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ENGINE AUXILIARY SYSTEM GUIDELINE: LUBRICATING OIL SYSTEMS

Technology and Communication

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Tämä päättötyö on tehty Wärtsilän Technical Services osastolle, työn tehtävänä oli koota yrityksen sisäisistä tietokannoista, asiantuntijoiden haastatteluista sekä alan kirjallisuuslähteistä ohje koskien moottorin voiteluöljyjärjestelmiä kattaen Ship Power sekä Power Plants yksiköiden tuotteet.

Työn lopputuloksena oli ohje sisältäen tyypillisten voimalaitos- sekä merimoottorijärjestelmien kuvaukset, kaikki voiteluöljyjärjestelmässä käytetyt komponentit ja niiden toiminnalliset kuvaukset, järjestelmien ongelmanratkaisu sekä olennaisena osana voiteluöljy ja siihen liittyvät ominaisuudet.

Avainsanat keskinopea 4-tahtimoottori, moottorin apujärjestelmät, voiteluöljy

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ABSTRACT

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This thesis was done for Wärtsilä Technical Services organization, the purpose of this work was to gather and structure information about the lubricating oil systems from the company's internal databases, interviews with system specialists and from different literature sources covering Ship Power and Power Plant products

The outcome was a guideline, covering typical power plant and marine system descriptions, all components used in the lubricating oil system with their functional descriptions, system troubleshooting, and information about the lubricating oil and its different functions and properties.

Keywords medium-speed 4-stroke engine, auxiliary systems, lubricating oil

CONTENTS

LIST OF ABBREVIATIONS

AE	Auxiliary engine
cSt	Viscosity measurement unit, Centistoke [1mm^2/s]
DF	Duel fuel
DE	Diesel electric
EAM	Engine auxiliary module
HFO	Heavy fuel oil
LFO	Light fuel oil
LO	Lubricating oil
ME	Main engine
MDF	Marine diesel fuel
MDO	Marine diesel oil
MGO	Marine gas oil
PHE	Plate heat exchanger
SLOC	Specific lube oil consumption

1 INTRODUCTION

This guideline was made for Wärtsilä Technical Services to cover lubricating oil systems and components used in both Power Plant and Ship Power installations. The guideline includes information about all the components used in the lubricating oil system.

The purpose of this guideline is to gather and structure existing information from Power Plants, Ship Power, R&D and Technical Services documents into one guideline that is used by Technical Services personnel for means of troubleshooting lubricating system and as a training material.

The guideline focuses on 4-stroke engines which are currently on production and on typical on- and off-engine lubrication oil system solutions used with these engines.

1.1 About Wärtsilä

Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets. By emphasizing technological innovation and total efficiency, Wärtsilä maximizes the environmental and economic performance of the vessels and power plants of its customers. In 2014, Wärtsiläs net sales totaled EUR 4,779 million with approximately 17,700 employees in more than 200 locations in nearly 70 countries around the world. /50/

1.2 Technical Services

Wärtsilä Services supports its customers throughout the lifecycle of their installations. Wärtsilä provides service, maintenance and reconditioning solutions both for ship machinery and power plants. Technical Services is a part of Services organization and the main functions of the unit is to provide technical support during the life cycle of products and solutions delivered or serviced by Wärtsilä, maintain, develop and make available technical knowledge and expertise in an efficient way and to analyse field experience and feedback, and processing this information into facts and knowledge to enable product improvement and secure customer satisfaction. /50/

2 LUBRICATING OIL SYSTEM

Lubricating oil systems between marine and power plant installation components and their locations may vary from each other but the systems still have to fill the same purpose.

The lubricating oil system main tasks are to:

- Store and transport new and used lubricating oil.
- Control lube oil flow, pressure and temperature.
- Maintain required lubricating oil quality.
- Pre-lubricate, to provide certain pressure before engine is started.

More specific information about components used in lubricating oil systems can be found in Chapter 3. Components and about the lubricating oil from Chapter 4.Lubricating oil. /16/

2.1 Engine Internal Lubrication Oil Circulation

Figure 1 shows all the components that are included in the system and the components needed for operation. The figure is from W32 engine with a wet oil sump and integrated lube-oil module, basic functions are the same for components if mounted on- or off-engine.

Lubricating oil is stored in the wet oil sump from where the pre-lubricating (2) and main lubricating pump (3) suck oil through the suction screen from the oil sump, or in dry sump installation suction is from the system oil tank.

The correct pressure in the system is adjusted with the pressure regulating valve (4) and depending on the temperature of the lubricating oil thermostatic valves (5) mix the hot oil from the pump with cooled oil from the lubricating oil cooler (6), and after that oil flows through an automatic filter (7) and dirty backflushing oil from the automatic filter flows through a centrifugal filter (1) and back to the oil sump.

Clean oil from the automatic filter lubricates intermediate gear wheels, injection pump, rocker arms (11), push rods, valve tappets, camshaft bearings (9) and turbo-charger (12). Also bearings for engine driven water pumps are in this circulation.

Clean oil from the automatic filter flows to the main distributing pipe in the oil sump then through hydraulic jacks to the main bearings and into the crankshaft and through the connecting rod to the gudgeon pin (10) and up to the piston crown cooling space and thereafter returned to the oil sump. Part of the lube oil is furthermore merged to the piston skirt lubrication before returned to the oil sump.

Main differences between engine- and installation-types usually concern the components in the lubricating oil module (5, 6, and 7) and pre-lubricating pump (2). If the engine is equipped with an external lubricating oil module, there typically is no centrifugal filter installed (1) and pre-lubrication pump, thermostatic valve, lubrication oil cooler and automatic filter are located in the engine auxiliary module. /43/

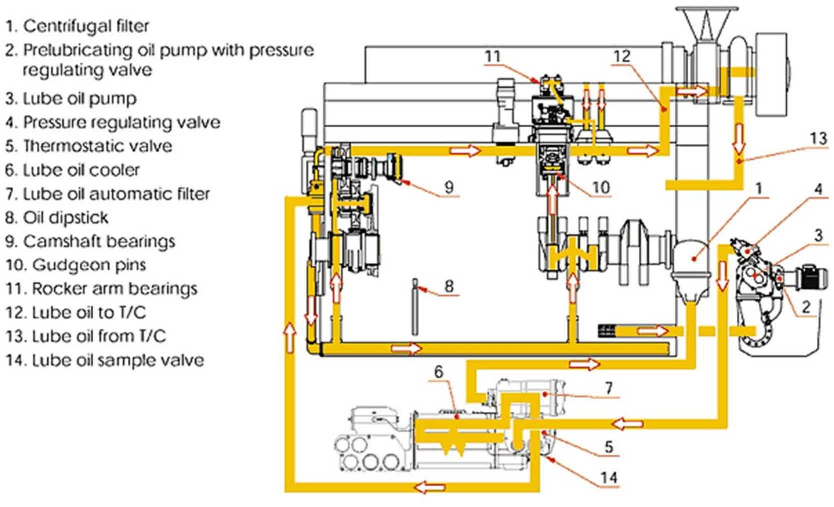


Figure 1. W32 engine internal lubricating oil diagram with on-engine built lube-oil module /43/

2.2 Description of Typical Power Plant System

Power plant lubricating oil systems are categorized to an internal lubricating oil system, containing lubricating oil system and components built on the engine and an external lubricating oil system which includes lubricating oil system and components installed to the power plant side. The external lubricating oil system depends on the lubricating oil system components built on the engine, the number of operating engines and power plant installation type.

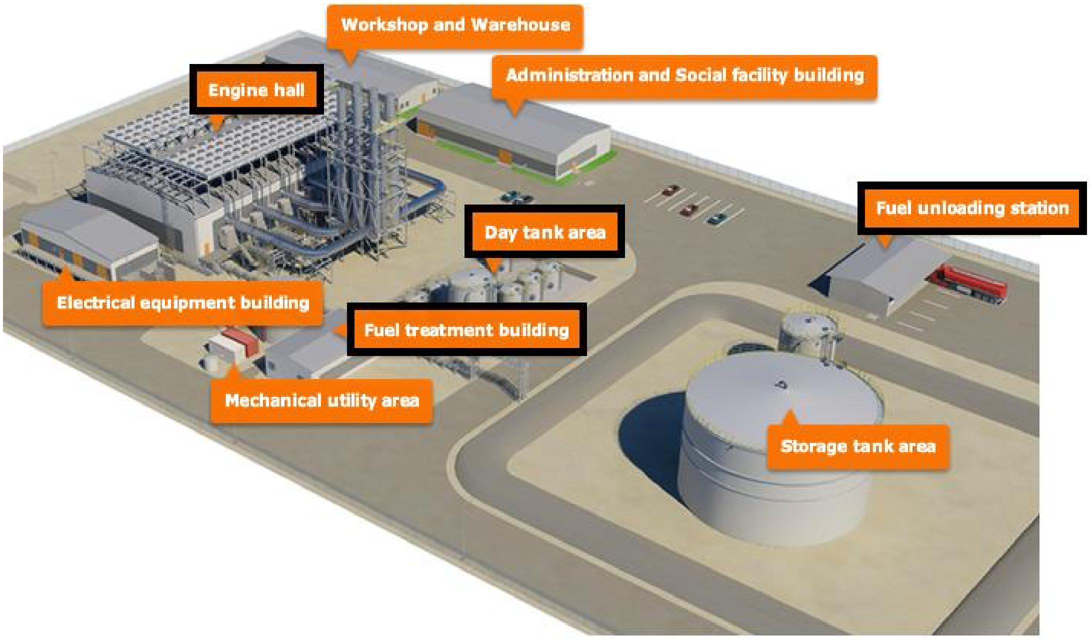


Figure 2. Oil plant layout /38/

The lubricating oil storage and transfer system components are installed to the day tank area, fuel treatment house and unloading station. The lubricating oil circulation and treatment system components are installed in the engine hall.

