Lubrication in Four-Stroke Marine Diesel Engines

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Table of contents

• Introduction to Wärtsilä

• Introduction to 4-stroke Diesel engines

• Diesel Engine Lubrication

• Future Prospectives
Wärtsilä Ship Power

- Merchant
- Offshore
- Cruise and Ferry
- Navy
- Special Vessels
Wärtsilä Power Plants

- **Flexible Baseload Power Generation** for the developing world, islands, remote areas
- **Grid Stability and Peaking** for strong grids, enabling increase of renewables
- **Industrial Self-Generation** for large industries
- For the **Oil and Gas Industry** mechanical drives and field power
WE SUPPORT OUR CUSTOMERS THROUGHOUT THE LIFE-CYCLE OF THEIR INSTALLATIONS BY OPTIMISING EFFICIENCY AND PERFORMANCE

We provide the broadest portfolio and best services in the industry for both ship power and power plants. We offer expertise, proximity and responsiveness for all customers regardless of their equipment make in the most environmentally sound way.
Wärtsilä Italia Engines

<table>
<thead>
<tr>
<th>Model</th>
<th>Power from</th>
<th>Power to</th>
</tr>
</thead>
<tbody>
<tr>
<td>W26</td>
<td>1,860 kW</td>
<td>7,200 kW</td>
</tr>
<tr>
<td>W38B</td>
<td>4,350 kW</td>
<td>11,600 kW</td>
</tr>
<tr>
<td>W46</td>
<td>5,850 kW</td>
<td>20,790 kW</td>
</tr>
<tr>
<td>W46F</td>
<td>7,500 kW</td>
<td>20,000 kW</td>
</tr>
<tr>
<td>W50DF</td>
<td>5,500 kW</td>
<td>17,100 kW</td>
</tr>
<tr>
<td>W64</td>
<td>12,060 kW</td>
<td>17,200 kW</td>
</tr>
</tbody>
</table>
4-stroke engine (4-cycle engine)
This is an engine in which the pistons complete their power stroke every second crankshaft revolution. The four strokes are: intake, compression, power and exhaust. (also called: inlet, compression, combustion and outlet).
The 4-stroke cycle is so called because it takes 4 strokes of the piston to complete the processes needed to convert the energy in the fuel into work. Because the engine is reciprocating, this means that the piston must move up and down the cylinder twice, and therefore the crankshaft must revolve twice.
Introduction to 4-stroke Diesel engines

Diesel engine operating principle (4-stroke)
Division of engines according to speed

- **Low speed engine (Slow speed engine)**
  An engine broadly defined as running at **speeds below 300 rpm**. Low speed engines are also called "slow speed" engines. Low speed engines are typically two stroke engines.

- **Medium speed engine**
  An engine broadly defined as running at **speeds of 300–1200 rpm**.

- **High speed engine**
  An engine broadly defined as running at **speeds above 1200 rpm**.

**Remarks!** These speed categories (low, medium, and high speed) are general "rules of thumb" and not officially defined by any regulatory body.
**Function of lubricating oil**

Lubricating oil is an integrated engine component.

Main function of lubricating oil is to maintain power producing efficiency and ability by

- lubrication and sealing
- cooling
- cleanliness
- corrosion protection

while staying in good condition.
Influence of lubricating oil properties on engine components

Fuel injection pump:
- Fuel / lubricating oil compatibility

Piston cooling gallery, ring groove area, Piston skirt, cylinder liner:
- High temperature detergency
- Thermal stability
- Alkalinity
- Antiwear
- Oxidation stability

Cams and rollers:
- Antiwear
- Extreme pressure

"Cold" engine components:
- Low temperature detergency
- Corrosion resistance

Bearings:
- Corrosion resistance
- Oxidation stability

Crankcase:
- Water resistance
- Foaming resistance
- Dispersancy
- Detergency

Cooler
Pump
Separator
Filter
Function of lubricating oil

- Lubrication and sealing
- Cooling
- Cleanliness
- Corrosion protection
Function of lubricating oil

