders.

The quantity of cylinder oil to be supplied to the engine is usually expressed in grams per kilowatt hour (g/kW-hr) and should be adjusted according to the needs of the specific engine or the mode of operation. Normally, the primary setting of the lubricators refers to the nominal output of the engine. In modern designs, the quantity of oil is controlled by a device varying the oil flow in relation to the speed and output of the engine. This device ensures safe and economical oil supply at all loads and speeds. In addition each lubricator element can usually be adjusted to meet the needs of a single cylinder unit, possibly during running-in after an overhaul.

Since the designs of the individual engine builders may vary in several details, it is necessary to refer to their detailed instructions given in their relevant literature such as instruction books, service bulletins etc. whenever an adjustment is to be carried out.

Feed rates are subject to a number of technical considerations. Excessive feed rates can promote fouling of the engine by build-up of deposits on piston crowns, exhaust valves and in the scavenge ports, while too low feed rates promote wear of piston rings and liners. The type of wear may be corrosive attack of these components because of insufficient supply of alkalinity. In this case, there is not enough reagent to neutralise the acids formed in the combustion of sulphur containing fuels. A secondary effect of corrosive attack on the liner material is abrasive wear. This is caused by particles loosened from the matrix of the liner material and transported by the movement of the piston rings along the piston stroke.

Another type of wear, known as adhesive wear (scuffing), occurs mainly when the oil film between the piston rings and the liner breaks down causing direct contact and micro welding between these two components. Too low feed rates enhance the risk of scuffing of piston rings because a certain amount of oil is needed to build up and maintain a hydrodynamic oil film all over the swept surface of the liner.

While generally feed rates of between about 1.0 to 1.6 g/kWhr are recommended for modern engines it may be advisable to deviate from such figures under certain circumstances. Factors which may influence the cylinder lubrication are:

- type of fuel used, primarily its sulphur content
- load pattern of the engine operation
- cooling water temperature setting
- water removal efficiency in the scavenge air
- running-in condition of rings and liners

The combustion of higher-sulphur fuel produces more acids which need also more alkalinity for their neutralisation than for fuels of comparably lower sulphur content.

Engines operating constantly at full load also need maximum protection since there is less safety margin against a possible overloading or other irregularities in service.

Engines not operating at the optimal cooling water temperature may be subjected either to

(a) increased acid formation because the liner temperature is well below the acid dew point.

(b) thinning of the oil film if liner temperature is too high.

In either case a reduced supply of cylinder oil would be detrimental.

The technical considerations reviewed above form the basis for an informed choice of lubrication for the task and ultimately for safety and optimised economy of operation.

3.5 Running-In

The running-in of new engines or new liners and piston rings after an overhaul is regarded as a critical phase in engine operation. It is advisable to observe a number of safety precautions which have been well proven in practice to safeguard against damage of cylinder liners and piston rings. Use of low-sulphur fuel, i.e. of less than about 0.5% sulphur content, is to be avoided during the running-in phase because there is insufficient acid produced which is considered helpful to promote some corrosive wear. If such fuels cannot be avoided, the running-in process must possibly be extended over a longer period and the load increased carefully with frequent visual control of the condition of the piston rings. While engine builders have their own recommendations to be followed for the running-in procedure, some general recommendations regarding the cylinder lubrication aspects are given. They are:

(a) The main purpose of the running-in procedure in a diesel engine is to achieve as quickly as possible the bedding-in of the piston rings on the liner surface. This ensures a good sealing effect which prevents the blow-by of the hot combustion gases which in turn can destroy the oil film between the liner and the piston ring. A new liner with insufficiently bedded-in rings cannot endure full power. Therefore, the engine speed and load can only gradually be increased over several hours of operation to give the rings the opportunity to adapt to the increasing combustion pressure.

(b) The bedding-in process is facilitated by some corrosive wear of the liner. For this reason, a lubricating oil with a high neutralisation effect i.e. with a high BN is not desirable during the first few hours of the running-in phase. In the past it was considered good practice to use an oil, without any neutralisation effect, to promote corrosive wear. Modern highly loaded, crosshead engine operate at higher liner wall temperatures which cause coking and deposit formation of such oils. Instead, a light-alkaline detergent type oil is normally recommended since these oils have enough detergency to control fouling of the piston ring area. The viscosity of the running-in oil is the same as the normal cylinder oil namely SAE 50.

(c) If running-in has to be carried out with low sulphur fuel ie of less than 0.5% sulphur content, then the process should be extended and the load increased carefully. Normally a low BN cylinder oil would be preferred.

(d) The very first hours of the running-in process should be run with an increased feed rate and this should be decreased in steps over several hours until the nominal feed rates are reached.

While the initial running-in process as described here is in the order of some 10 to 20 hours, it takes several thousand hours before the optimum condition of the piston ring/liner system is established. This will result in normal values of liner and piston ring wear rates.

The above guidance is for an ideal situation. Sometimes a low BN, SAE 50 oil is not available. Also one lubricator box may supply two cylinders and only one cylinder may require running-in. In such circumstances the normal cylinder oil is to be used at an increased feed rate. Also greater vigilance is to be exercised on the running-in condition of the rings and liners by more frequent visual inspections during a slow increase in engine power.

3.6 Selection Criteria for Cylinder Lubricants

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

3.6.1 Fuel in use and type of operation.

A list of current specifications on fuels for diesel engines is:

ISO8217/CIMAC specification.
Supplier specifications where/if different
Engine manufacturers minimum requirements

The following are examples of operation that are different from normal HFO and high alkaline cylinder oil usage and may require different types of cylinder lubricants:

Running-In:	If a running-in oil is required this should have a viscosity of SAE 50 and a low BN. Cylinder Oil Detergency is needed
Dual Fuel Operation :	Normally gas and diesel fuel. For a suitable lubricant refer to the engine builder.
Poor Fuel Quality:	Some heavy fuel oils give rise to combustion problems which increase demands on lubricant performance. Detergency and dispersancy are more important than the BN of the lubricant.
Emission:	If special fuel has to be used for prolonged periods then the lubricant quality and feed rate need to be adapted.

3.6.2 Wear and Economics of Cylinder Lubrication

Minimising operational costs is a balance between acceptable wear rates of engine cylinder liners and piston rings (and thus time between overhaul) and the amount of cylinder oil consumed. The following are some of the factors that have to be taken into account:

Average Engine Load Factor :	Low or high lubricant feed rates may give rise to high wear rates.
Design/Age of Engine:	More modern engines are less sensitive to corrosive wear due primarily to higher liner temperatures.
Alkalinity Throughput:	Increased alkalinity throughput does reduce wear. Use of higher base number lubricants and the selected feed rate needs to be balanced against the overall cost of engine operation .
Oil Film Viscosity:	The lubricant should have a viscosity high enough to provide a hydrodynamic film on the liner but low enough to be able to spread across the whole surface.

4. THE SYSTEM LUBRICATION

4.1 Principles of System Lubrication

The purpose of the system lubricant is to:

(a) provide lubrication to the crankshaft bearings, camshaft and crosshead slides;

(b) provide lubrication for ancillary drives such as power-take-offs.

(c) provide cooling to pistons when required by engine design;

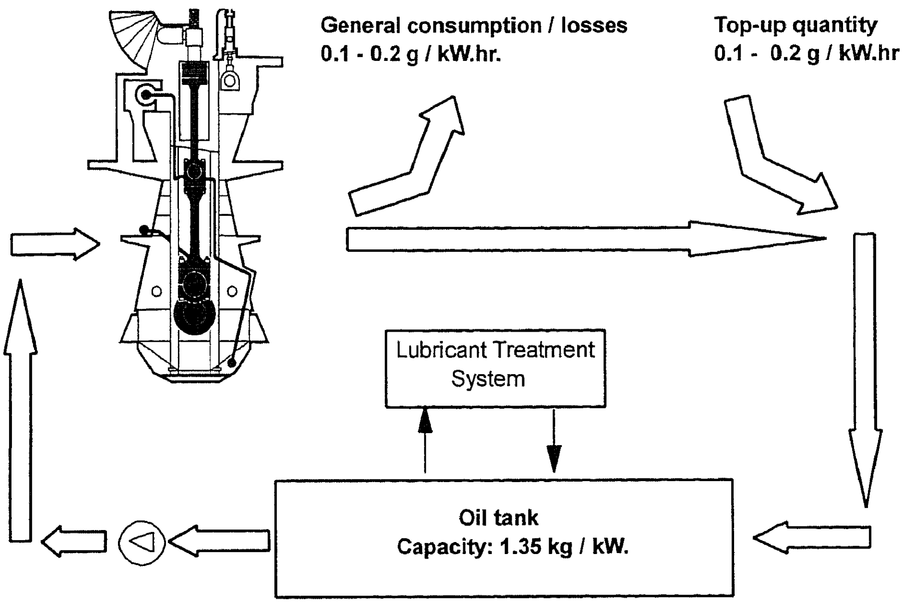
(d) perform the functions (a) to (c) for extended periods.

System lubricants are formulated to meet the wide ranging load and lubrication requirements. They remain in service for extended periods and require only to be replenished due to losses and to be effectively cleaned in a separator.

With a system oil consumption of 0.1 to 0.2 g/kWh and a system content of typically 0.75 to 1.5 kg/kW (dependent on engine design) the time to replenish the entire volume in the crankcase system is approximately 7500 hours. Figure 3.

Fig 3 System Oil Circulation Rate and Replenishment Speed

	B&W	15 -18,
Circulation rate : Times / hour.	Misubishi	9 - 15
	Sulzer	8.5 - 13.3



To obtain the maximum life of the crankcase 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 necessitating a complete oil change.

Achieving the most efficient balance is very much dependent upon the capacity and operation of the lubricant maintenance system detailed at Section 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 oil should inform the user on what he has ordered, and that the product is meeting the engine manufacturer's specifications. They allow conformance control but cannot give complete information on the performance to be expected in an individual engine under individual conditions. The system lubricant is specifically required to provide:

4.1.1 The Lubrication of Bearings, Crosshead Shoe, Drive Gear/Chain, Crankcase.

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

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. Typically SAE 30 lubricants are used.

4.1.2 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. 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 separability and anti-foaming.