The storage of lubricating oil is important at a power plant. Different types of storage tanks are used, fresh lubricating oil is stored in a clean lubricating oil tank while there usually is also a lubricating oil service tank and a used lubricating oil tank. The service tank is used when an engine has to be emptied on oil during the maintenance, during that time the oil is stored temporarily in this tank. The used lubricating oil tank is used as a storage place for used oil prior to disposal, in some cases it has been found that used lubricating oil has been used as a fuel but it is not recommended by Wärtsilä and it can be detected in the fuel oil analysis. These tanks are usually placed in the day tank area. For LFO and gas plants the service and used oil tank can be combined to one tank, which means that the plant can manage with just two tanks. For plants where HFO is involved all three tanks should be used. /16/

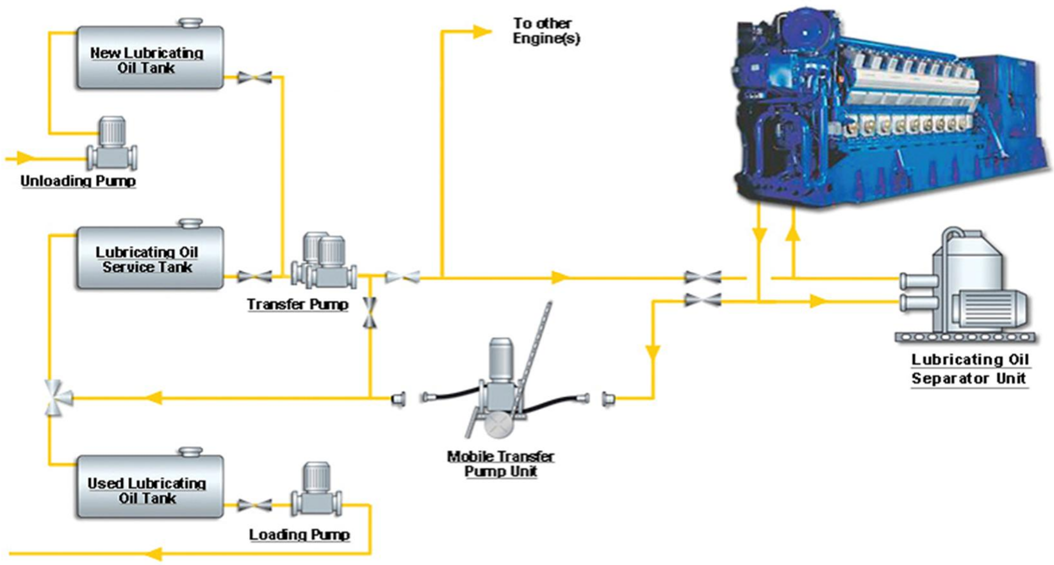


Figure 3. Lubricating oil system principle for small plant (W32/W34). /37/

WL38B and smaller engines usually have on engine integrated lubricating oil module as indicated in Figure 3. In these engines automatic filter, oil cooler, thermostatic valve, pre-lubrication pump and centrifugal filter are installed on-engine, the external system contains lubricating oil tanks and pumps that are needed for moving and storing the oil. If the separator unit is used, it is always an external component no matter the engine size.

Oil is pumped from a tanker, tanker trucks or from oil drums directly into the clean lubricating oil tank. The unloading is performed manually, the pump must be started and stopped manually and the valves must be opened and closed as required to prevent overfilling of the tank. When the engine is to be filled with fresh oil, the transfer pump unit is used to pump oil from the clean lubricating oil tank to the engine. The oil filling pipes are connected to the engine via the pipe module. The transfer pump unit is also used to transfer oil from the service tank for reuse or disposal. The mobile transfer pump unit is used to drain oil from the engine crankcase when necessary. The oil can be pumped either to the service tank or to the used lubricating oil tank to be disposed properly. The used lubricating oil tank is emptied using a separate unloading pump unit.

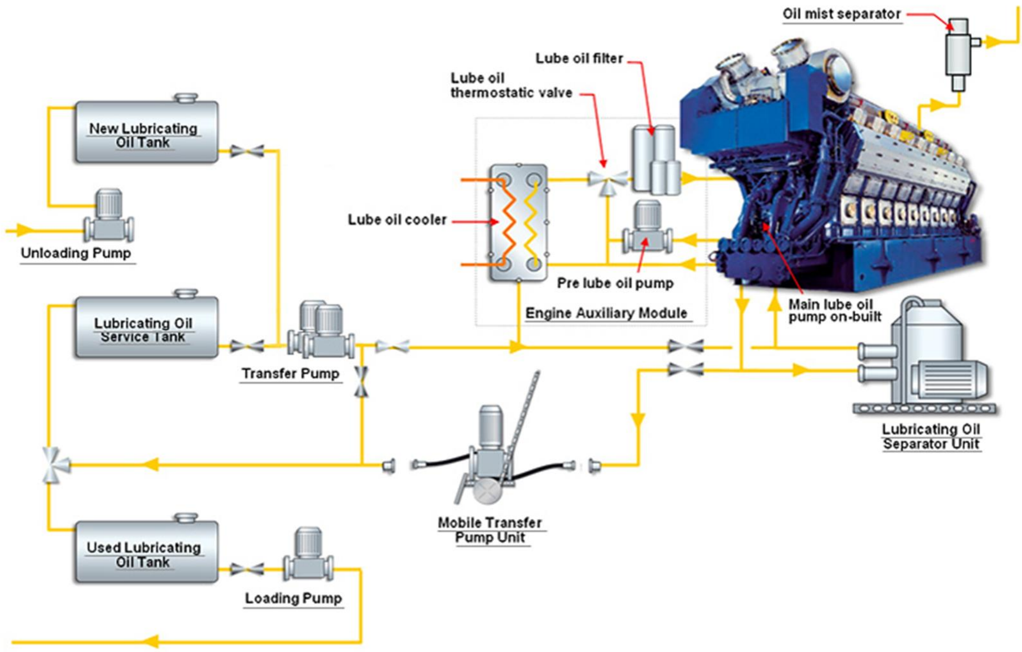


Figure 4. Lubricating oil system principle for big plant (W46/W50). /38/

The oil storing and transporting system is similar to smaller plants but on a larger scale, the main lubricating oil pump is also engine driven, the main difference compared to smaller plants when operating with W46 and bigger engines is that an external lubricating oil module is used, as shown in Figure 4. Automatic filter, oil cooler, thermostatic valve and pre-lubrication pump are installed on the engine auxiliary module (EAM). Each engine should have a lubricating oil system of its own, to avoid mixing up bad lubricating oil in several engines in case of e.g. water leakage in one engine. /16/; /21/

2.3 Description of Typical Marine System

Installations in marine applications can be divided between dry or wet sump and main or auxiliary engine installation and there are multiple variations for external system of these solutions since marine engines are more customized for the installation type and customer needs.

Wet and dry sump solutions are available from W20 to W34 and the dry sump based design is usually used from W38B to W64 in marine use. If both options are available, the dry sump is recommend for the main engines operating on HFO and the wet sump solution for diesel-electric and auxiliary engines. In an installation to a small ship sometimes it is not possible to build a system oil tank that the dry sump solution needs due to a lack of space, then the wet sump is the only reasonable solution.

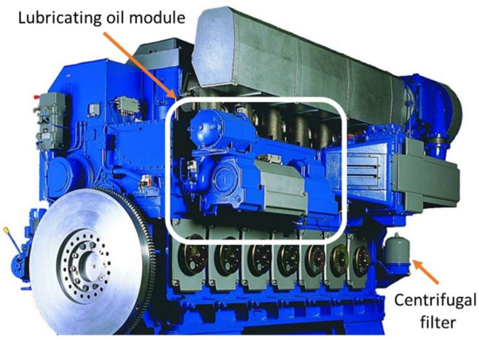


Figure 5. Lubricating oil module W6L32.

Usually in marine installations the lubricating oil module (see Figure 5) containing automatic filter, oil cooler, thermostatic valve, and centrifugal filter is installed on-engine to save space due to a less required external piping. In the figure below there are two simple examples of the external lubricating oil system layout possibilities. /39-42/; /44-48/

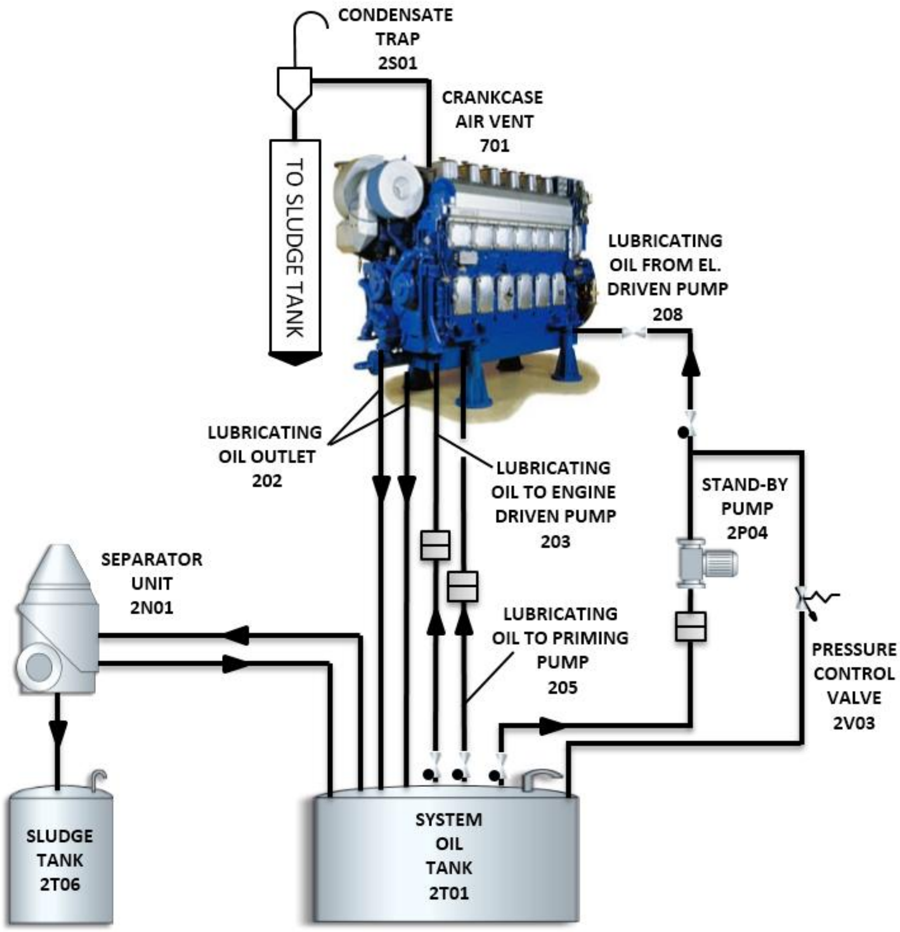


Figure 6. External lubricating oil system layout, W32 main engine dry sump /44/

A simple dry sump layout is displayed in Figure 6. The engine has an on-engine built lubricating oil module which includes automatic filter, thermostatic valve, and oil cooler. Also an engine driven main oil pump and on engine mounted pre-lubrication pump is used in this setup. The separator unit (2N01) takes oil directly from the system oil tank (2T01) and impurities are passed to the sludge tank

(2T06). A stand-by pump (2P04) is used with the main engine or emergency generator in case one of the other pumps fails or capacity is insufficient. /13/