- Lubrication and sealing
- Cooling
- Cleanliness
- Corrosion protection
Types of lubrication

Hydrodynamic lubrication

Hydrostatic lubrication

Boundary lubrication

Metal to metal contact
Properties related to lubrication

Viscosity:

- Measure of fluid’s resistance to flow
- Viscosity increase indicates:
  - oil oxidation
  - presence of soot & combustion originated material
  - HFO leakage to lube oil
- Viscosity decrease indicates LFO leakage to lube oil
- Wärtsilä’s limit:
  - -20% / +25% change @ 100 °C
  - -25% / +45% change @ 40 °C
Function of lubricating oil

- Lubrication and sealing
- Cooling
- Cleanliness
- Corrosion protection
Cooling of engine components

- Bearings
- Pistons

Example of average oil temperature in piston
Function of lubricating oil

- Lubrication and sealing
- Cooling
- Cleanliness
- Corrosion protection
Engine cleanliness

The lubricant must remove sludge to prevent deposit formation

- Sludge originates from:
  - water
  - fuel
  - solid residues

- Deposits and lacquer
  - combustion products from fuel
  - combustion products from lubricant
  - lubricant / fuel that has oxidised
  - lubricant / fuel that has cracked
  - lubricant / fuel that has polymerised

- Fuel / lubricating oil compatibility is important
Influence of piston cooling gallery deposit thickness on piston top temperature

Limits:
W32, 38, 46, 64
- aver. 300 μm
- max. 400 μm
W20, W26
- aver. 200 μm
- max. 300 μm
**Properties related to cleanliness**

**Insolubles:**

- Describes the amount of solid contaminants present in lube oil.
- Consists of soot, dust and wear debris as well as oxidation products derived from fuel/lube oil.
- Several analysis methods exist having an influence on the exact analysed value.

**Wärtsilä’s limit:**
- Max. 2.0 % m/m measured with ASTM D 893b method.
Function of lubricating oil

- Lubrication and sealing
- Cooling
- Cleanliness
- Corrosion protection
Properties related to corrosion protection

Base Number (BN):

- Describes the available alkali reserve in lube oil
- BN is decreasing when acid sulphur and nitrogen originated combustion residues are reacting with alkali reserve
- SLOC and fuel S content are the main factors influencing on BN depletion rate
- Wärtsilä’s limit:
  - min. 20 mg KOH/g on HFO operation
  - max. 50% depletion on LFO operation
Example of wear rates

- Corrosive wear increases at higher fuel sulphur levels
- Corrosive wear decreases dramatically at higher BN

Graph showing wear rate vs BN for high and low sulphur fuels.
Reasons for oil change, HFO operation

![Bar chart showing reasons for oil change with and without anti-polishing ring.]
Base number depletion

- **Fuel sulphur**
  - S = 1.75 % m/m
  - SLOC = 1.2 g/kWh
  - LV = 1.5 l/kW

- **No antipolishing ring, Dry sump**
  - S = 3.5 % m/m
  - SLOC = 0.4 g/kWh
  - LV = 0.75 l/kW

- **Condemning limit**
  - S = 3.5 % m/m
  - SLOC = 1.2 g/kWh
  - LV = 1.5 l/kW

- **Change interval**
  - S = 3.5 % m/m
  - SLOC = 0.4 g/kWh
  - LV = 1.5 l/kW

- **Fuel sulphur**
  - S = 1.75 % m/m
  - SLOC = 1.2 g/kWh
  - LV = 1.5 l/kW
Properties related to wear

Iron (Fe):

- Indicates mainly wear of cylinder liners and pistons
- Fresh oil can contain iron up to 10 ppm originating from tanks and pipes
- Typical analysis accuracy ±10%
## Summary of main lube oil characteristics