4.1.3 Other Lubricated Components (e.g. Turbocharger, Camshaft, Exhaust Valve, PTO/PTI Units, etc)

(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 more critical in PTO/PTI systems where specific load carrying is essential.

(b) PTO/PTI (Power Take Off/Power Take In systems. For lubrication of the PTO drive gear wheel, there may be a minimum "load carrying" requirement as measured by an anti-wear and EP gear test. (FZG performance)

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 much higher FZG and specific hydraulic oil performance.*

(c) Exhaust Valve Hydraulic Control System. In the function of a hydraulic oil, the foaming, air release, load carrying, and water tolerance properties are relevant.

(d) Turbocharger Bearing Lubrication (some engine designs). Requirements here are for lubricity, oxidation stability, thermal stability and anti-foam.

Many engine designs have turbochargers with a separate dedicated oil charge and needing a special lubricant.

Other parts of the engine having separate dedicated systems and utilising special lubricants are:

(e) Turning gear. Has its own separate oil system and is typically filled with an ISO VG 220 gear lubricant.

(f) Hydraulic Governor. A lubricant of suitable viscosity at typical operating temperature would normally be specified by the equipment manufacturer. The lubricant also needs to have rust and oxidation inhibitors and good anti-foam and air release properties. Depending on the equipment manufacturer, a suitable lubricant (eg 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 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.

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

4.2.1 Dispersancy

The dispersancy defines the ability of the oil to maintain in suspension all contaminants, eg used cylinder oil drainings from the stuffing box. All the impurities must be transported by the oil to the purifier 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.

4.2.2 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.

4.2.3 Water Tolerance

The oil must be water tolerant but still provide 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.

4.2.4 Filterability

Filterability must be safeguarded in the event of water contamination. The lubricant should also be tolerant of used cylinder oil drain contaminants and have adequate dispersancy to transport solid contaminants to the centrifuge for removal. Good maintenance, good "house-keeping" and a well planned system design also help to keep stagnant areas to a minimum and free from deposits. In adverse condition, eg in rough sea, deposits could get agitated and "over-load" the filters. Section 4.5 also recommends a planned oil top-up practice to avoid destabilising the system oil charge leading to sludge precipitation and filter blockage.

The oil is circulated through the engine, at approximately 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.

4.2.6 Contamination by Cylinder Oil

4.2.5 Anti-Foaming/Air Entrainment

Contamination from cylinder drainings is possible via the stuffing box. Compatibility of the system oil with cylinder drainings is important to avoid deposits settling out and to maintain all entrained solid contaminants in suspension for removal in the purifier. 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.

4.2.7 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.

4.2.8 Viscosity and Viscosity Index

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

4.2.9 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 230°C. An adequate thermal stability is essential.

4.2.10 Detergency

In engines with oil cooled pistons, the oil has to keep the piston undercrown clean from oxidised and thermally degraded products as well as contaminants, eg 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 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.

4.2.11 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 in the case of cylinder oils. The alkalinity is defined by the base number (BN).

4.2.12 Crosshead Assembly Lubrication Requirements

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

4.2.13 Oxidation Stability

Good oxidation stability is required as the lubricant is in contact with air at high temperature within the engine. eg piston undercrowns.

4.2.14 EP/Anti-wear

Required when the system oil is used to lubricate cams and gears (such as in power- take-off systems).

Table 1 summarises engine requirements using the terminology developed.

Table 1 **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	FLUID AND SOLID CONTAMINANTS	LOW DISPERSANCY WATER TOLERANCE
	OIL COOLERS,	DEPOSITS	HIGH DISPERSANCY
	HEATERS	DEPOSITS	COMPATIBILITY WITH FUEL
CAMSHAFT/GEARS	SURFACE	WEAR, CORROSIVE, ABRASIVE & ADHESIVE	CORROSION INHIBITOR, ANTI -WEAR/EP PROPERTIES, OIL VISCOSITY
PTO/PTI UNITS	SURFACE	WEAR ADHESIVE & ABRASIVE	ANTI--WEAR/ EP PROPERTIES OIL VISCOSITY
VARIOUS HYDRAULIC SYSTEMS, EG EXHAUST VALVE	PERFORMANCE EFFICIENCY	LOSS IN EFFICIENCY	ANTI-FOAM/AIR RELEASE, ANTI-WEAR/EP PROPERTIES TOLERANT TO WATER CONTAMINATION
CROSSHEAD SHOE	SURFACE	WEAR CORROSIVE & ABRASIVE	CORROSION INHIBITOR, OIL VISCOSITY COHESION/SPREADABILITY
TURBOCHARGER BEARING	PERFORMANCE	LOSS IN PERFORMANCE LEADING TO WEAR	ANTI-FOAM
	SURFACE	WEAR CORROSIVE, ABRASIVE & ADHESIVE	CORROSION INHIBITOR OXIDATION STABILITY THERMAL STABILITY LUBRICITY, VISCOSITY
MULTI-PURPOSE APPLICATION AS MEDIUM SPEED ENGINE OIL	VARIOUS SEE GUIDELINES FOR MEDIUM SPEED ENGINES	VARIOUS SEE GUIDELINES FOR MEDIUM SPEED ENGINES	VARIOUS SEE GUIDELINES FOR MEDIUM SPEED ENGINES

4.3 The 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.

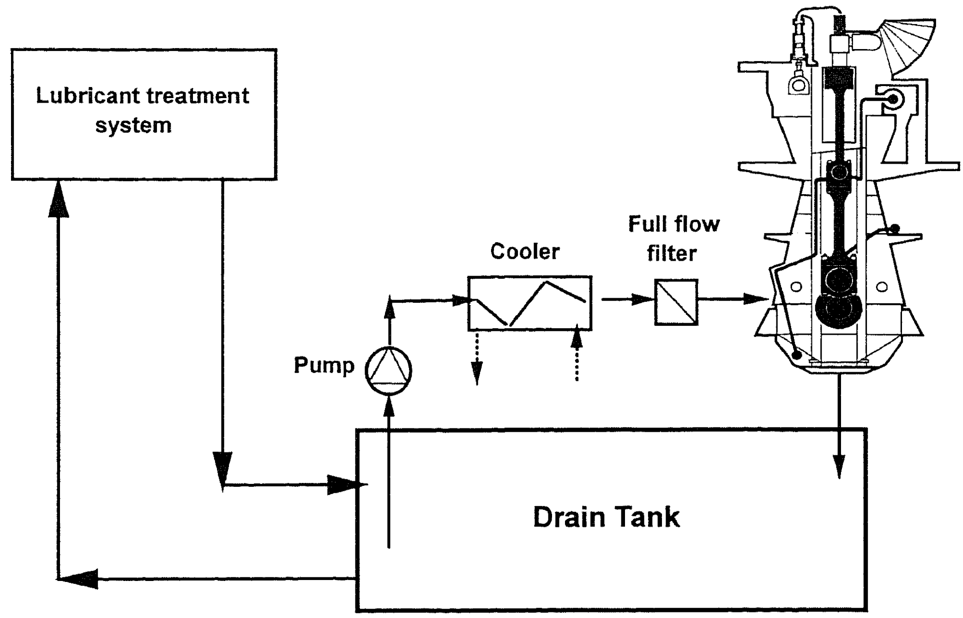
4.3.1 Design

It is common practice to allow for an oil quantity of between 0.75 to 1.5 kg/kW (depending on engine design) for the oil tank charge. In order to assure that the engine's requirements are met, the engine manufacturer provides the following guidelines:

- 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. Figure 4 is a simplified system diagram showing all major components.
- The filter type to be installed. A filter size of 50 micron absolute appears to be a typical recommendation. It is, furthermore, recommended to dimension the main filter according to the nominal oil pump capacity (flow rate) and to the design pressure drop (0.5 bar is typical).
- The required flow rate.
  Lubricating oil pressure at inlet to the engine.
  Inlet/outlet temperature, max./normal/min.
- The max. pressure drop in lubricating oil coolers.
  Lubricating oil outlet temperature. (Alternatively lubricating oil outlet viscosity).
- Heat dissipation requirements.
- A list of all alarms and shut downs should also be available.
- Recommended flow rates through a separator.

Safe operation of an engine very much relies on a qualified specification of all the above together with the cleanliness level required.

Fig. 4 Two-Stroke Crosshead Engine Lubrication System



4.3.2 Piping

- (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.
- (c) Accessibility of all welds for mechanical cleaning (grinding).
- (d) Use of the minimum number of flanges, preferably of the spigot type. All flanged connections, flanges and valve lengths should comply with recognised international standards.
- (e) Clip fitting for prevention of vibration.
- (f) Piping layouts permitting absorption of expansion.
- (g) Preferential use of flexible fittings.
- (h) Piping in the neighbourhood of pumps and heat exchangers in general to be arranged permitting overhaul of the units with minimum dismantling of the piping system.
- (i) Care to be taken to minimise 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) Install sampling cocks according to CEC M-12-T-91.

(l) Pipe vibrators or shock facilities to be considered for flushing application.

(m) Flow velocities of oil to be related to the inside diameters of the pipes.