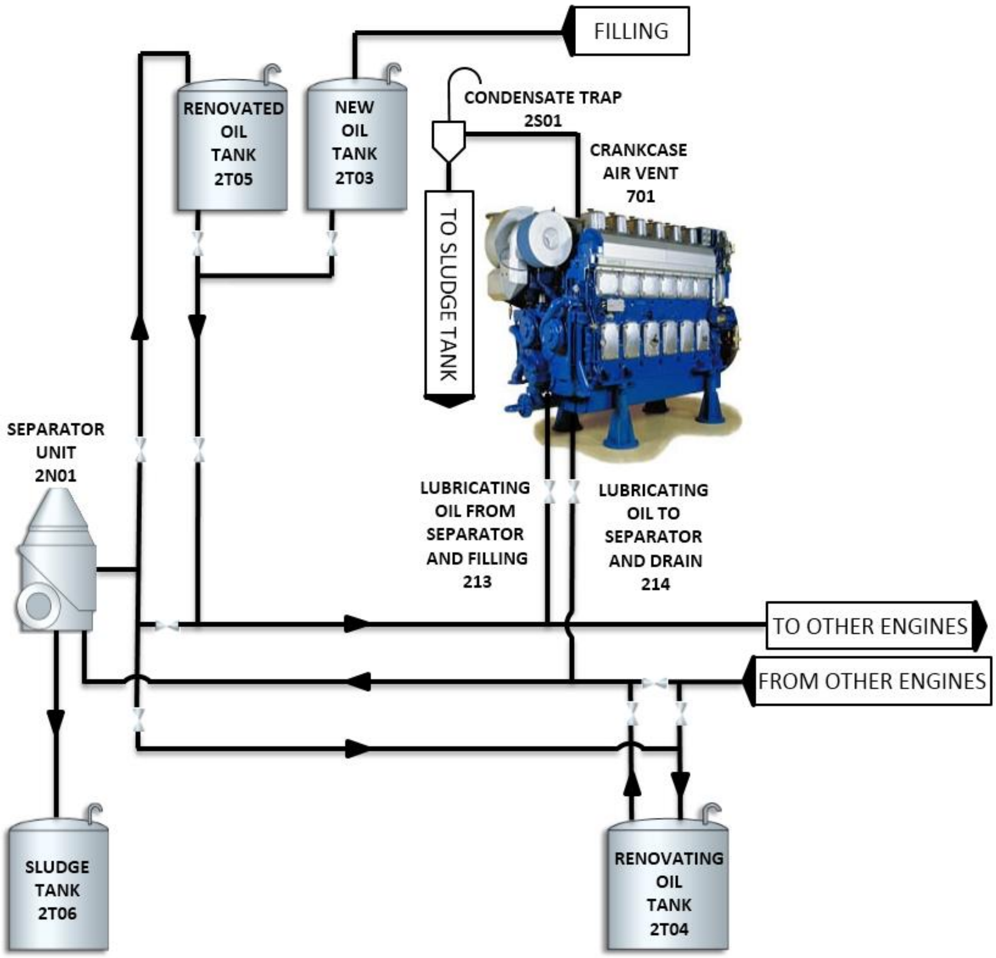


Figure 7. External lubricating oil system layout, W32 auxiliary engine, wet sump /44/

The lubricating oil system used with auxiliary engines equipped with a wet sump and on-engine built lubricating-oil module which includes automatic filter, thermostatic valve, and oil cooler is displayed in Figure 7. An engine driven main oil pump and on engine mounted pre-lubrication pump are used in this setup, the pumps take lubricating oil directly from the wet sump. Oil can be drained to the renovating tank from the oil sump prior to separation. The separator unit (2N01) is cleaning oil from the renovating oil tank (2T04), impurities are discharged into the sludge tank (2T06) and cleaned oil is transferred into the renovated oil tank (2T05). A new oil tank (2T03) is used to store fresh lubricating oil and engines can be filled from the new oil tank or the renovated oil tank. /13/

2.4 Essential Parameters

The primary function of the lubrication system is to provide the engine with a sufficient quantity of clean lubricating oil with required pressure and temperature. It is important that an adequate flow rate is maintained throughout the system. Oil lubricates the engine and removes heat and contaminations generated by the combustion process. The proper function of the system protects the engine from breakdown caused by high temperature, too low pre-lubricating pressure or impurities in the oil. /21/

2.4.1 Viscosity and Temperature

Viscosity can be defined as measurement of fluid internal resistance to flow at specified temperature. The resistance is caused by intermolecular friction when the layers of fluid attempt to slide by one another. The viscosity of oils is dependent on temperature, pressure, and shear rate. Viscosity is one of the most significant properties for establishing the thickness, pressure, and temperature of an oil film in lubrication. Oil film thickness increases with viscosity, as does the friction of the fluid and consequential power loss. Viscosity is also a significant factor in predicting the performance and fatigue life of bearings and gears. There are two ways to measure fluids viscosity, dynamic viscosity and kinematic viscosity.

Dynamic (absolute) viscosity is defined as the resistance of the fluid to flow or the resistance to deform when subjected to a force at specific temperature and pressure. The SI unit for dynamic viscosity is Pascal-second [Pas], before the SI system and still commonly used unit is Poise [P] and to suit practical applications a smaller centipoise [cP] is still commonly used. SAE 40 engine oil has approximately the viscosity of 650-900cP at 21°C compared to the viscosity of water of 1cP at the same temperature.

Kinematic viscosity is defined as the ratio of dynamic viscosity to fluid density. The Official SI unit of kinematic viscosity is m^2/s but the values are too large for practical applications therefore a smaller unit centistoke [cSt] (=1mm^2/s) is commonly used. Fresh SAE 40 lubricating oil has the viscosity of 13.5-15.0cSt at 100°C and 135-150cSt at 40°C

The viscosity of lubricating oils is very sensitive to operating temperature; when the temperature rise, the viscosity falls. It is important to know and control the temperature of the lubricating oil since it has a big impact on the film thickness, oil decomposition and oxidation. Viscosity-temperature relation is not linear, viscosity index (VI) indicates viscosity behavior on temperature changes, and a higher VI number of the oil indicates a smaller change in viscosity with temperature changes. A typical VI of oils used with medium speed engines is 95-110.

For any lubricating oil system the viscosity is considered as the most important single parameter since the main function of the oil is to create and maintain a lubrication film between two moving surfaces and this function depends on the viscosity of the lubrication oil. When oil viscosity is not within the required viscosity range, insufficient lubrication will occur and as a result increased friction, wear and heat will shorten component lifetime. /35/; /19/; /34/

2.4.2 Flow and Pressure

To maintain the flow through the lubricating system oil must be supplied with a sufficient and steady pressure to the bearing surfaces to avoid metal to metal contact between moving components and to maintain hydrodynamic lubrication conditions. The required flow depends on leakage caused by bearing clearances, flow through gear wheel nozzles and amount of backflushing oil returning from the automatic filter. Also the viscosity of the oil impacts on the required flow since oil with a lower viscosity is harder to pressurize and the lubricant lost due to the side leakage increases when the viscosity decreases.

If the oil supply pressure is too low or the flow rate is too slow there might encounter gaseous cavitation in journal bearings caused by a suction effect of the rotating shaft and it can cause damage to the engine components. Or if the suction line before the oil pump restricts the flow too much and the pressure drops it can also cause cavitation and damage the engine components. /31/

2.4.3 Filtration and Conditioning

A filter is a device for separating one substance from another and to do so it requires placing of a filter medium in the way of the fluid flow to trap solids. Filtration is based on particle size, particles below certain size will pass through while larger particles are trapped in the filter. Filters are rated according to their ability to remove particles of a specific size, actual efficiency is a compromise between the amount of particles allowed through and energy used to capture the rest. Removing particles and maintaining lubrication oil quality by a separator are crucial for lubricating oil and engine component life-time. /31/, /32/

Nominal filtration ratio is arbitrary value for the performance of the filter determined by the manufacturer which is expressed by the percentage of retention of a specified contaminant of a given size. For example, 30 micron 95% means that filter removes 95% of the particles that are 30 microns or larger, at the same time it may well retain a significant proportion of smaller particles also. Many manufacturers declare performance of their filters with the nominal filtration ratio but due to a lack of test uniformity products from different manufacturers cannot be compared. /32/

Absolute filtration ratio describes the pore size of the filter element indicating the largest particle able to pass through filter. The filter media must have an exact and consistent pore size or opening to use an absolute rating to determine the specific cut-off point. Rating is usually based on testing with spherical particles which means that single surface filters do not consider the length of the particle. For example, 30 micron means that the filter will remove all particles above that size. /32/

Beta filtration value is a ratio between the number of particles per unit volume above the specified size in the upstream of the filter to the same parameter in the downstream flow of the filter. The system was introduced to give for the manufacturer and the user an accurate and representative comparison method between filters.

$$\beta x = \frac{number\ of\ particles\ upstream > x\ (N_U)}{number\ of\ particles\ downstream > x\ (N_D)} \qquad (1)$$

For example ß30 = 100, means that 1 out of 100 particles of 30 micron size will pass through, giving a filtration efficiency of 99%. /32/

Centrifugal oil conditioning, although these systems do not work by filtration these are important components to maintain lubricating oil quality. Centrifugal oil conditioning can be used to remove dirt, sludge, and water from lubricating oil by rotating a bowl or a disk stack. Centrifugal force caused by a rotating element separates heavier particles or liquids with different density from lubricating oil. There are two types of centrifugal conditioning methods used for different purposes with Wärtsilä engines:

- Centrifugal filter, which is used to capture heavier particles into the filter paper and act as an indication filter only to monitor lubrication oil quality. More information about the component can be found in Chapter 3.4.7 “Centrifugal filter”

- Separator module, which is used to remove water and heavier particles from lubricating oil. More information about the component can be found in Chapter 3.4.3 “Separator”

/32/

3 LUBRICATING OIL SYSTEM COMPONENTS

In this chapter the components used in the lubrication oil system are presented. Components are grouped between marine and power plant system, and by function of the component.

3.1 Power Plant Storing System

The storage of lubricating oil is important at a power plant. For the storage different types of storage tanks are used. Fresh lubricating oil is stored in the new lubricating oil tank while there usually is also a lubricating oil service tank and if HFO is involved, a used lubricating oil tank is used also. The service tank is used when an engine has to be emptied on oil during the maintenance, during that time the oil is stored temporarily in this tank. The used lubricating oil tank is used as a storage place for used oil. For LFO and gas plants the service and used tank can be combined to one tank, which means that only two tanks are required. For plants where HFO is involved all three tanks should be used. /16/

3.1.1 Oil Sump

The oil sump is a light welded construction, it is mounted on the engine block from below. The wet oil sump is most common solution for the power plant engines combined with engine driven main lubrication oil pump. This construction includes also the flange connection for lubrication oil separator and for filling and emptying sump. /16/

3.1.2 Clean Lubricating Oil Tank

Fresh lubricating oil is stored in the clean lubricating oil tank for oil changes and for compensating the oil consumption. The filling interval for the lubricating oil is an important factor when dimensioning the clean lubricating oil tank. The lubricating oil tank must store a sufficient quantity of lubricating oil for an oil change in case there will be lubricating problems. This means that the tank size is based on the lubricating oil consumption and the filling interval or as a minimum. The tank should contain a sufficient quantity of lubricating oil for an oil change in one engine. The standard filling interval is 28 days. In installations with many engines it is better to divide the engines in groups or sections. In that case the lubricating oil tank is serving a group of engines. /16/

3.1.3 Lubricating Oil Service Tank

The lubricating oil service tank is used as a temporary storage for the lubricating oil, during maintenance of the engine. The tank size should be at least 15% larger than the oil volume for one engine oil sump. /16/

3.1.4 Used Lubricating Oil Tank

Instead of pumping used oil into oil barrels, a storage tank with enough volume can be installed. This type of storage tank is called used lubricating oil tank. In this tank, used oil is temporarily stored before the final disposal. Similarly to the lubricating oil service tank, the size of this type of tank should be at least 15% bigger than the oil volume from one engine oil sump. /16/

3.1.5 Piping

The lubricating oil piping in the lubricating oil system is designed as short and straight as possible to minimize air pockets, flow resistance, pressure drop and heat losses.