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>CHANGE IN PROPERTY</th>
<th>IMPACT ON ENGINE OPERATION</th>
<th>CONDEMNING LIMIT (HFO OPERATION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base number</td>
<td>Low base number</td>
<td>Corrosive wear</td>
<td>min. 20 mg KOH/g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liner, piston ring groove</td>
<td></td>
</tr>
<tr>
<td>Insolubles</td>
<td>High insolubles</td>
<td>Dirty engine</td>
<td>max. 2.0 % m/m in n-pentane</td>
</tr>
<tr>
<td></td>
<td>content</td>
<td>Deposit formation</td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>High viscosity</td>
<td>Wear of bearings etc.</td>
<td>45% increase at 40 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25% increase at 100 °C</td>
</tr>
<tr>
<td></td>
<td>Low viscosity</td>
<td>More friction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduced cooling</td>
<td></td>
</tr>
<tr>
<td>Water content</td>
<td>High water content</td>
<td>Thinner oil film</td>
<td>25% decrease at 40 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metal - metal contact</td>
<td>20% decrease at 100 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deterioration of oil film</td>
<td>max. 0.3 % V/V</td>
</tr>
</tbody>
</table>
FUTURE PROSPECTS IN ENGINE LUBRICATION
Engine energy losses

About 10-15% of all energy supplied to an engine is lost due to friction.
Solid lubricants

- Low friction coefficient ($\leq 0.4$)
- Lattice structure arranged in layers
- Strong bonds between atoms within a layer and relatively weak interatomic interactions (van der Waals forces) between atoms of different layers allow the lamina to slide on one another

Low shear strength
Solid lubricants

✓ Graphite

- graphite is structurally composed of planes of polycyclic C atoms that are hexagonal in orientation. The distance of carbon atoms between planes is longer and therefore the bonding is weaker.

- water vapour is a necessary component for graphite lubrication. The adsorption of water reduces the bonding energy between the hexagonal planes of the graphite to a lower level than the adhesion energy between a substrate and the graphite → graphite is not effective in vacuum.

Graphite structure
Solid lubricants

✓ MoS$_2$
  - the most widely used form of solid film lubrication today
  - like graphite, it has a hexagonal crystal structure with the intrinsic property of easy shear: weak atomic interaction (Van der Waals) of the sulphide anions, while covalent bonds within molybdenum are strong
  - lubrication relies on slippage along the sulphur atoms; all the properties of the lamella structure are intrinsic → effective in vacuum or dry atmosphere
  - the temperature limitation of MoS$_2$ at 400°C is restricted by oxidation.

✓ WS$_2$
  - Max working temperatures about 100°C higher than MoS$_2$
BN, “white graphite”
- Hexagonal Boron Nitride (h-BN, α-BN, or γ-BN graphitic BN)
- high temperature resistance, 1200°C service temperature in an oxidizing atmosphere
- lubricant at both low and high temperatures (up to 900 °C, even in oxidizing atmosphere)
- since the lubricity mechanism does not involve water molecules trapped between the layers, boron nitride lubricants can be used even in vacuum
- high thermal conductivity
- the cubic structure is very hard and used as an abrasive and cutting tool component

BaF₂/CaF₂  High Temperatures (effective lubricating above 400°C)

Ag
Self-lubricating coatings

✓ Thin coatings
  - Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), …
  - Thickness ≤ 10 μm

✓ Thick coatings
  - Air or Vacuum Plasma Spray (APS and VPS), High-velocity Oxy-fuel Spray (HVOF), Plasma Transferred Arc (PTA), …
  - Cermets coatings
  - 0,1 mm ≤ thickness ≤ 15 mm
Properties & Selection:

- Thermal stability: very important since one of the most significant uses of these materials is in high temperature applications not tolerated by other lubricants:
  - Oxidation stability
  - High temperature corrosion
- Volatility
- Adhesion on base material
- Hardness
- Thermal shock resistance
- …

SEM backscattered micrograph of a NiCr(80/20)/Cr₂O₃-Ag-BaF₂·CaF₂ coating
Benefits in engine components

*Functional coated components enabling:*

- Use of new clean fuels (ultra low sulphur) and other new fuels (biofuels etc.)
- Use of different fuels in multi-fuel engines
- Improve durability (especially for components running at high temperature)
- Better performance (↓NOₓ and ↓CO₂)
- Reduce oil dependence
- Green products
Thank you for your attention