4.3.3 The Cooling Circuit

It is essential that the lubricating oil inlet temperature meets the specification of the engine manufacturer (normally 40-50°C). 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:

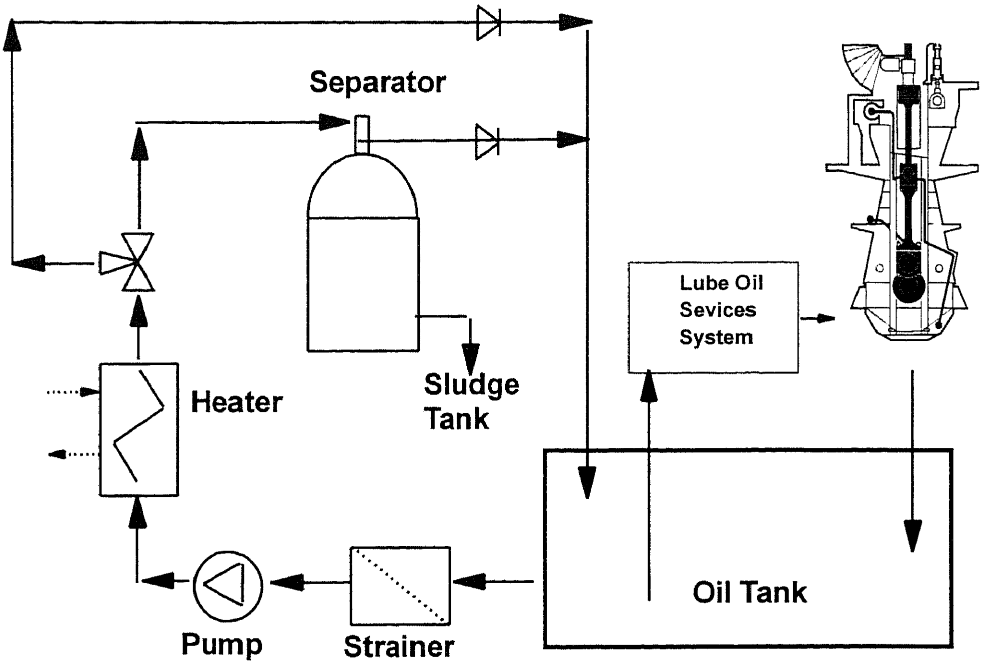
- heat dissipation at 110% engine load,
- lubricating oil flow,
- maximum pressure drop on oil side (0.5 bar typical),
- lubricating oil outlet temperature (45°C typical),
- sea water inlet temperature (32°C typical) or
- fresh water inlet temperature (36°C typical)
- fouling margin (+15%)

4.4 The Engine Lubrication

This system consists of two major parts - the lube oil service system and the treatment system. The crosshead gland (or stuffing box) drain system is dealt with separately. The lube oil service system is shown in Figure 4 and the treatment system is shown in Figure 5.

The system oil line is equipped with a pump, cooler and filter to provide a constant and uninterrupted flow of cooled and filtered lubricant to bearings, cams, oil cooled pistons etc. and to the drive of the exhaust valve hydraulic system. Not shown in Figure 4, an additional filter may be fitted for the crosshead system.

Fig 5 **Lubricant 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.

Stuffing Box Drain System

A stuffing box is fitted to separate the crankcase from the underside of the cylinder to prevent contamination of the crankcase oil system by waste cylinder oil. Consequences of this contamination can be seen in Table 2. Cylinder waste oil handling and stuffing box drain oil regeneration are important factors. They are dealt with in detail in Chapter 6.

4.4.1 The need for Cleaning and Protecting

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 contaminating the system oil.

Additionally the oil used for piston cooling can be subjected to oxidation on hot piston undercrowns giving rise to further contamination.

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	Sources	Consequences
○ Combustion Products ○ Oxidation and deteriored cylinder oil ○ Calcium salt and sulphate.	○ Combustion ○ Cylinder oil ○ Acidic products and degraded cylinder oil additives	○ Increase of viscosity and BN ○ Increase of lacquer and sludge ○ Poor anti-corrosive characteristics
○ Fuel	○ Incomplete combustion ○ Blow-by ○ Leak from fuel pump ○ Poor fuel atomisation	○ Dilution ○ Oil mist generation ○ Low oil stability ○ Deposit formation
○ Soot	○ Poor Combustion of fuel	○ Deposit formation ○ Black colouration, ○ Increase of viscosity ○ Increase in insolubles
○ Dust, sand, atmospheric contamination	○ Fuel ○ Scavenge air ○ Ore powder, etc. from cargo	○ Filter plugging ○ Wear
○ Water, salt	○ Leak from cooling system ○ Blow-by moisture condensate ○ Incorrect operation of the purifier	○ Rusting ○ Oil emulsification ○ Deposit formation ○ Scale ○ Microbial growth ○ Impact on cleaning systems
○ Metallic debris	○ Engine parts wear ○ Rust and scale	○ Wear ○ Deposit formation

4.4.2 Methods for Cleaning and Protecting

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

The centrifugal separators separate the particulate matter 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 also can 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 handling capability.

Whilst the filter for engine protection is installed as a full flow filter, the cleaning by separator is done in a by-pass circuit where only a small quantity of the oil is treated at a time. (If fine filters are used for the cleaning they also are used in by-pass). A by-pass system is optimised 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.

4.4.3 Cleaning System, Components and Operation

The major components of the oil cleaning system are the feed pump, the preheater and the centrifugal separator. See Figure No. 5. The oil is pumped from the oil tank, heated up to the appropriate separation temperature by the preheater and finally cleaned in the separator before being pumped back to the oil tank.

The suction line for the feed pump should be installed in the lowest section of the lube oil tank.

The 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.

Components

(a) Separator:

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

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

(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 Preheater:

Preheater dimensioning should not only take into account the temperature of the 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 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 which 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.

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 which is to be conveyed as a "group alarm" from an individual panel to an Engine Control position.

(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.

For treatment, 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 analysed during treatment to ensure the oil is within the engine manufacturer's used oil limits, before returning to the engine system. (see Section 7)

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

4.4.4 Dimensioning of the Lube Oil Cleaning System

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

- engine output
- type of fuel oil
- type of lube oil
- type of service
- lube 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:

$$Q = \frac{P \times z \times n}{t}$$

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 separator per day. Recommendations:

t = 24 hr	for partial desludging systems (continuous feeding of oil during desludging)
t = 23.5 hr	for total desludging systems (supply of oil is stopped during desludging)

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.

4.4.5 Recommendation for Operation

The 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 separator should always be operated as a purifier, eg being able to discharge separated water during operation.

The cleaning efficiency 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 lube oil properties.

The correct interface position should be outside the distributing holes/disc stack but inside the top disc (see Figure 6). If the interface is allowed to go into the disc stack the separation efficiency will decrease. If it is allowed to go outside the top disc the water seal will break and oil will flow into the water outlet.

In order to maintain the hydraulic balance between oil and water, the separator is equipped with a gravity disc. 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 utmost importance to ensure that these parameters are kept as stable as possible.

In the case of both the engine and purifier being stopped then before the engine is restarted it is recommended that the purifier 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 is passed through the purifier.

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:

$$Vg = \frac{d^2 (\rho p - \rho e 1) g}{18 n}$$

Vg = Sedimentation rate (m/s)
d = Particle diameter (m)
ρp = Particle density (kg/m^3)
n = Viscosity of the continuous phase (kg/m.s)
g = Gravitational acceleration (9.81 m/s^2)
ρe = Density of continuous phase kg/m^3

Both density and viscosity of the lube oil decrease when the temperature rises, thereby increasing the sedimentation rate and the separation efficiency of particles. The effect of temperature on 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 85°C to 90°C oil inlet temperature gives satisfactory separation.

Feed Pump Arrangements:

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

Oil Preheater:

The heater must always be started after and switched off before the feed pump to prevent blockages caused by coking.

4.4.6 Guideline for the Intermittent Operation of Centrifugal Separators

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.

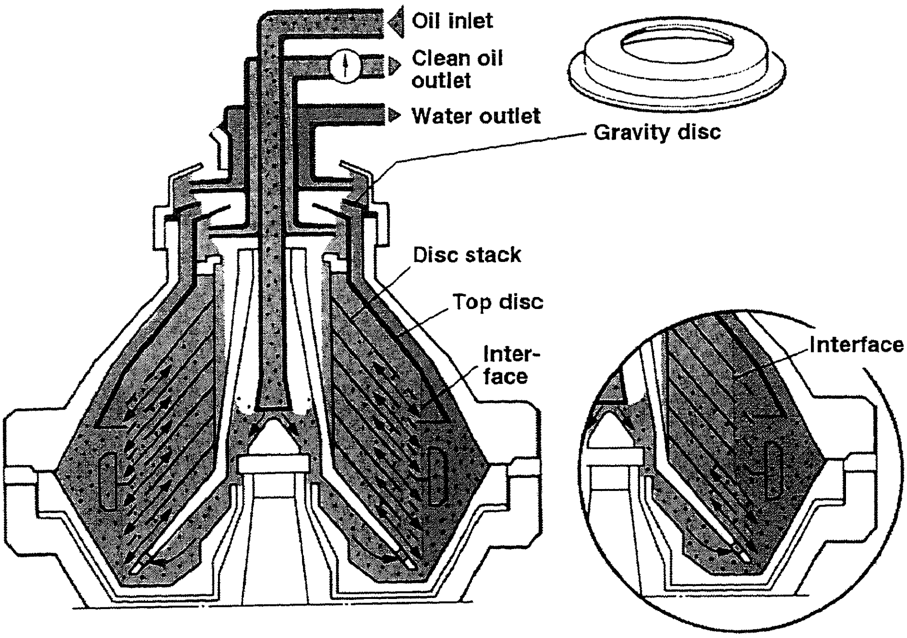
In general, crosshead engines require a minimum separator turnover rate of 2 to 3 times in 24 hours. Thus, separation should take place for a period of 8 - 12 hours before the engine is started.

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.

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.

Fig. 6 Correct Interface Position in a Purifier



4.4.7 The Engine Protection System

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.

This protection of the engine is ensured by the full flow filter placed just before the engine. See Figure 4.

There are manually cleaned, automatic backflushing as well as disposable filters.

The filters must provide a good protection for the engine but this should not be done at the cost of spending excessive man-hours on adjustment and maintenance.

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 (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:
    - motor fault
    - max. differential pressure
    - exceeded backflushing frequency
    - flushing-oil cartridge saturated
      (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. In some filter designs filtration of the backflushed oil is provided.