Other important parameters are inclinations, draining and supporting of pipes. A flexible pipe connection are used between pipes and units in places where dynamic or thermodynamic forces occur. The lubricating oil pipelines are designed for maximum temperature of 100 °C and pressure of 10 bar. The lubricating oil velocity is one factor that has influence on the pressure drop in a pipe, the higher velocity the higher pressure drop. To keep the flow resistance in the piping within acceptable limits the flow velocities is design to be within limits shown Table 1. Some piping mounted on the engine can have smaller diameter and therefore higher velocity due to a shorter pipe length the impact for the system is minimal. /21/; /16/

Table 1. Lubricating oil velocities. /16/

Pipe dimension DN	Suction [m/s]	Delivery [m/s]
25	0.3-0.5	0.7-0.9
32	0.4-0.6	0.8-1.0
40	0.5-0.7	1.0-1.2
50	0.6-0.8	1.2-1.4
65	0.6-0.8	1.3-1.5
80	0.7-0.9	1.4-1.6
100	0.8-1.0	1.5-1.7
125	0.8-1.0	1.5-1.7
150	0.8-1.0	1.5-1.7
200	0.8-1.0	1.5-1.7
250	0.9-1.0	1.5-1.7
300	1.0-1.1	1.5-1.7

3.1.6 Heating

In warm countries there is usually no need to for heating the storage tanks. In installations with colder conditions, attention has to be paid to the pumpability of the oil from the storage tanks. For typical SAE 40 lubricating oils this means a minimum ambient temperature of 6˚C. For installations in areas where the ambient temperature can fall below 6˚C a special design with heating of the lubricating oil tanks and trace heating and isolation of the lubricating oil pipes should be considered. /16/

3.2 Marine Storing System

Marine storing systems can vary more than in power plant installations due to variety of different installation environments and vessel purposes. Also classification societies have their own rules that needs to be noted.

3.2.1 Wet Sump

The oil sump is a light welded construction, it is mounted on the engine block from below and is usually equipped with an engine driven main lubrication oil pump. This construction includes also the flange connection for lubrication oil separator and for filling and emptying pump.

The wet oil sump solution is recommended for diesel electric and auxiliary engines. It is also used in some installations in smaller ships where it would be recommended to use the dry sump solution but there is not the needed space to build the lubricating oil system according to dry sump solution. /39-42/; /44-48/

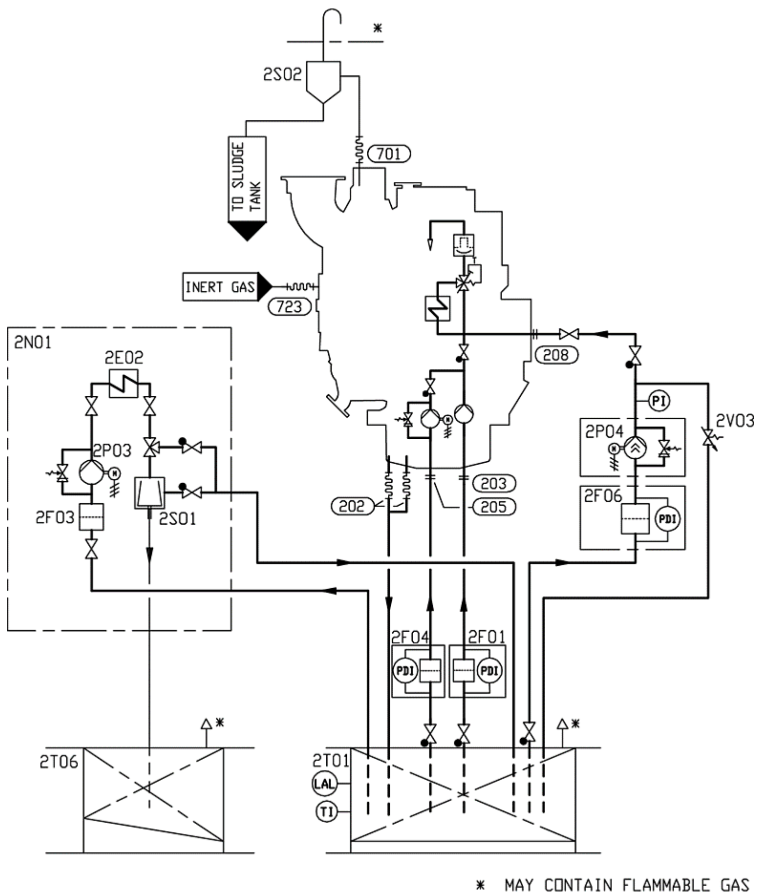
3.2.2 Dry Sump

The dry sump system differs from the wet sump system only in that the oil flows freely from the oil sump to a separate system oil tank and the main lubrication oil pumps suction line is from the system oil tank. This option makes it possible to have a larger oil volume and reduces slightly the height of the engine since there is no lubricating oil stored in the sump under the engine. The dry sump has two oil outlets at each end of engine from where oil flows back to the system oil tank. Recommendation for how many of the four connections should be connected to the system oil tank depends on engine size and type.

The dry sump solution is available for all engines, but it is a recommended solution for main engines operating on HFO, and for W38B and larger engines. /39-42/; /44-48/

3.2.3 System Oil Tank (2T01)

The system oil tank is used as a main oil tank in dry sump installations. Recommended oil tank volume is usually around 1.2-1.5 l/kW, the system oil tank is usually located beneath the engine foundation (see Figure 9). *The* suction height is especially important with the engine driven lubricating oil pump and losses in strainers and piping add to the geometric suction height.



System components		2P03	Separator pump	Connections	
2E02	Heater (separator unit)	2P04	Stand-by pump	202	Lube oil outlet (from oil sump)
2F01	Suction strainer (main LO. pump)	2S01	Separator	203	Lube oil to engine driven pump
2F03	Suction filter (separator unit)	2S02	Condensate trap	205	Lube oil to priming pump
2F04	Suction strainer (prelub. pump)	2T01	System oil tank	208	Lube oil from el.driven pump
2F06	Suction strainer (stand-by pump)	2T06	Sludge tank	701	Crankcase air vent
2N01	Separator unit	2V03	Pressure control valve	723	Inert gas inlet

Figure 8. Example of external lubricating oil system, W20DF dry oil sump. /41/

The pipe connection between the engine oil sump and the system oil tank must be flexible to prevent damages due to thermal expansion. The return pipes from the engine oil sump must end beneath the minimum oil level in the tank to avoid foaming and return pipes must not be located in the same corner of the tank as the suction pipe of the pump circulates the oil inside the tank. A pressure gauge shall be installed close to the inlet of the lubricating oil pump to monitor the negative pressure in the suction line. The suction pipe shall further be equipped with a non-return valve of flap type without spring. The non-return valve is particularly important with the engine driven pump and it must be installed in such a position that self-closing is ensured to avoid damaging the pump by running it dry. Suction and return pipes of the separator must not be located close to each other in the tank. The ventilation pipe from the system oil tank may not be combined with crankcase ventilation pipes.

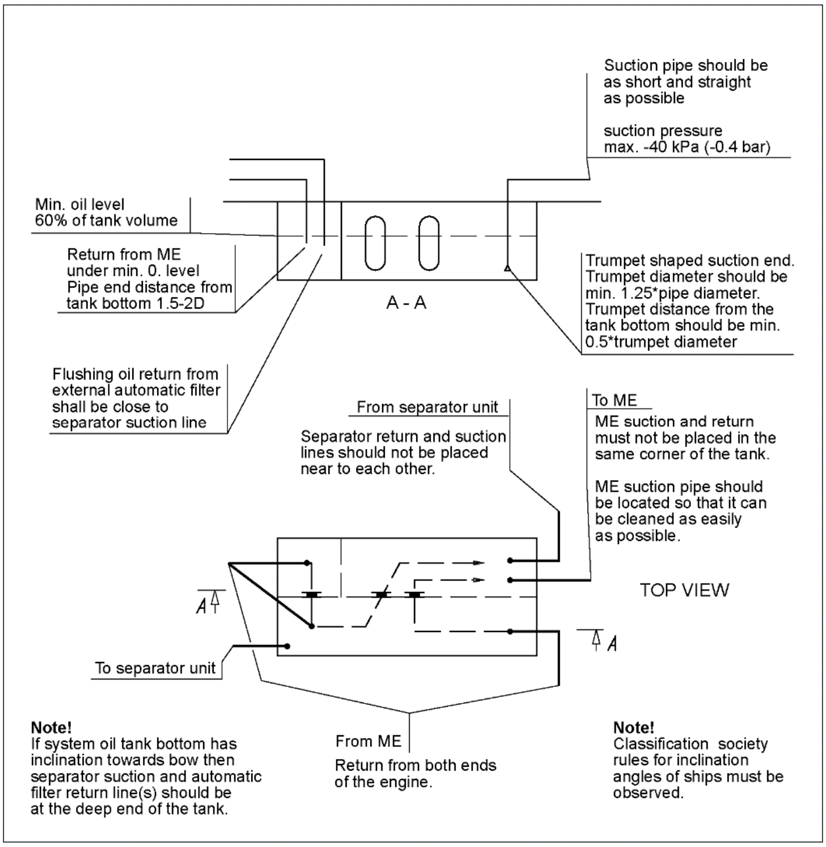


Figure 9. Example of system oil tank arrangement. /44/

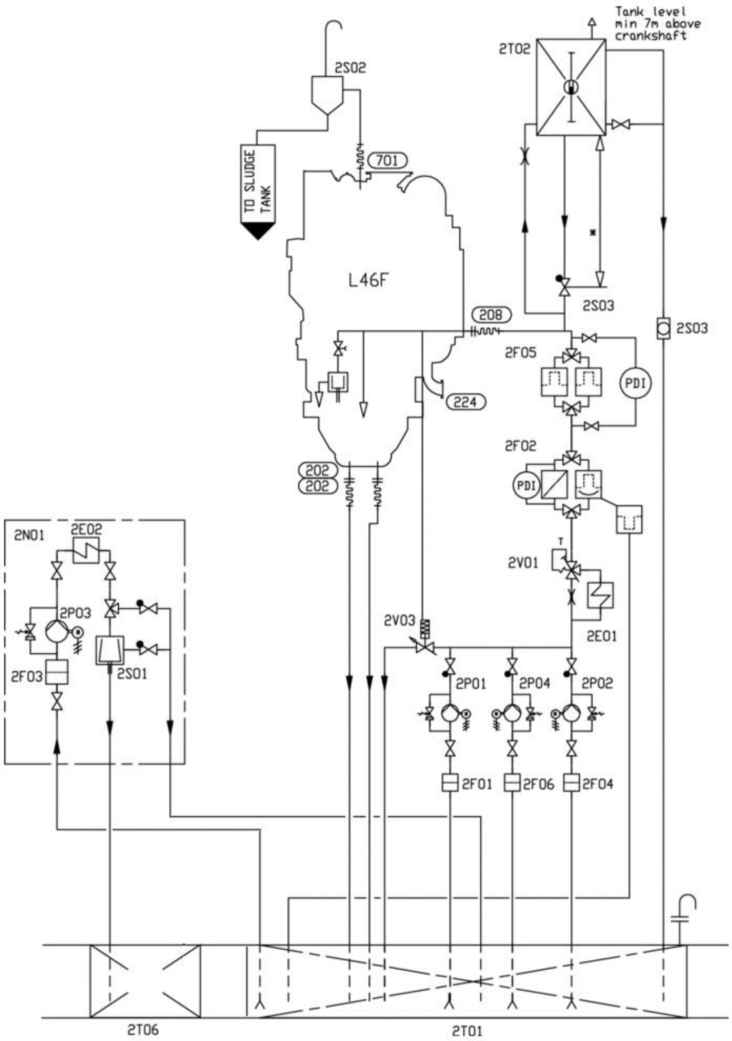
It must be possible to raise the oil temperature in the tank after a long stop. In cold conditions it can be necessary to have heating coils in the oil tank in order to ensure pumpability. The separator heater can normally be used to raise the oil temperature once the oil is pumpable. Further heat can be transferred to the oil from the pre-heated engine, provided that the oil viscosity and thus the power consumption of the pre-lubricating oil pump does not exceed the capacity of the electric motor.

With Dual Fuel engines, the fuel gas in the crankcase is soluble in very small portions into lubricating oil. Therefore, it is possible that small amounts of fuel gas may be carried with lubricating oil into the DF-engine system oil tank and evaporate there in the free space above the oil level. Therefore, the system oil tank has to be of the closed-top type. The DF-engine system oil tank has to be treated similarly to the gas pipe ventilation or crankcase ventilation. Openings into open air from the system oil tank other than the breather pipe have to be either closed or of a type that does not allow fuel gas to exit the tank. The system oil tank breathing pipes of engines located in the same engine room must not be combined.

The structure and the arrangement of the system oil tank may need to be approved by a Classification Society project-specifically. Any instrumentation installed in the system oil tank has to be certified. /48/

3.2.4 Gravity Tank (2T02)

In installations with an electrically driven main lubricating oil pump it is required to have a lubricating oil gravity tank (see Figure 10) to ensure lubrication during the time it takes to engine to stop rotating during a blackout situation to avoid damage to the engine. The required height of the tank is about 7 meters above crankshaft level. A minimum pressure of 50kPa must be measured at the inlet to the engine. The sizing of the tank depends on the cylinder size and quantity. /47/



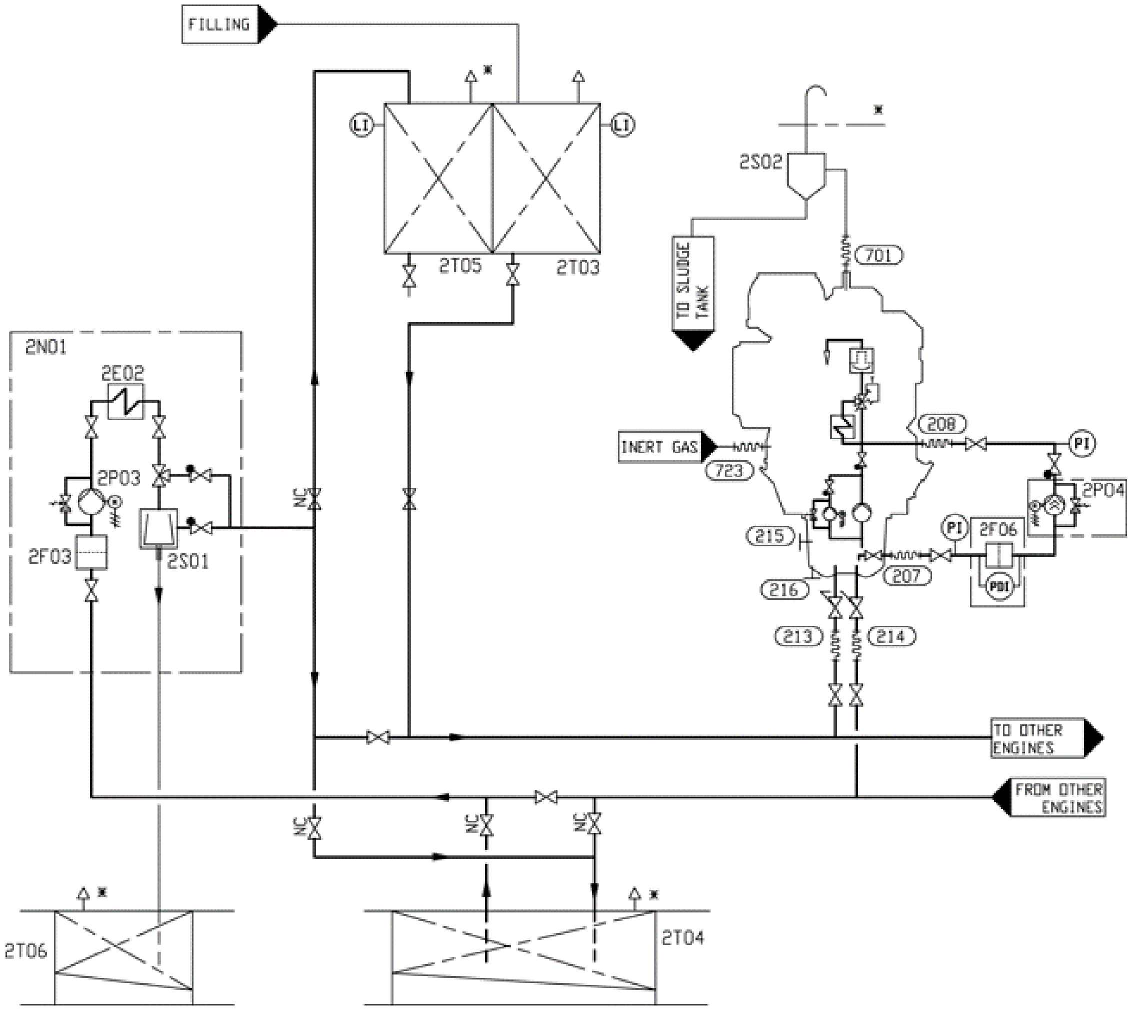
System components		2P02	Pre-lubricating oil pump	Connections	
2E01	Lubricating oil cooler	2P03	Separator pump	202	Lubricating oil outlet
2E02	Heater (separator unit)	2P04	Stand-by pump	208	Lubricating oil from el. pump
2F01	Suction strainer (main LO. pump)	2S01	Separator	224	Control oil to pressure ctrl. valve
2F02	Automatic filter	2S02	Condensate trap	701	Crankcase ventilation
2F03	Suction strainer (separator unit)	2S03	Sight glass		
2F04	Suction strainer (prelub. pump)	2T01	System oil tank		
2F05	Safety filter	2T02	Gravity tank		
2F06	Suction strainer	2T06	Sludge tank		
2N01	Separator unit	2V01	Temperature control valve		
2P01	Main lubricating oil pump	2V03	Pressure control valve		

Figure 10. Example of external lubricating oil system, W46F with electrically driven LO pumps. /47/

3.2.5 New Oil Tank, Renovating oil tank, Renovated Oil Tank & Sludge Tank

Fresh lubrication oil is stored into the new oil tank (2T03) from where lubricating oil can be added into the engines. The oil transfer system should be arranged so that it is possible to measure the filled oil volume. The renovating oil tank (2T04) is used to store lubricating oil prior to separation. The renovated oil tank (2T05) is used to store cleaned lubricating oil from the separator before feeding it back to engines, these tanks are used with wet sump installations (see Figure 11).

Impurities from the lubricating oil separator and crankcase condensate trap flow into the sludge tank (2T06) where used oil is temporarily stored before the final disposal. The sludge tank should be located directly beneath the separators, or as close as possible below the separators. To avoid blocking the piping in the system the sludge pipe must be continuously falling. /44/, /47/

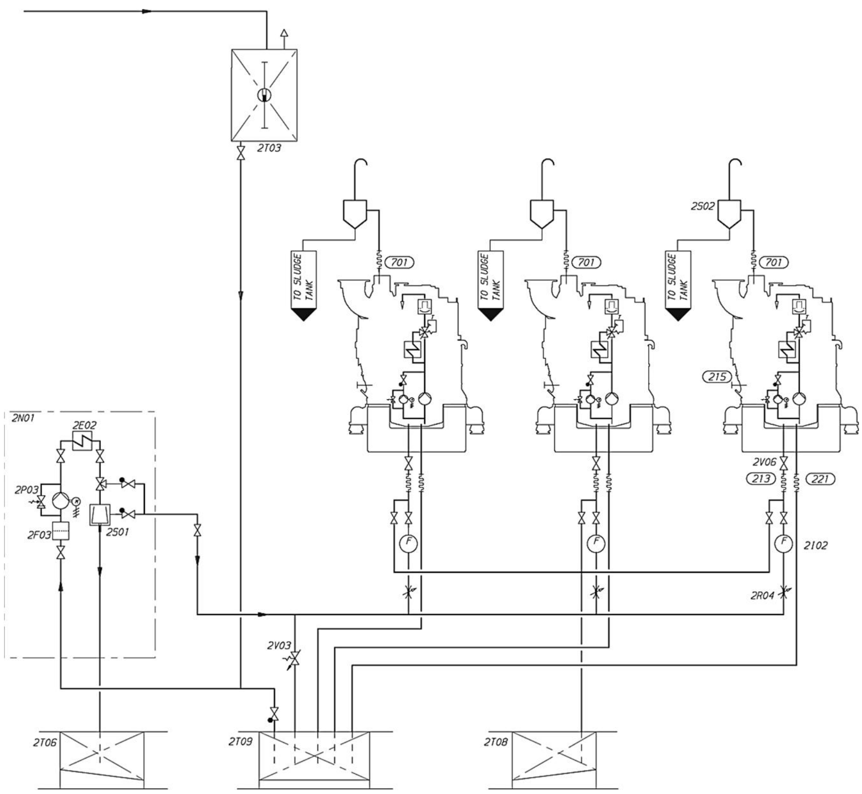


System components		2P04	Stand-by pump	Connections	
2E01	Heater (separator unit)	2S01	Separator	207	Lubricating oil to el.driven pump
2F03	Suction filter (separator unit)	2S02	Condensate trap	208	LO from el. driven pump
2F06	Suction strainer (stand-by pump)	2T03	New oil tank	213	LO from separator and filling
2N01	Separator unit	2T04	Renovating oil tank	214	LO to separator and drain
2P03	Separator pump (separator unit)	2T05	Renovated oil tank	215	Lubricating oil filling
		2T06	Sludge tank	216	Lubricating oil drain
				701	Crankcase air vent
				723	Inert gas inlet