4.4.8 Filter Fineness

There are several definitions for filter fineness in use:

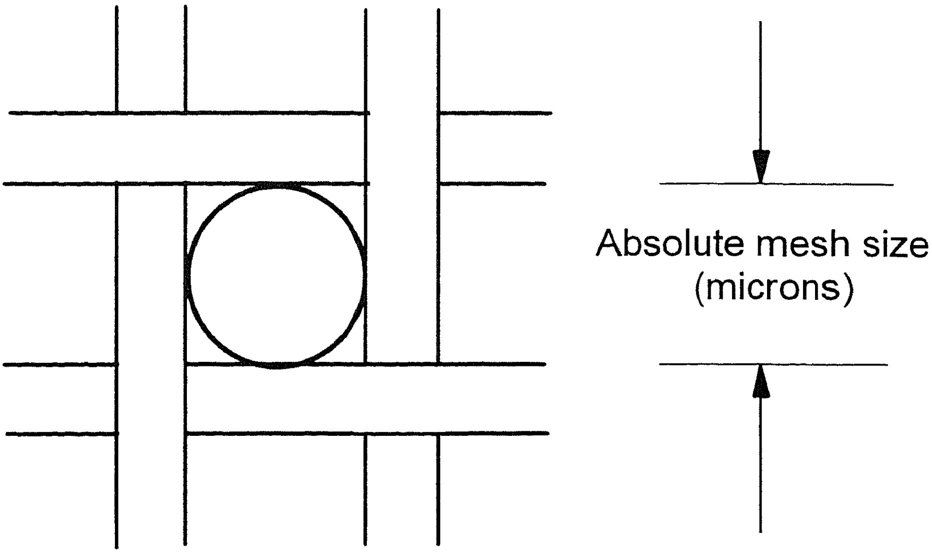
- Absolute fineness (sphere passing mesh). One definition of absolute fineness mesh size is the square opening as shown at Figure 7.

- Nominal Fineness. The nominal fineness is a practical definition. It indicates that about 85-90% of the particles bigger than the nominal fineness are retained by the filters.

Experience shows that the nominal fineness figure is approximately 30 - 40% smaller than the corresponding absolute fineness figure.
The removal characteristic of the surface filter is such that it removes particles bigger than the specified mesh 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 fineness) or "nominal fineness", together with filtration efficiency is meant.

Fig. 7 Definition of Absolute Mesh Size



4.4.9 Beta Value

The filter's removal efficiency is sometimes presented as the "Beta value" (ß). 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.

4.4.10 Installation

The filter should be placed as close as possible to the engine.

A typical filter installation for an engine operating on heavy fuel consists of:

- One automatic backflushing filter as main filter. The filter fineness is typically 40-50 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 max 0.2 bar (clean 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 increased pressure needed for backflushing.

- A manual duplex safety filter (optional).

The safety filter size is usually 80 - 100 micron absolute. The purpose of this filter is to act as safety net 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.

4.5 Lube Oil Storage and Handling

Because correct lubrication is vital to the operation of diesel engines, it is reasonable that lubricants are 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 and handled inadequately.

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 secure 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 stowage and in a horizontal position.

If for any reason it is necessary to add oil to the system in service, this should be done through a filter or via the lube oil purifier.

For topping-up of the system oil no more than 10%, preferably less than 5% of the total content should be added at a time if possible. Reasons for this are to keep an equilibrium and to avoid potential risks of sludge precipitation and 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.

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

4.6 Preparation and Flushing of the Lubrication System

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

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.

- to grind all weldings inside the pipes and elsewhere to remove welding burrs,
- to clean with acid all pipes before fitting,
- to neutralize after acid cleaning,
- to flush all inside surfaces very carefully,
- to ensure the pipe system is sealed after flushing or filled with the lubricating oil to be used.

Flushing the System

- Develop a flushing diagram and procedure.
- All flushing to be executed in one direction only.
- Close attention to be given to flushing of pipe ends.
- All tanks inspected before filling with oil.
- Oils added into the system through a filter and/or purifier.
- Flow to be turbulent (Reynolds Number above 3000).
- Oil temperature to be ideally 65°C but not less than 55°C.
- Pipe vibrators or shock facilities to be fitted.
- A flushing filter, with a mesh finer than the original system filter to be fitted during the flushing process.
- The purifier to be in service.

The flushing has to be continued until the pre-determined cleanliness level of the system and the lubricant is achieved. Ideally check-back filter and particle counting should be employed. Normally the cleanliness level is specified by the engine manufacturer.

When the cleanliness of the pipes is acceptable, the lub 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 oil 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 flushing medium. However, a thin flushing oil, typically SAE 20, compatible with the lubricant can also be used.

4.6.1 Running-in

It is well known that many contamination products are released during the running-in period. 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.

4.6.2 Service Overhaul and Repair

When executing an overhaul or repair during later service there is always a risk that particles may enter the engine. It is therefore essential that great care is taken to keep these out from the engine and the lubricating system. To prevent external contamination all openings in the lubricant system should be blanked off during such periods.

4.7 Selection Criteria for System Lubricants

It is the responsibility of the engine manufacturer, who in close co-operation with the lubricant suppliers must specify the preferred type and grade. A general picture of the available options is shown in Table No. 3. Individual deviations from this basic scheme appear less advisable due to vessel's lubricant grade rationalisation and the logistical problems to be envisaged when asking for a tailor-made formulation in minor ports.

Table 3 **SELECTION OF SYSTEM OIL**

APPLICATION	VISCOSITY	OXIDATION STABILITY & HIGH TEMP. DETERGENCY	DISPERSANCY & MULTI-PURPOSE PROPERTIES	R&O 0-2 BN	ALKALINE 4 - 6.BN	ALKALINE 8-12 BN
WATER COOLED PISTON ENGINE DESIGN	SAE 30	CAN ACCEPT LOWER	FLEXIBLE	√	√	√
OIL COOLED PISTON ENGINE DESIGN	SAE 30	HIGHER	FLEXIBLE	▨	√	√
WATER AND OIL COOLED PISTON ENGINE DESIGN PLUS MULTI-PURPOSE REQUIREMENT IN AUXILIARY ENGINE	SAE 30	HIGHER	HIGHER	▨	▨	√

From the engine designer point of view the decision is based on whether the engine has oil cooled or water cooled pistons. When used as a cooling medium, oxidation stability, thermal stability and detergency are required and these needs are often satisfied by an alkaline (~4 to 12 BN) system lubricant. In engines with water cooled pistons where the oil is less stressed, R&O (rust and oxidation inhibited) oil may be considered. This type of oil may have an alkalinity of between 0 and 2 BN.

From the user end, the decision may be influenced by product rationalisation on the ship. For example, (~8-12BN) alkaline oil could be adopted typically where the system oil is also used as the crankcase oil in auxiliary engines running on MDO or MGO.

Another oil selection criteria comes from the wider use of PTO/PTI units which deploy system oil for their gear lubrication. The oil in-use also has to provide a certain FZG performance - however, most lubricant formulators are aware of this requirement, and most system oils in general use today meet at least the minimum requirement.

5. LUBRICANT COMPATIBILITY

Oils may become mixed for a variety of reasons. It may happen that because the owner changes the lubricant supplier, alternative cylinder oils or system oils may be mixed. Also system oils may become contaminated via crosshead gland leakages of cylinder oils.

5.1 Compatibility of Cylinder Oil

Because of their extremely high base number, cylinder oils contain a greater proportion of chemical additives than any other class of lubricants. While most additive systems will tolerate mixing with others to some extent, the effect of incompatibility will be most obvious in mixtures of cylinder oils. Furthermore, because additive technologies are blends of components designed to work together, a mixture of two different technologies may not perform as well as either one on its own.

For both these reasons, it is better to avoid mixing cylinder oils as far as possible. Fortunately, since cylinder oils are consumed on the total loss principle, this can easily be achieved by running down storage tanks before changing oils. If this is not possible, the oil suppliers concerned should be consulted.

5.2 Compatibility of System Oils

Interactions between system oils are possible. However, the additive content of these oils is very much lower, which makes any effect less pronounced.

Wherever possible, the system oil charge should be totally, or at least partially, replaced when changing oils. Again, if this is not possible, advice should be obtained from the oil suppliers. It is common practice for samples of existing system oil from all tanks to be taken prior to changing over from one supplier to another. Also samples of the new oil should be taken. One set of samples should be retained and one set sent to the oil supplier for analysis. This practice has been established to protect all parties in the event of any subsequent lubrication problems that may arise and compatibility of the lubricants is questioned.

5.3 Contamination of System Oils with Cylinder Drain Oil

In engines with high scavenge air pressures and long strokes, the system oil may become contaminated with large amounts of used cylinder oil. This is indicated by a rise in base number and viscosity. Less obviously, but more importantly, the detergency/dispersancy and the amount of combustion contaminants will increase. The rise in base number in itself is not cause for concern. Similarly an increase in viscosity is unlikely to cause problems although in extreme cases it could conceivably reduce oil flow rates (in oil cooled pistons, for example). However, a rise in detergency/dispersancy can reduce the ability of the system oil to shed water and solid contaminants while additional levels of combustion by-products will increase the likelihood of deposits.

For these reasons, excessive contamination with cylinder drain oil should be controlled by partial oil changes, in line with recommendations given in Section 6. Since cylinder drain oil has been exposed to combustion, its performance reserves (oxidation inhibition, stability etc) will be depleted, relative to fresh oil. Therefore BN from drain oil is not a good indicator of the additive reserve in the oil. Topping up with a diluent oil to reduce BN, viscosity and insolubles is not recommended.

6. THE HANDLING OF STUFFING BOX DRAIN OIL

The stuffing box that separates the crankcase from the scavenge spaces is designed to seal against the leakage of cylinder oil drainings down into the crankcase and also to prevent leakage of system oil up into the scavenge spaces. In fact, leakage of system oil into the scavenge space contributes to a loss in the system as well as increasing the likelihood of scavenge space fires. Leakage of cylinder lubricant (that has drained down the liner) into the crankcase will cause contamination of the system oil. If the contamination is excessive, the charge of system oil may have to be changed.

The arrangement of a typical stuffing box as shown in Figure 8 is such that it is subdivided into two or more sections. Each section incorporates a drain to allow any oil that passes the seals to be collected and treated. These collected oils are termed "cylinder drain oils" and can be handled in one of three ways:

(a) by holding in storage tanks or containers until collection is made for treatment on shore. This option is similar to the disposal of waste products (Section 9.3).

(b) by incineration on board.

(c) by returning to the system after suitable treatment.

The case for disposal (Options (a) and (b)), is very strong. Untreated cylinder drain oil is a contaminant of the system oil with significant potential for engine operational malfunctions due to impaired performance of the system oil. The severity of the contamination depends on the nature of the degraded substances and on the relative quantity of drain oil finding its way into the system. Table 4 highlights the key features of the contamination leading to the possibility of engine operational malfunctions which include: reduced heat transfer, piston undercrown deposits, and lacquer formation affecting the oil film in bearings. Ultimately in the most severe cases of contamination, there is potential for piston seizure and damage to bearings.

There is of course an economic perspective in favour of reclaiming the cylinder drain oil (Option (c)). This is particularly compelling when the amount of cylinder drain oil is substantially above the norm of about 10 litre/cyl/day and when there is no obvious and ready change to engine design and operation to reduce the amount of drain oil. In such cases, reclaiming the cylinder drain oil can be considered provided the procedure highlighted in Table 5 is rigorously followed. Briefly, the cylinder drain oil should be treated; checked for flash point on a PASS-FAIL basis; analysed for insolubles and water contents to ensure they are within limits and finally added to the system in quantities small enough to keep the charge of system oil within the prescribed viscosity limits. The anti-rust and water handling properties of the system oil should also be checked periodically.

Fig. 8 Arrangement Of Typical Stuffing Box

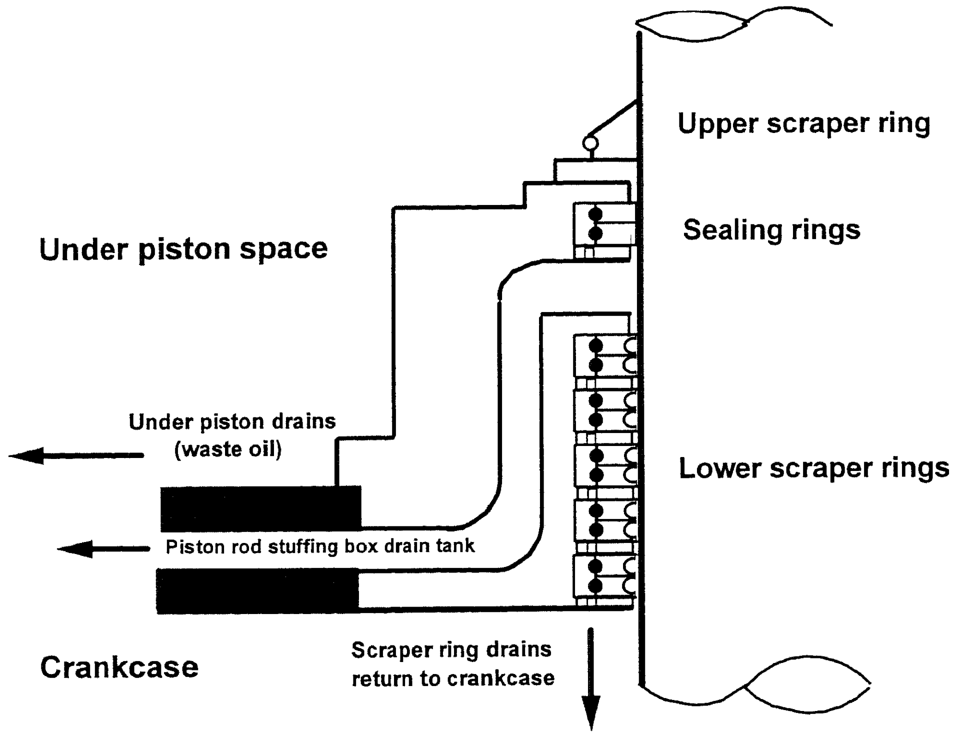


TABLE 4

CYLINDER DRAIN OIL CONTAMINATION OF SYSTEM OILS

Contamination

- fuel-derived
    - asphaltenes
    - metal salts (Ni. V, Al, Si, Na...)
    - particulates, soot
    - sulphuric acids

- cylinder oil
    - degraded base fluids
    - neutralised inorganic base ie calcium sulphate
    - residual/excess base

Associated Impact on System Oil

- analytical changes:
    - higher BN (D2896)
    - increased Ca, metals contents, sulphated ash
    - higher viscosity
    - increased insolubles content
    - oxidation catalysts and oxidised organic species

- adverse interactions:
    - with chemicals
    - with water

Probable Consequences

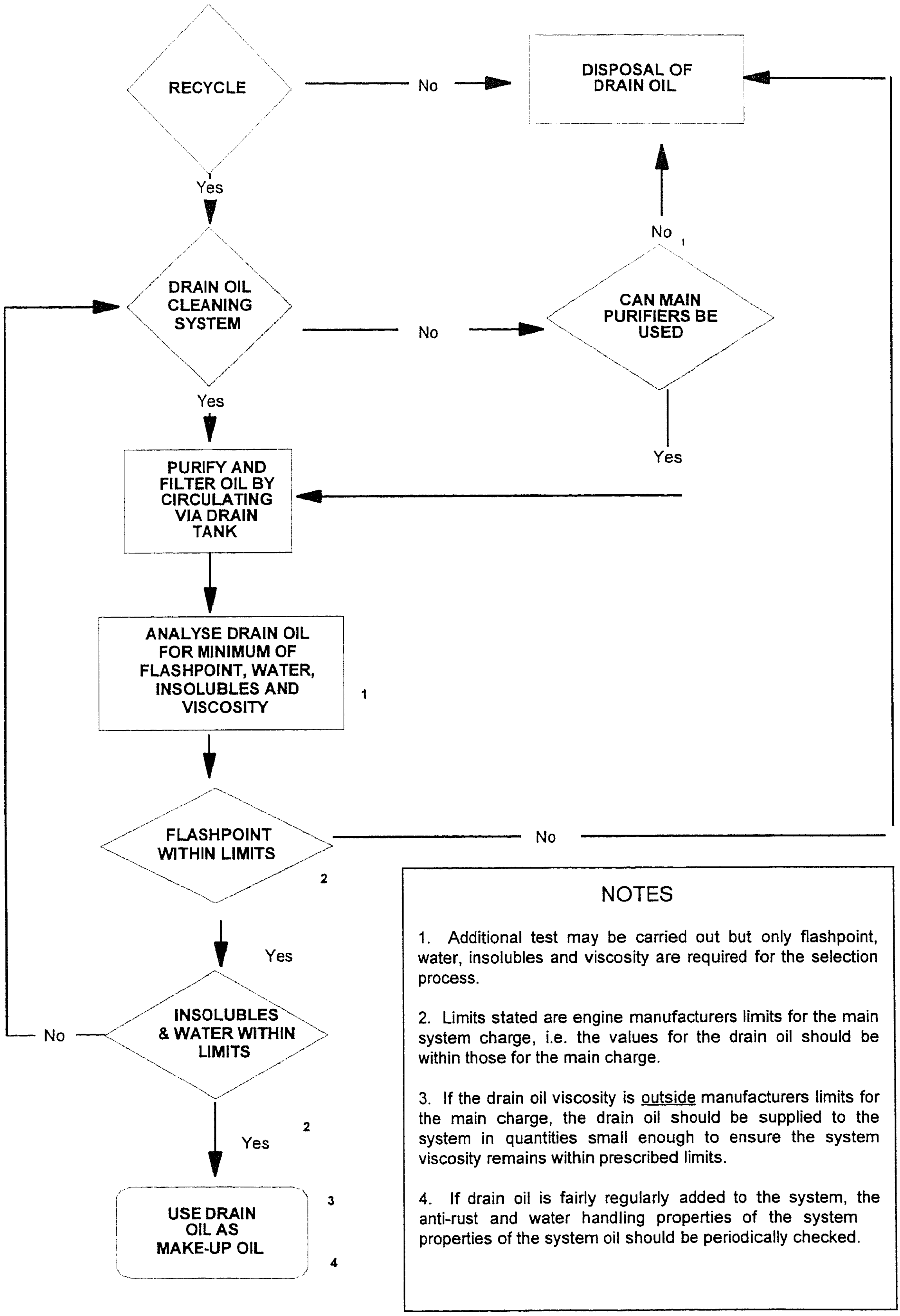
- disruption to colloidal stability:
    - sludge formation
    - deposit formation
    - emulsion stabilisation

- changes to morphology of inorganic components:
    - crystalline species created
    - relative hardness and crystal growth

- possibility of operational malfunctions:
    - reduced heat transfer by more viscous oil
    - piston undercrown deposits and seizure risk
    - lacquer formation affecting oil film in bearings.

TABLE 5

PROCEDURE FOR RECLAIMING CYLINDER DRAIN OIL



NOTES

1. Additional test may be carried out but only flashpoint, water, insolubles and viscosity are required for the selection process.

2. Limits stated are engine manufacturers limits for the main system charge, i.e. the values for the drain oil should be within those for the main charge.

3. If the drain oil viscosity is outside manufacturers limits for the main charge, the drain oil should be supplied to the system in quantities small enough to ensure the system viscosity remains within prescribed limits.

4. If drain oil is fairly regularly added to the system, the anti-rust and water handling properties of the system properties of the system oil should be periodically checked.

7. ANALYSIS OF LUBRICATING OIL IN SERVICE AND ITS SIGNIFICANCE

7.1 The Purpose of the Oil Analysis

The analysis of lubricants in service in crosshead engines is confined to the system oil and is similar to that prescribed in the CIMAC "Guidelines for the Lubrication of Medium Speed Diesel Engines", (Number 13, 1994). The main reasons for the analysis are as follows:

1. To determine the condition of the oil and to confirm whether or not it is fit for further service.

2. To detect and prevent trouble with lubricated parts if possible at an early stage, ie. to use as a machinery monitoring tool.

3. To assist in investigating the cause of engine problems.

7.2 Drawing of Samples

The results from any analysis, either in the laboratory or on site, will reflect the condition of the sample. Care must, therefore, be taken to ensure that meaningful samples are obtained. The details are described in Reference 2 (CEC M-12-T-91 Code of Practice).

7.3 Sampling Intervals

Specific sampling intervals may be recommended by the engine designer/builder for such conditions as trials etc but usually sampling intervals between 1000 and 2000 hours are more normal. More frequent sampling may be necessary if the condition of the system oil is in doubt or has been contaminated. The results of the analyses will indicate any trends on condition and perhaps the effectiveness of the purifying equipment.

7.4 Information Required for Oil Analysis

1. Name of vessel or plant.
2. Owners.
3. Date sample drawn.
4. Date and port sample handed in.
5. Oil brand, product name.
6. Hours in service, oil and machinery.
7. Engine model and manufacturer.
8. Position in lubricating oil system from which drawn.
9. Type of fuel used.
10. Date previous sample from same source drawn.
11. Quantity of lubricating oil in system and top up.
12. Any special reasons for analysis being required (if non-routine samples).