Figure 11. Example of external lubricating oil system, W34DF auxiliary engine with wet sump. /45/

3.2.6 Used Oil Tank (2T08) and Overflow Oil Tank (2T09)

These tanks are used with auxpac engines. The used oil tank (2T08) is used to store lubricating oil that is no longer used. The overflow oil tank (2T09) is used with auxpac engines where there is continuous separation of three engines. The separator (2N01) pumps the oil from the overflow tank and back to all three engines at the same time, excessive oil flows from the engines back to the overflow tank (see Figure 12). /39/



System components		2S01	Separator	Connections	
2E01	Heater (Separator unit)	2S02	Condensate trap	213	LO from separator and filling
2F03	Suction filter (Separator unit)	2T03	New oil tank	215	Lubrication oil filling
2I02	Flow indicator	2T06	Sludge tank	221	Lubrication oil overflow
2N01	Separator unit	2T08	Used oil tank	701	Crankcase air vent
2P03	Separator pump (Separator unit)	2T09	Overflow oil tank		
2R04	Orifice (adjustable)	2V03	Pressure control valve		
		2V06	Shut-off valve		

Figure 12. Example of overflow lubricating oil system used with Auxpac engines. /39/

3.2.7 Piping

Lubricating oil piping is usually made of seamless carbon steel (DIN 2448) and seamless precision tubes of carbon or stainless steel (DIN 2391) Flanged connections shall be used in lubricating oil piping and pockets shall be avoided when routing the piping. The recommended maximum velocity on the pump delivery side for guidance is 1.5m/s, in open circuits the velocity in the suction pipe is typically about 2/3 of the velocity. In the delivery pipe for the suction side the maximum of -40kPa pressure is defined.

The pressure class of the piping should be higher than or equal to the design pressure, which should be higher than or equal to the highest operating (working) pressure. The highest operating (working) pressure is equal to the setting of the safety valve in a system. The classification societies categorize the piping systems, DNV in different classes and ABS in groups, depending on pressure, temperature and media. The pipe class can determine the type of connections to be used, heat treatment, welding procedure and test method. In the absence of specific rules or if less stringent than those of DNV the application of DNV rules is recommended. Insulation is recommended for pipes between the engine or the system oil tank, the lubricating oil separator and exposed parts of pipes with temperature over 60°C.

Pressurized flexible connections carrying flammable fluids have to be type approved and piping must be aligned without causing excessive stress for flexible connection. It is very important to fix the pipes to rigid structures next to flexible pipe connections in order to prevent damage caused by vibration. The following guidelines should be applied:

- Pipe clamps and supports next to the engine must be very rigid and welded to the steel structure of the foundation.

- The first support should be located as close as possible to the flexible connection. The next support should be 0.3-0.5 m from the first support.

- First three supports closest to the engine or generating set should be fixed supports. Where necessary, sliding supports can be used after these three fixed supports to allow thermal expansion of the pipe.
- Supports should never be welded directly to the pipe. Either pipe clamps or flange supports should be used for flexible connection./44/;/47/

3.3 Pumps

The lubricating oil system includes various pumps with different purposes, some of which are only used to transfer oil from a container to another without any critical pressure or flow requirements, and with some of which the pressure and flow has a big influence on the functionality of the engine, but still common for all pumps handling lubricating oil is that they need to produce a steady flow and treat the oil carefully to avoid foaming or emulsifying water into oil.

The pumps used in the lubrication oil system are positive displacement pumps. To be more precise, gear and screw type pumps are commonly used. The positive displacement pumps have advantages when moving viscous fluids since the fluid is moving axially with minimal turbulence, it reduces the risk of foaming that would occur when pumping viscous fluids. They are also able to pump fluids of higher viscosity without losing flow rate. /49/, /51/

A *screw pump* is a positive displacement pump, powered by electric motor or crankshaft, which uses one or several screws to move fluids along the screws' axis. The development of the screw pump has led to a variety of multi-axis technologies where carefully crafted screws rotate in opposite directions or remain stationary within a cavity. /51/

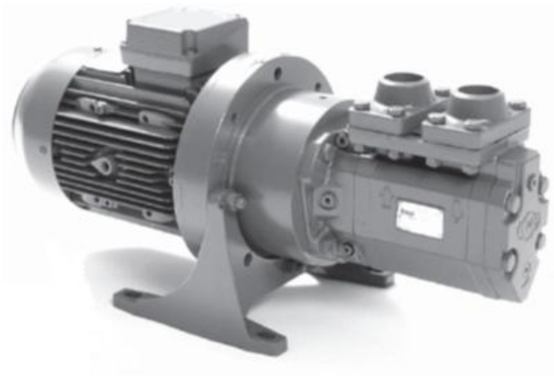


Figure 13. IMO ACE screw pump /51/

The pump presented below in Figures 14 and 15 shows a screw pump with three screws or rotors, with an electric motor driving the power rotor. The rotors drive the liquid forth in a closed chamber that exists between the idle rotor and the pump housing, i.e. the fluid is transferred through the pump in an elevator-type of move.

A pump is normally equipped with an integrated pressure-relief valve, which limits the differential pressure over the pump and protects the pump if the discharge line is blocked. The valve is adjustable for different opening pressures. The opening pressure is not allowed to be higher that the designed system pressure, unless a separate over-pressure valve exists in the system.

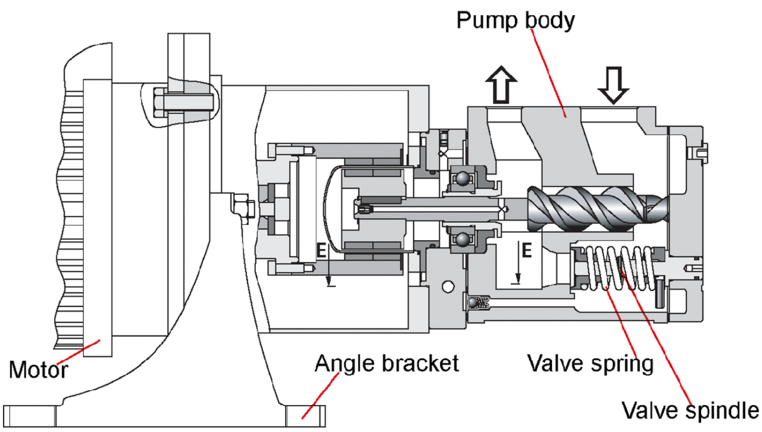


Figure 14. Internal parts of the screw pump seen from the side /51/

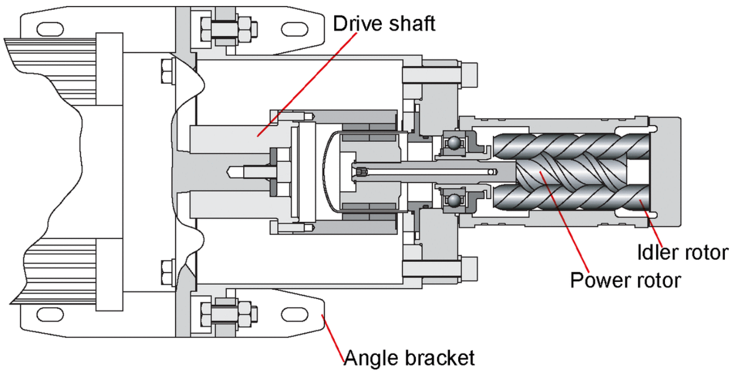


Figure 15. Internal parts of the screw pump seen from above /51/

The *gear pump* is also included in the positive displacement-pump category. The working principle of both gear-pump types is that two gears come into and out of mesh to produce a flow. The gear pump uses two identical rotating gears, of which one is driven by an electric motor or crankshaft, causing the other gear to rotate.

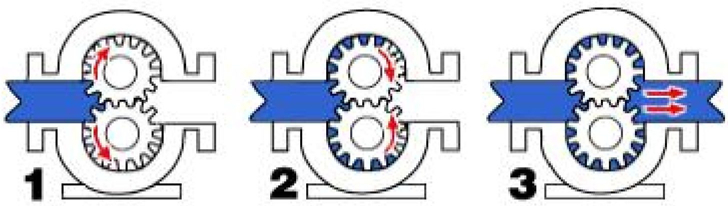


Figure 16. Three-stage pumping method: inlet, displacement and outlet /26/

1. An expanding volume is achieved on the inlet side of the pump by the gears coming out of mesh. As the gears rotate, liquid is trapped by the teeth of the gears.

2. Liquid is displaced between the pockets of the gear teeth and the casing as the gear is rotating the fluid from the inlet. The displacement causes a rise of pressure.

3. The pressurized liquid is pushed through the outlet port by the meshing of the gears.

The internal tolerances between gears and casing are very tight, which causes a good flow control, allows high pumping pressure and prevents internal leakages. /26/

3.3.1 Main Lubricating Oil Pump

The main lubricating oil pump is used to create a needed pressure and flow throughout the engine, and is typically engine driven. The required lubrication oil flow varies from $18m^3/h$ to $600m^3/h$ and therefore, both gear and screw type pumps are used. The gear type pump is cheaper than the screw pump but due to a larger pressure variation with gear pumps these pumps are feasible only to around 200 m^3/h flow rates. Due to a smaller pressure variations the screw pump is quieter than the gear pump and at the same time more complex structure increases the price of the pump, Therefore screw pumps are used when a steady flow with large flow rate is required. The gear pump is used for W38L, W32/34L and smaller engines and a screw pump is used for W32/34V, W38V and larger engines.

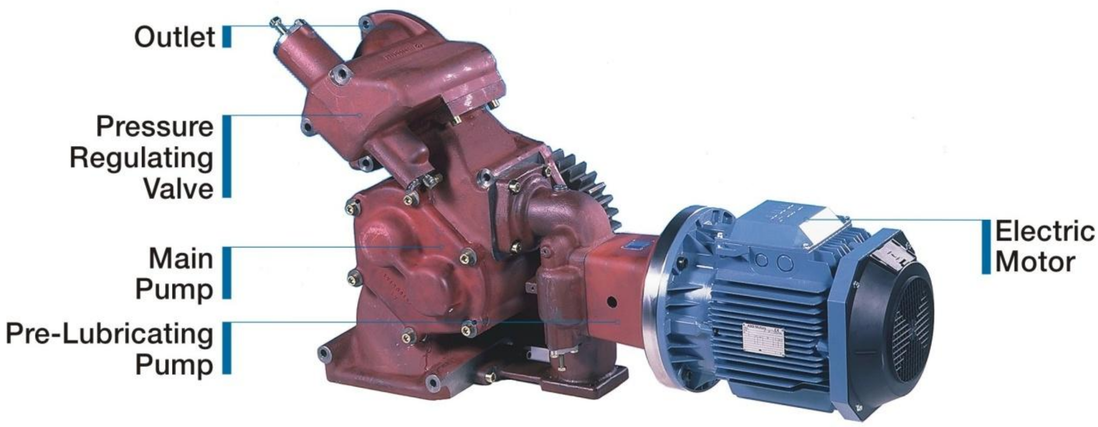


Figure 17. W32L gear type main lubricating oil pump and pre-lubrication pump. /36/

3.3.2 Pre-lubricating Pump

The pre-lubricating pump is an electric motor driven pump. When mounted on engine, the gear type pump is used and when mounted on the external system, the screw type pump is used. The pumps are equipped with a safety overflow valve and the pump is used for:

- Filling of the engine lubricating oil system before starting, e.g. when the engine has been out of operation for a long time
- Continuous pre-lubrication of a stopped engine through which heated heavy fuel is circulating on a stopped engine.
- On a stopped engine; if the engine is subject to vibrations, e.g. on a ship, the pre-lubricating pump should be running continuously and the crankshaft turned to a new position every second day to avoid damaging engine components.
- Cooling the turbochargers bearings and seals after stopping the engine.
- To provide additional capacity to the engine driven lubricating oil pump in installations where the engine speed drops below a certain value. In these cases, the pump starts and stops automatically on signals from the speed measuring system. This is used only for variable speed engines. /16/; /44/

3.3.3 Stand-by Pump

The stand-by pump is an electrically driven screw pump installed into external system, it is designed to provide roughly the same flowrate and pressure as the main lubricating oil pump. The pump is used with Ship Power installations to provide additional flow when the engine driven main lubricating oil pump cannot provide a sufficient flow, for example with variable speed engines. Also classification societies require a stand-by lubricating oil pump for main engines. /44/

3.4 Filtering and Conditioning

The main task for components used in filtering and conditioning systems are to separate and remove particles and foreign matter from lubricating oil and to keep oil temperature between the specified limits, and by this way to extend lubrication oil life-time and to protect engine components from possible damages caused by lubrication oil quality or temperature.

3.4.1 Lubricating Oil Module

The lubricating oil module is a compact module bolted directly into the crankcase. The module includes lubricating oil cooler, thermostatic valves and automatic filter in a one compact module.

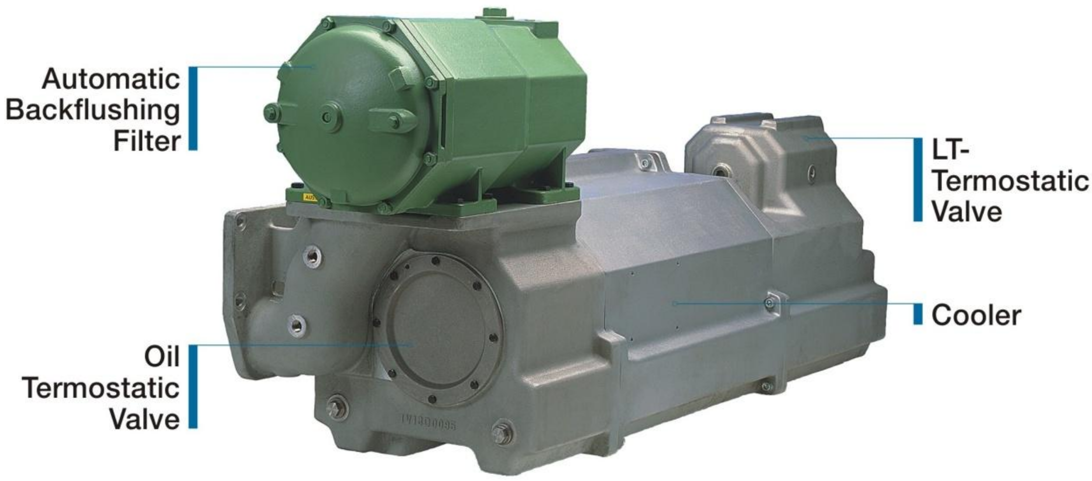


Figure 18. Lubricating oil module W32L /36/

Figure 19 describes the lubrication oil flow through the lubrication oil module. To reach the desired temperature of the lubricating oil thermostatic valve mixes the hot oil from the pump with cooled oil from the lubricating oil cooler, and after that oil flows through automatic filter and dirty backflushing oil from automatic filter flows through centrifugal filter and back to oil sump or to system oil tank.

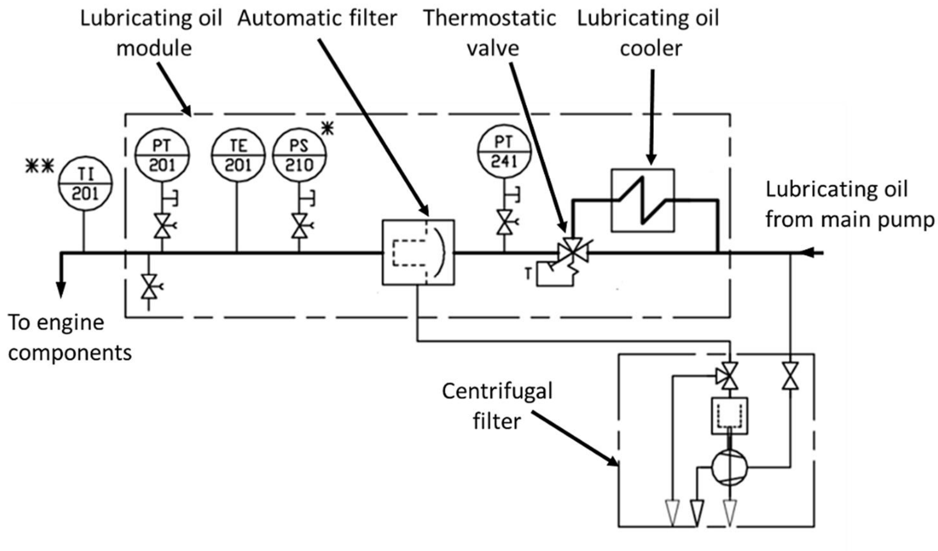


Figure 19. W32L lubricating oil module flow scheme. /44/

3.4.2 Engine Auxiliary Module

The engine auxiliary (EAM) module is a pre-fabricated engine-wise module located in the free end of the engine and acts as a junction box connecting the engine with lubricating oil, fuel and cooling water auxiliary system. EAM is used only with power plant installations; there has been some modularisation with Ship Power installations but not in the same scale as EAM usage with power plant installations.

The same components installed on the lubricating oil module can be installed into EAM, typically lubrication oil components for W20, W32 & W34 are installed on-engine and for W46 & W50 lubrication oil cooler, automatic filter and pre-lubricating pump are installed into EAM. There are multiple variations of EAM´s available. /24/

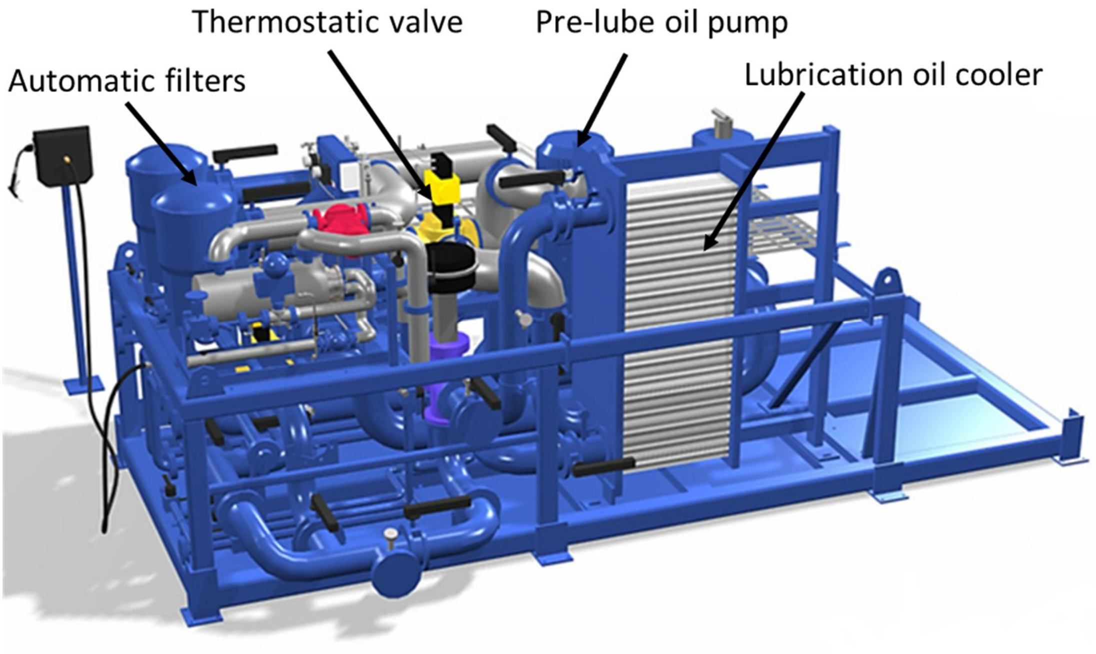


Figure 20. Lubrication oil component locations in W46/W50DF EAM 1-C MC S. /38/

3.4.3 Separator

Although separators do not work by filtration, the separator is an important component to maintain lubricating oil quality. The main purpose of the lube oil separator is to remove dirt and water from the lube oil to maintain the required lube oil quality. Keeping lubricating oil clean by means of separation helps to prevent the accumulation of substances that increase viscosity as well as any solid particles that can cause engine wear.

Contaminants that result from blow-by, such as particles of soot and other partly burned hydrocarbons, must therefore be removed from lubricating oil. Most of the sludge produced by the separator is water, in addition, calcium sulphate or gypsum forms as a result of the reaction between sulphur in the fuel and the neutralizing calcium-based base number (BN) additives in the lubricating oil, and comprises a major portion of the resulting sludge. The BN additives are important for preventing the formation of sulphuric acid and thus protect against acidic, or cold, corrosion, therefore also the need of a separator is heavily depending on the fuel quality used. A general rule is that lubricating oil volume should pass the separator 4-5 times per day. /32/, /5/

Wärtsilä does not give exact rules for all cases when to use lube oil separators. Instead Wärtsilä gives engine specific requirements on the lube oil quality (see Chapter 4.1). If the given limits are exceeded the lube oil must be changed. The time that it takes for the oil to exceed the limits depend on many factors and must be checked from case to case. /16/

The main components (see Figure 21) of the separator module are:

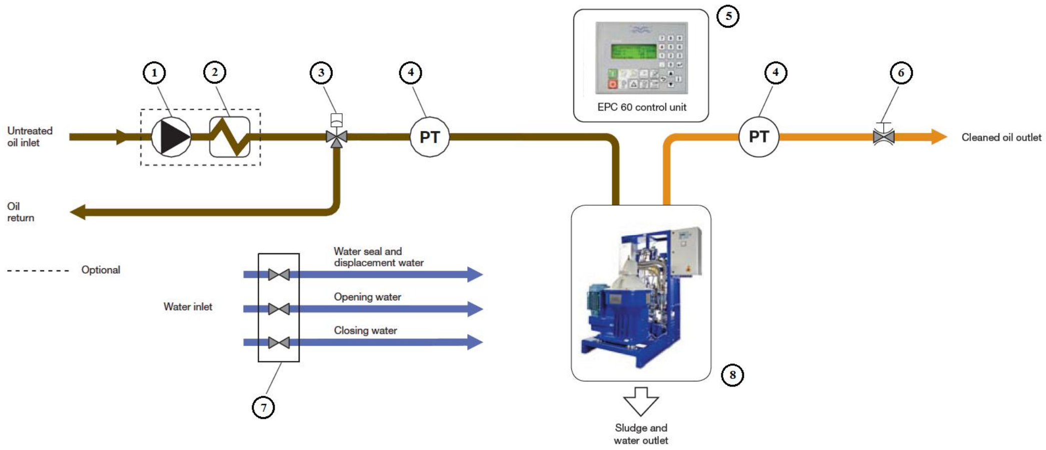
- Feed pump which controls the flow through the separator; the pump must be selected to match recommended throughput of the separator and normally the pump is supplied and matched to the separator by the manufacturer.