7.5 Properties to be Tested

The significance of the tests and their relevant information are described in the publication CEC L-47-M-97. The methods used are dependent on the purpose of the oil analysis.

8. QUALITY LIMITS OF SYSTEM OIL IN USE

Table 6

LIMITS FOR PRECAUTIONARY AND MANDATORY ACTION ON SYSTEM OIL

PROPERTY	METHOD[2]	UNIT	PRECAUTIONARY ACTION[3]	MANDATORY ACTION	REMARKS
Viscosity[1]	ISO 3104	mm^{2}s-^{1}	-2.95 / +3.00	-3.45 / +3.50	SAE 30 Oils
Acid Number	ASTM D-664	mgKOH/g	> 11	<4	
BN	ISO 3771	mgKOH/g	-	3min	
For Alkaline oil			15[4]		over fresh oil level
Water Content	ISO 3733	% vol	0.2 - 0.49	0.5 max	
Flash Point	ISO 2719	° Celsius	-	180 min	
Insolubles	ASTM D-893/B	% mass	0.5 - 1.49	1.5 max	
Wear Metals		mg/Kg	30		

1) Viscosity determined at 100°C. The "mandatory action" limits apply only in cases where there are no specific recommendations from the engine manufacturer.

2) Alternative test methods can be used on condition that results demonstrably correlate with methods listed.

3) Precautionary limits are for guidance only.

4) The rate of rise is as important as the absolute value provided it is below that recommended by the engine manufacturer. BN should not be interpreted on its own but should be used in conjunction with other characteristics eg viscosity, insolubles to assess the condition of the oil in service.

9. HEALTH, SAFETY, ENVIRONMENT

9.1 Exhaust Gas Emission : Contribution of Lubricating Oil

Lubricating oil mainly affects exhaust gas emissions in two ways. Firstly, lubricating oil generates additional particulate matter which is mainly associated with its relatively high ash content. Secondly, the particulate emissions and certain ash constituents in the particulate matter may have an effect on catalyst systems and catalyst operation in emission control.

Lubricating Oil Contribution to Particulate Matter

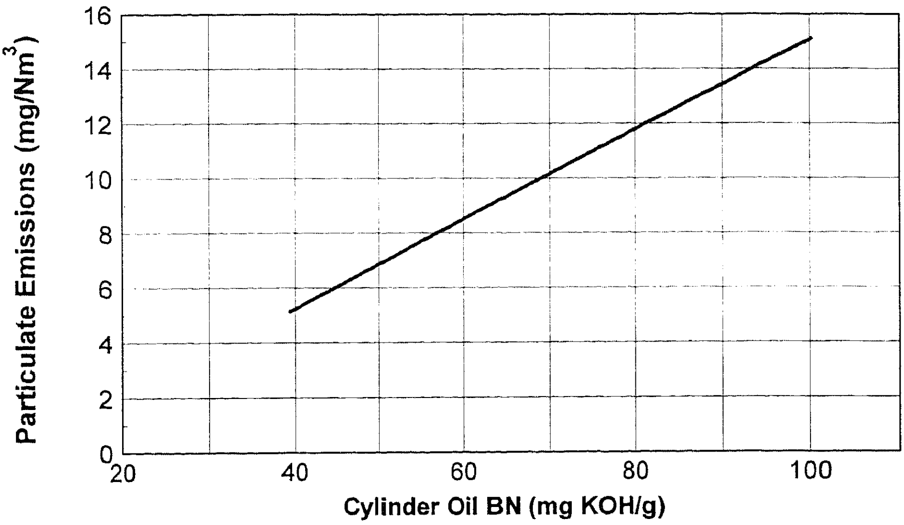
Lube oil contains earth alkali metals which contribute to particulate emissions in the form of metal sulphates or carbonates. Calcium is by far the dominant metal constituent and Calcium is mainly associated with the acid neutralising properties of lube oil.

Cylinder lubricating oil may also contain small amounts of other elements which will be present in the exhaust ash. Additionally minor amounts of other elements which are contaminants of the cylinder oil may also be present.

Figure 9 shows the lubricating oil contribution to particulate emissions with an assumed lubricating oil consumption of 0.7 g/kW-hr and an air consumption of 7 kg/kW-hr. The figure also demonstrates that the particulate portion originating from the lube oil dry ash is substantial but hardly dominant. Naturally, the indicated particulate values are higher if the lube oil consumption is higher, and vice versa. It must also be emphasised that the total lube oil consumption consists of contributions other than the portion going to the exhaust. Unburned or partially burned lubricating base oil may also increase emissions.

Under certain conditions the calcium sulphate originating from the lubricating oil can add to deposit formation in the exhaust pipes and funnels. This deposit may flake off during start and fast load application and generate large particles in the exhaust gas for a short time. This phenomenon is very much a function of both exhaust pipe and funnel insulation and design as well as of the operating pattern.

Fig. 9 Model of Lube Oil Contribution to Particulate Emissions



The lube contribution to particulate emissions assuming that the proportion of the lube oil consumption ending up in the exhaust, is 0.7g/kW.h and air consumption is 7 g/kW.h. The ash is taken to be sulphate for calcium- based lubricants. In the model only the ash contribution is taken into account. Unburnt/partially burnt hydrocarbons and water may also contribute to emissions.

9.2 Influence of Lube Oil on Catalysts

Catalyst Compatibilities As the IMO environmental proposals and local legislation on emissions take effect, reduction in critical pollutants may have to be achieved via selective catalyst systems in the exhaust stream. To retain activity for adequate periods the exhaust gases should contain the minimal potential for poisoning or blocking the reactive catalyst surfaces.

With the present state of understanding, such selective catalyst reduction (SCR) systems would be applied to engines operated on gas oil rather than residual fuels. Research is going on to establish the optimum exhaust cleaning techniques to prevent carbonaceous deposits from de-activating the catalyst system which in turn will allow the use of residual fuels.

Further information in detail on exhaust catalysts is to be found in the CIMAC publication on emissions. (Reference Section 12)

9.3 Disposal of Waste Products

Waste Products are defined here as those which are gathered in the main sludge tank. Their composition is varied and generally includes drainings from : cylinder liners, piston rod glands, settling and service tanks of fuels and lubricants, centrifuges, filters. Water and sludge from other sources are also part of them.

From the stand point of ship operation, there are only two waste disposal options that are fully aligned to environmental principles:

* **Option a** is to have specialised contractors removing the waste products when the ship is in port and disposing of them ashore in an environmentally friendly fashion. It would be the ship operator's responsibility to hire suitable contractors.

* **Option b** is to treat the waste products on board on an ongoing basis with the potential of reducing the material to be disposed of, to a small proportion of the original quantity.

The choice between the two options is influenced by the volume of waste products to be handled and the respective economics. This topic is also addressed in Section 6.

10. TROUBLE-SHOOTING GUIDE

A list of operating problems encountered on two-stroke crosshead diesel engines is given below. This is a general list which is not restricted to lubrication but covers all problems.

10.1. Ring Sticking

1. Continuous overload operation.
2. Distorted pistons or cylinders.
3. Worn pistons.
4. Worn rings or those that have lost tension (ring collapse).
5. Insufficient ring side clearance.
6. Bad combustion.
7. Excessive blow-by.
8. Use of piston ring of wrong dimensions.
9. Insufficient spreadability, detergency of oils, and thermal degradation.

10.2 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.
3. Low oil viscosity.
4. Insufficient oil feed/distribution to cylinders.
5. Low jacket water temperature.
6. Access of drain water condensed at air inter cooler.
7. Excessive blow-by.
8. Pistons or cylinders distorted by mechanical force and/or thermal expansion.
9. Frequent cold start.
10. Excessive piston clearance.
11. Improper running-in.
12. Inadequate surface finish condition.
13. Unsuitable cylinder liner material.
14. Overloading of 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.

10.3 Piston Crown (fire-side) Deposits

1. Improper air filtration.
2. Wet or corrosive gas in dual fuel engine.
3. Improper fuel filtration.
4. Improper combustion. (see also 10.10)
5. High cylinder oil feed rate.
6. Worn rings or those that have lost tension.

7. Continuous overload operation.
8. Excessive ash (vanadium and/or sodium) content in fuel.
9. Undercrown deposits due to insufficient piston cooling.
10. Faulty injectors

10.4 Crankcase Deposits

1. Improper oil filtration/purification (insufficient capacity/operation of the purifier or neglected replacement of filter element).
2. High oil temperature.
3. Low oil temperature.
4. Water condensation.
5. Leaking water jacket.
6. Too low oil consumption.
7. Clogged crankcase breather or vent.
8. High insolubles content.
9. Improper suction pipe line of purifier.
10. Ingress of cylinder oil and unburnt fuel via stuffing box.
11. Micro organisms

10.5 Bearing Wear or 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 oil.
8. Corrosive oil (high T.A.N. or presence of S.A.N.).
9. Water in oil.
10. Defective bearing construction.
11. Insufficient removal of contaminants in oil by purifier/filter.
12. Vibration of engine (when not running) caused by external source.
13. Hard deposits, based on calcium ashes, removed from piston crown and ring lands (Hard deposits are believed to be formed at high temperatures under the presence of sodium and/or vanadium with calcium from the oil additives).
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).

10.6 Wear of Crankshaft

1. Refer to 10.5 Bearing Wear or Failure.
2. Wear due to migrating electric currents.
3. Hard particles in oil being embedded in bearing overlay surfaces.

10.7 Deterioration of Crankcase Oil

1. Water contamination.
2. Worn stuffing box rings.
3. Increase in insolubles - due to leakage via 2.
4. Increase in oil viscosity - due to leakage via 2.
5. Wrong fitting of stuffing box rings (e.g. upside down).
6. Frequent discharge of sludge accumulated in centrifuge (dirty oil).
7. High oil temperature at outlet of oil cooler.
8. High volatility of system oil.
9. Excessive foaming of oil.
10. Excessive backflushing of filters (dirty oil)
11. Excessive increase of Base Number - due to leakage via 2

10.8 High Oil Temperature

1. Clogged oil cooler.
2. Clogged oil lines.
3. Crankcase sludge .
4. Continuous overload operation.
5. Insufficient jacket 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.

10.9 Lack of Power

1. Improper combustion.
2. Insufficient air.
3. High back pressure.
4. Low fuel energy content.
5. Heavy blow-by.
6. Low compression pressure.
7. Leaking exhaust valves.
8. Leaking injectors.
9. Late injection timing.

10.10 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 (due to blockage of air cooler/exhaust gas economiser).
7. Low compression pressure.
8. Leaking or sticking intake or exhaust valves.
9. Low load.
10. Low jacket temperature.

10.11 Significant Increase of Viscosity.

1. Increase of insolubles in used oil.
2. Insufficient capacity of purifier.
3. No oil consumption because of cylinder drain leakage into crankcase.
4. Higher viscosity of cylinder drain oils.
5. Faulty operation of purifier.
6. Filter element not replaced.
7. Insufficient capacity of filter.

10.12 Foaming of System Oil

1. Faulty design of oil return pipes above oil surface in sump tank
2. Ingress of air into lubricating system.
3. Contamination with grease and/or rust preventives (Complete replacement of oil recommended).

10.13 Exhaust Valve Failure

1. Improper cooling.
2. Valve material.
3. Valve setting.
4. Trouble with valve rotator.
5. Hot corrosion (Na, V in fuel)

10.14 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.
8. Improper material.

10.15 Turbocharger Deposits

1. Prolonged low speed 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 content in the fuel.

11. GLOSSARY

Acid	Any substance containing hydrogen in combination with a non-metallic element(s) and capable of producing hydrogen ions in solution. An acid is capable of neutralising or being neutralised by a base.
Acidity	In lubricants, acidity denotes the presence of acidic constituents whose concentration is usually defined in terms of an acid number.
Additives	A chemical compound or compounds added to a lubricating oil for the purpose of imparting new properties or enhancing existing properties.
Aniline Point	The lowest temperature at which a hydrocarbon fluid is completely miscible with an equal quantity of aniline. The higher the reading, the lower the aromatic content, and hence the smaller the effect on rubber.
Antifoam Agent	An additive used to suppress the foaming tendency of petroleum products in service. May be a silicone oil to break up surface bubbles or a polymer to decrease the number of small entrained bubbles.
Antiwear Agent	Additives or their reaction products which form thin, tenacious films on highly loaded parts to prevent metal-to-metal contact.
Aromatics	Hydrocarbons of ring structure having the smallest hydrogen to carbon ratio.
API Gravity	An arbitrary scale adopted by the American Petroleum Institute for expressing the relative density of an oil. $\text{Degrees API} = \frac{141.5}{\text{rel.density @ 60°F}} - 131.5$
Ash	Some additives, particularly conventional detergent additives, leave behind a powdery residue after combustion. This residue is known as ash and can cause engine malfunction if allowed to build up in the combustion chamber, cylinder liner ports and turbochargers.
Ash (Sulphated)	The ash content of an oil, determined by charring the oil and breaking the residue with sulphuric acid and evaporating to dryness. Expressed as % by mass.
Asphaltenes	Components of asphalt which are insoluble in petroleum naphtha but are soluble in aromatic solvents. They are hard and brittle and made up largely of high molecular weight polynuclear hydrocarbon derivatives containing carbon, hydrogen, sulphur, nitrogen, oxygen and usually nickel, iron and vanadium.
Bactericide	A biocide specifically formulated to kill bacteria.
Barrel	A unit of volume measurement used for petroleum and petroleum products. a barrel = 42 US Gallons, ≃ 35 Imperial Gallons or ≃ 159 litres.
Base	A compound which reacts with an acid to produce a salt plus water.
Base Number	A measure of the amount of acid-neutralising additive present in a lubricating oil, previously known as Total Base Number.
Base Stock (Base Oil)	Refined petroleum oil used in the production of lubricants and other products. The base stock may be used alone or blended with other base stocks and/or additives, to manufacture a finished lubricant.

Bitumen	A viscous liquid or solid consisting of hydrocarbons and their derivatives which is soluble in an aromatic solvent such as benzene. It is non volatile and softens when heated. Bitumen may be black or brown in colour and possesses waterproofing and adhesive properties. It is obtained from refinery processes but is also found as a natural deposit.
Black Oils	Asphaltic materials are added to lubricants used for open gears and steel cables to impart extra adhesiveness, giving them the characteristic black colour.
Blending	The intimate mixing of various components, including base oils and additives, in the preparation of a product of specified properties.
Blow-by	Passage of combustion gases past the piston rings of internal combustion engines, resulting in contamination of the crankcase oil.
Boundary Lubrication	Lubrication between two rubbing surfaces without the development of a full fluid lubricating film. It occurs under high loads and requires the use of antiwear or EP additives to prevent metal-to-metal contact.
Bulk Modulus	The reciprocal of the compressibility of an oil. The higher the Bulk Modulus of a fluid, the greater its incompressibility.
Cams	Eccentric lobes attached to a camshaft and driven by a crankshaft which are used in most internal combustion engines to open and close valves and sometimes operate fuel pumps.
Carbon Residue	Coked material remaining after an oil has been exposed to high temperatures under controlled conditions. Carbon residue is thus an indicator of the coke forming tendencies of an oil. It can be expressed as Conradson, Ramsbottom or Micro-Carbon Residue .
Catalyst Fines	Small (typically less than 50 micron) particles of aluminium silicate used as a catalyst in catalytic cracking (cat cracker) refineries. They are sometimes carried over in the refinery process and can be found in residual fuels. They are very abrasive and can cause excessive wear in engine parts - particularly fuel pumps, injectors, cylinder liners and piston rings.
Centipoise (cP)	See **Poise**
Centistoke (cSt)	See **Stoke**
Cetane Index	A measure of the ignition quality of a distillate fuel, that is the relative ease with which the fuel will ignite when injected into a compression - ignition engine. Cetane Index is calculated from the API gravity and the mid boiling point of the fuel. High Cetane Indices indicate shorter ignition lags and are associated with better combustion performances.
Cetane Number	Similar to Cetane Index but is derived from a standard engine test rather than by calculation.
Cloud Point	The temperature at which a cloud or haze begins to appear when an oil, which has been previously dried, is cooled under prescribed conditions. Such a cloud or haze is usually due to the separation of wax from the oil.
Cold-end Corrosion	Corrosion phenomena at cold area of lower cylinder liner and or piston skirt area due to H_2SO_4 condensation at those areas.
Cold Filter Plugging Point (CFPP)	A measure of the ability of diesel fuels to flow at low temperature. A fuel with a low CFPP is capable of being used satisfactorily at low ambient temperatures and not cause blockages in fuel systems through the precipitation of wax particles.

Copper Strip Corrosion	A qualitative measure of the tendency of a petroleum product to corrode pure copper.
Corrosion Inhibitor	A substance added to a lubricant to protect against metal corrosion.
Crosshead Diesel Engine	Slow-speed marine diesel engine with separate lubrication systems for cylinders and crankcase. Invariably operating on the 2-stroke cycle these engines derive their name from the crosshead bearing which couples the piston rod and the connecting rod.
Crown	The top of the piston of an internal combustion engine above the firing ring which is exposed to direct flame impingement.
Cylinder Oil	Lubricating oil having a high BN for the lubrication of the cylinders of crosshead marine diesel engines and some types of trunk piston engines.
Demulsibility	The ability of a lubricant to withstand the formation of an emulsion with water. This property is measured in a test which determines the separation of a well-mixed sample of oil and water, and gives a 'demulsification Number' or 'Value'.
Density	Mass per volume unit.
Detergent	A substance added to a lubricant to keep engine parts clean. In engine oil formulations, the detergents most commonly used are metallic soaps with a reserve of basicity to neutralise acids formed during combustion.
Dew Point	The temperature at which water vapour in the air starts to condense to liquid.
Dispersant	An additive designed to disperse oil insoluble sludge in suspension, thus preventing harmful deposition in oilways.
Distillate	A product obtained by condensing the vapours distilled from petroleum or its products.
Distillation Range	The range of temperatures, usually determined at atmospheric pressure by standard apparatus, over which boiling, or distillation, of a liquid proceeds. Only a pure substance has one definite boiling point at a particular pressure. Petroleum distillates contain a complex range of hydrocarbon compounds and consequently a range of boiling points is determined which is different for different distillates.
Drop Point	The temperature at which a grease passes from a semi-solid to a liquid under specified test conditions.
Emulsibility	The ability of an oil or other non-water soluble fluid to form an emulsion with water.
Emulsifier	A type of surfactant effective at producing stable emulsions.
Emulsion	An intimate mixture of fine particles of one liquid in another. An emulsion is said to "break" when the particles join up and the liquids separate.
End Point (final Boiling Point)	The highest temperature indicated on the distillation thermometer when a light distillate is subjected to one of the standard laboratory methods of distillation.
Engine Deposits	Accumulations of sludge, varnish and carbonaceous residues due to blow-by of unburned and partially burned fuel, or from partial breakdown of the crankcase lubricant. Water from condensation of combustion products, carbon, residues from fuel or lubricating oil additives, dust and metal particles also contribute.

Engine Test	Use of an internal combustion engine to evaluate lubricants. Parameters such as piston ring groove fill, piston varnish, component wear, oil viscosity etc. are measured.
Esters	Compounds of alcohols and fatty acids which form the major constituent of many synthetic lubricating oils.
Extreme Pressure (EP) Lubricants	EP oils and greases contain additives (usually based on sulphur, phosphorus or chlorine) which, under the effects of high temperature and pressure, form a protective film on metallic surfaces, preventing metal-to-metal contact if the normal hydrodynamic film breaks down under high pressure.
Ferrography	Ferrographic Analysis. A method for detecting wear metal particles arrested on a magnetic field by using photo sensor or a microscope.
FCC Fine	See Catalyst fines
Fire Point	The lowest temperature at which an oil vaporises rapidly enough to burn for at least five seconds after ignition under standard conditions.
Flash Point	The temperature to which a combustible liquid must be heated to give off sufficient vapour to form a momentarily flammable mixture with air when ignited under specified conditions.
Floc Point	A measure of the tendency of an oil to flocculate - or precipitate wax - under prescribed conditions. It is mainly applicable to refrigeration oils.
Four Ball EP Test	Method for determining extreme pressure (EP) properties of fluids. One steel ball under load rotates against three stationary balls in the form of a cradle. Heated test fluid is subjected to a series of timed tests at increasing loads until welding occurs. Wear is described by scar diameter plus load to weld in kg.
Friction	The resisting force encountered at the common boundary between two bodies when, under the action of an external force, one body moves, or tends to move, relative to the other.
FZG Gear Test Rig	A method for determining the load carrying ability of lubricants. Calibrated spur gears are operated at fixed speed and controlled initial oil temperatures for 15 minute stages. The load on the gear teeth is increased after each stage. Performance is judged by the number of stages run up to a defined weight loss of the test gears or visual assessment of damage to the tooth flanks.
Gas Oil	A petroleum distillate having a viscosity and distillation range between those of kerosene and light lubricating oil. The distillation range of gas oils usually extends from 200°C to 380°C. Gas oil is used as a fuel in medium and high speed diesel engines and as a burner fuel in heating installations.
Grease	A lubricant composed of an oil, or oils, thickened with a soap or other thickener, to a semi-solid or to a solid consistency.
Hot-end Corrosion	Corrosion phenomena at piston crown and ring land by the mixture of V_2O_5 plus Na_2SO_4 above 330°C
Hydrocarbons	Chemical compounds which consist entirely of carbon and hydrogen. They form the basic composition of all fuels and lubricants derived from petroleum.
ICP(or PES)	Inductively Coupled Plasma Emission Spectrochemical Analysis. A method for detecting metal elements in oil at ppm level by using plasma emissions.
Immiscible	Incapable of being mixed to form a homogeneous mixture, eg. oil plus water.

Inhibitor	A substance which is added in a small proportion to a lubricant to prevent or retard undesirable changes in the quality of the lubricant, or in the condition of the equipment in which the lubricant is used.
Insolubles	Contaminants found in used oils due to dust, dirt, wear particles and/or oxidation products. Often measured as pentane or benzene insolubles to reflect insoluble character.
IR, Infrared (or FTIR) Analysis	A method for detecting the oxidation level of lubricants and base oils. Can also be used to detect water.
Kinematic Viscosity	Measure of a fluid's resistance to flow under gravity at a specific temperature (usually 40°C or 100°C).
Lands	The vertical surfaces of the piston crown and the areas between the piston rings.
Lubricant	Any substance interposed between rubbing surfaces for the purpose of reducing friction between them.
MIL-	US Military specifications
Mineral Oil	Oil derived from mineral sources, notably petroleum.
Miscible	Descriptive of substances, usually liquids, which mix together to form a homogeneous mixture.
Multigrade	'Multigrade' is a term used to describe an oil for which the viscosity/temperature characteristics are such that its low temperature and high temperature viscosities fall within the limits of two different SAE numbers.
Naphthenic Base Stock	A type of base stock prepared from Naphthenic crudes (crudes containing a high percentage of ring type aliphatic hydrocarbons). They are characterised by high specific gravity plus low viscosity index.
Neutralisation Number	A measure of the acidity or alkalinity of an oil. The number is the mass in milligrams of the amount of acid (HCl) or base (KOH) required to neutralise one gram of oil.
Nitration	The process whereby nitrogen oxides attack petroleum fluids at high temperature, often resulting in viscosity increase and deposit formation.
NLGI Number	A numerical scale devised by the U.S. National Lubricating Grease Institute for classifying the consistency range of lubricating greases. The higher the number, the 'stiffer' or more viscous the grease and vice versa.
Oxidation	A process by which oxygen combines with a material (eg oil), to form another substance.
Oxidation Inhibitor	An additive which slows down the rate of oxidation of an oil.
Oxidation Stability	A measure of resistance of a product to deterioration through exposure to air.
pH	A measure of acidity or alkalinity in terms of the logarithm of the hydrogen ion concentration with the sign reversed pH 0 = extreme of acidity pH 7 = neutral pH 14 = extreme of alkalinity

Paraffinic Base Stock	A type of base stock prepared from Paraffinic crudes (crudes containing a high percentage of open-chain aliphatic hydrocarbons). They are characterised by low specific gravity and high viscosity index.
Penetration	Measure of consistency (hardness) of a grease. All penetration measurements are in inverse scale of consistency - that is, the softer the consistency, the higher the penetration number.
Petrolatum	Also referred to as "mineral Jelly" or "petroleum jelly", petrolatum is a salve like mixture of oil and microcrystalline wax obtained from petroleum.
Petter WI	Single cylinder gasoline engine. Evaluates oil oxidation by viscosity increase and copper/lead bearing weight loss. Duration is 36 hours at 1500 rpm with sump oil temperature at 137°C.
Poise (P)	The standard unit of dynamic viscosity, usually quoted as centipoise (cP).
Polishing (Bore)	Excessive smoothing out of the surface finish of the cylinder bore or cylinder liner in an engine to a mirror-like appearance, resulting in depreciation of the ring sealing efficiency and adhesion of the oil to the liner surface, leading to high oil consumption. Bore polishing can be produced by excessive quantities of combustion products which build up on the piston lands and rub on the liner, or by ring scuffing.
Polyalphaolefin	A synthetic lubricant produced by polymerisation of unsaturated hydrocarbons.
Pour Point	The lowest temperature at which a lubricant will pour or flow under specified conditions. Gives an indication of the lowest operating temperature for which an oil is suitable.
Pour Point Depressant	An additive used in a small proportion to lower the pour point of a lubricant by modifying the formation of wax crystals so that they do not agglomerate.
Pumpability	The characteristics of an oil that permit satisfactory flow to and from the engine oil pump and subsequent lubrication of moving components.
Refining	Series of processes for converting crude oil and its fractions to finished petroleum products, including thermal cracking, catalytic cracking, polymerisation, alkylation, reforming, hydrocracking, hydroforming, hydrogenation, hydrogen treating, solvent extraction, dewaxing, deoiling, acid treating, clay filtration and de-asphalting.
Residual Fuel Oil	Very heavy fuel oils produced from the residue of the fractional distillation process rather than from the distilled fractions.
Rings	The circular metallic elements that ride in the grooves of a piston and provide compression sealing during combustion. Also used to spread oil for lubrication of the cylinder liners.
Ring Sticking	The situation when the piston grooves become sufficiently full of deposits or covered with lacquer to prevent the piston rings from moving freely.
Rust Preventive	Compound for coating metal surfaces with a film that protects against rust. Commonly used for the preservation of equipment in storage.
Scuffing	Abnormal wear occurring in engines due to localised welding and fracture. It can be prevented through the use of antiwear, extreme pressure and friction modifier additives.
Shear Stability	The property of resisting physical change under high rates of shear when applied to a Viscosity Index Improver. It is the ability of the VI improver molecules to withstand breakdown into smaller molecules.

S.I.P.W.A	Sulzer Integrated Piston Ring Wear detecting Arrangement. This equipment monitors the rate at which piston rings wear in crosshead engines.
Sludge	Oil insoluble products formed from lubricants and/or fuels used in internal combustion engines, and deposited on engine parts other than those in contact with the combustion space.
Solvent Extraction	Refining process used to separate reactive components (unsaturated hydrocarbons) from lube distillates in order to improve the oils oxidation stability, viscosity index and response to additives.
Surfactant	A compound able to reduce surface tension and commonly used to achieve emulsification, wetting or detergency.
Stoke (St)	The unit of kinematic viscosity, ie, the measurement of a fluid's resistance to flow defined by the ratio of the fluid's dynamic viscosity to its density; usually quoted as 'centistokes (cSt).
Straight Run	Fuels produced by distillation without cracking or alteration to the structure of the constituent hydrocarbons.
Thermal Cracking (Visbreaking)	An oil refinery process in which the reaction is produced by the action of heat and pressure.
Timken OK load	Measure of the EP properties of a lubricant. Lubricated by the product under investigation, a standard steel roller rotates against a block. Timken OK load is the heaviest load that can be carried without scoring.
Tribology	The science of lubrication, friction and wear.
Trunk Piston Diesel Engine	Medium-speed, or High-speed, diesel engine generally using the same oil for both cylinder and crankcase lubrication, and utilising connecting rods to transmit piston power directly to the crankshaft rather than through a crosshead.
Turbine	A piece of equipment in which a shaft is steadily rotated by the impact of a current of steam, air, water, or other fluid directed from jets or nozzles upon blades of a wheel or series of wheels.
Turbocharger	Compressor driven by exhaust gas driven turbine supplying air at higher pressure to the engine to increase power.
Viscosity	The property of a liquid by virtue of which it offers resistance to motion or flow. It is commonly regarded as the 'thickness' of the liquid. Viscosity decreases with increasing temperature.
Viscosity Index (VI)	An arbitrary scale used to measure a fluid's change of viscosity with temperature.
Viscosity Index Improver	An additive employed to raise the VI of a mineral oil and other products.
Zinc (ZDP)	Commonly used name for zinc dithiophosphate, an antiwear/oxidation inhibitor chemical.

12. BIBLIOGRAPHY AND REFERENCES

CIMAC No. 11	Recommendations regarding Fuel Requirements for Diesel Engines
CIMAC No. 12	Exhaust Emissions Measurement
CIMAC No. 13	Guidelines for the Lubrication of Medium Speed Diesel Engines
CEC M-12-T-91	Representative Sampling of Engine Lubricants on board Ship
CEC L-47-T-97	Recommended Standard Methods Analysis of Used Oil from Large Diesel Engines

13. APPENDICES

Appendix 1 Membership of Working Group

APPENDIX 1

Membership

The following companies, institutions and associations have co-operated with the CIMAC Working Group "Lubricants".

1. Alfa Laval
2. BP Marine
3. Castrol
4. Cegielski
5. DNV
6. Elf
7. Esso
8. Germanischer Lloyd
9. Lloyd's Register of Shipping
10. Lubrizol
11. MaK
12. MAN - B&W
13. Mitsubishi Heavy Industries
14. Mobil
15. Nippon Kaiji Kyokai
16. NSD
17. Odense Steel Shipyard
18. Oronite
19. SEMT Pielstick
20. Shell
21. Ship Research Institute
22. Texaco
23. Wartsila Diesel
24. Westfalia
25. Witco