- Pre-heater which is dimensioned according to the feed pump capacity and the temperature in the oil sump or system oil tank. The heater capacity must be sufficient to maintain separating temperature without heat supply from the engine, recommended temperature after the heater is 95°C. The lubricating oil can be heated with electricity or steam and the surface temperature in the heater must not exceed 150°C to avoid cooking of the oil.

- Sludge tank and pump to collect discharged sludge and to pass it to main sludge tank.

- Control system to manage the system.

- Separator.



1. Feed pump	5. Process controller
2. Heater	6. Regulating valve
3. Change-over valve	7. Solenoid valve block, water
4. Pressure transmitter, oil	8. Separator

Figure 21. Alfa Laval P separator scheme. /5/

The efficiency of the separator is based on the centrifugal force created by an electric motor which rotates via a drive belt a bowl containing disc stack at high speed (see Figure 22) and causing centrifugal forces and separating heavier particles from the lighter clean lubricating oil. The discs are mounted close together so that as lubricating oil flows through the stack, the particles have only a short distance to travel before they come attached to one side or other of each disc. After becoming attached particles move up or down on the surface of the discs, heavier particles and solid contaminants are collected to its periphery to be discharged out of the bowl and lighter cleaned lubricating oil flows out from the center of the bowl via a clean oil outlet.

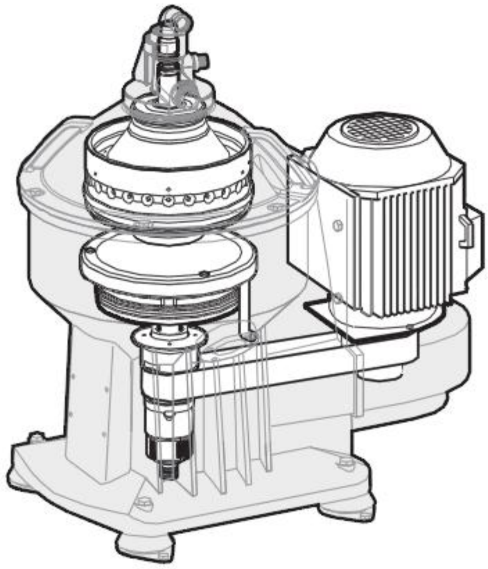


Figure 22. Alfa Laval P-separator. /5/

Separators with self-cleaning bowl are able to periodically discharge the separated solids at full speed. For this purpose, several ports are spaced evenly around the bowl periphery. These ports are opened and closed by moving the bottom half of the bowl. The opening mechanism is actuated hydraulically and water is used as a control medium. /32/

There are three different types of separators used within Wärtsilä products. The main differences between these separator types are related to water handling: purification and Alcap process can remove water and solids as products from the lubricating oil, and clarification process can only separate solids out from the lubricating oil.

3.4.3.1 Purifier

The centrifugal oil purifier has a bowl designed for the separation of water, solids and clean lubricating oil as products, with the intention of separating two intermixed and mutually insoluble liquids of different densities. In a purifier, water is continuously discharged from the bowl. A gravity disc is fitted on top of the bowl to obtain the correct interface position in the separator bowl (see Figure 23), setting the boundary between the oil and the water seal. The size of the gravity disc must match the oil density, viscosity, temperature and oil feed rate to the separator and therefore any changes in previous parameters can interrupt the process and therefore purifier is designed to work with well-defined and consistent liquids. The correct size of the clarifying disk size can be defined from the separator manufacturer's gravity disk nomogram table. /32/, /3/

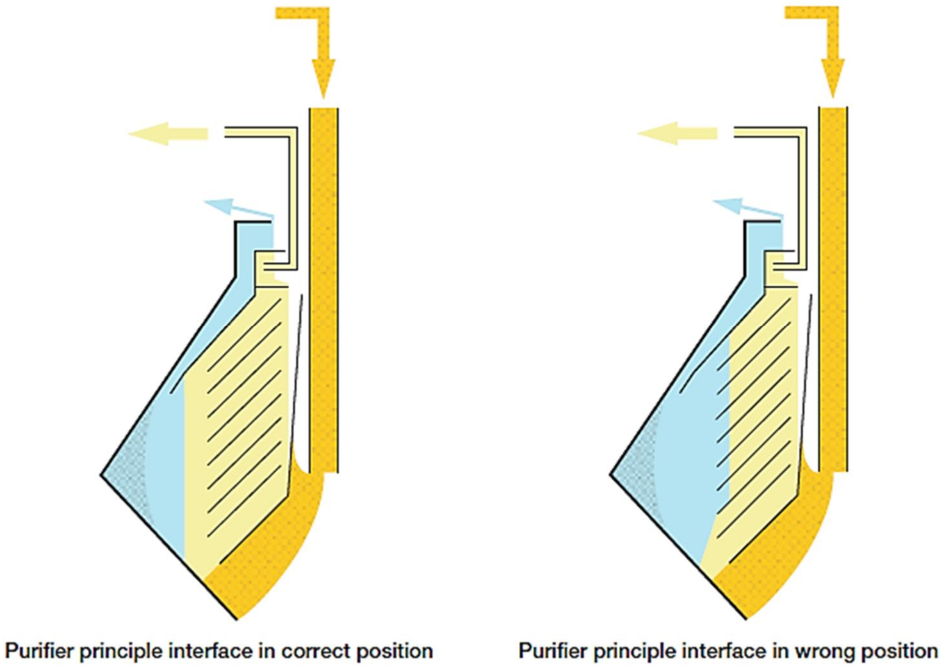


Figure 23. Purifier interface position. /26/

If the interface moves too far away from the centre, the result is a broken water seal. This means that oil escapes via the water outlet and is lost. If the interface gets too close to the centre, water will block the upper part of the disc stack, and the lower flow channels will be overloaded. This results in poor separation efficiency. /26/, /32/

3.4.3.2 Clarifier

The centrifugal oil clarifier is designed for separating particles from a liquid having a lower density than the particles. The clarifier disk is an optional disc, which replaces the gravity disc in the separator bowl, in the case of clarifier operation. The disc seals off the heavy phase outlet in the bowl, thus no liquid seal exists (see Figure 24). In a clarifier, the water outlet is blocked, thus limiting the clarifier's capability to handle water. Part of the water in lubricating oil is accumulated into sludge and removed with sludge discharge. /32/

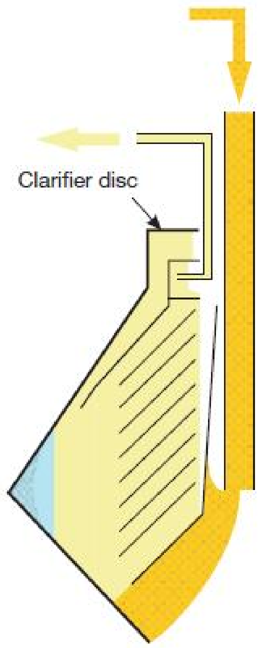
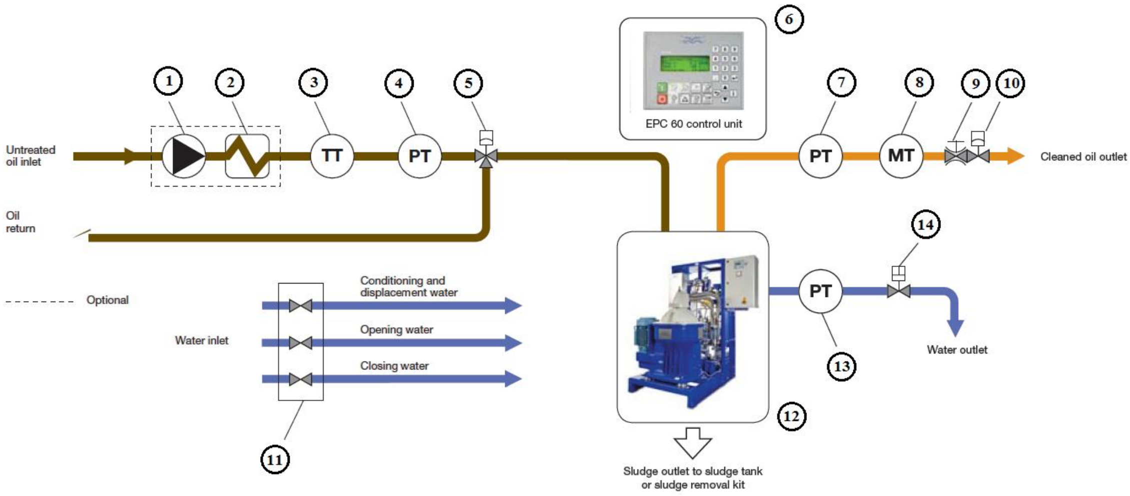


Figure 24. Clarifier operation. /26/

3.4.3.3 Alcap

Alcap is an intermediate between a purifier and a clarifier. Depending on the actual process conditions, the process controller selects the operating mode. The water transducer supplies information about process conditions in the cleaned oil outlet to the control unit (see Figure 25). This makes it possible to operate under optimal conditions with regard to discharge, oil displacement and other cleaning operations.



1.	Feed pump	8.	Water monitoring sensor
2.	Heater	9.	Regulating valve
3.	Temperature transmitter, oil	10.	Shut-off valve
4.	Pressure transmitter, oil	11.	Solenoid valve block, water
5.	Changeover valve	12.	Separator
6.	Control unit	13.	Pressure transmitter, water
7.	Pressure transmitter, oil	14.	Drain valve

Figure 25. Alfa Laval Alcap separator scheme. /26/

Dirty pre-heated oil is continuously fed to the separator, which essentially operates as a clarifier. Clean oil is continuously discharged from the cleaned oil outlet. Separated sludge and water accumulate at the periphery of the bowl. When separated water approaches the disc stack, traces of water start to escape with the cleaned oil. This minor increase in water content of the cleaned oil is detected by a sensor which is installed in the cleaned oil outlet (see Figure 26). Increased water content in the cleaned oil is a sign of reduced separation efficiency, not only of water, but of solid particles too.

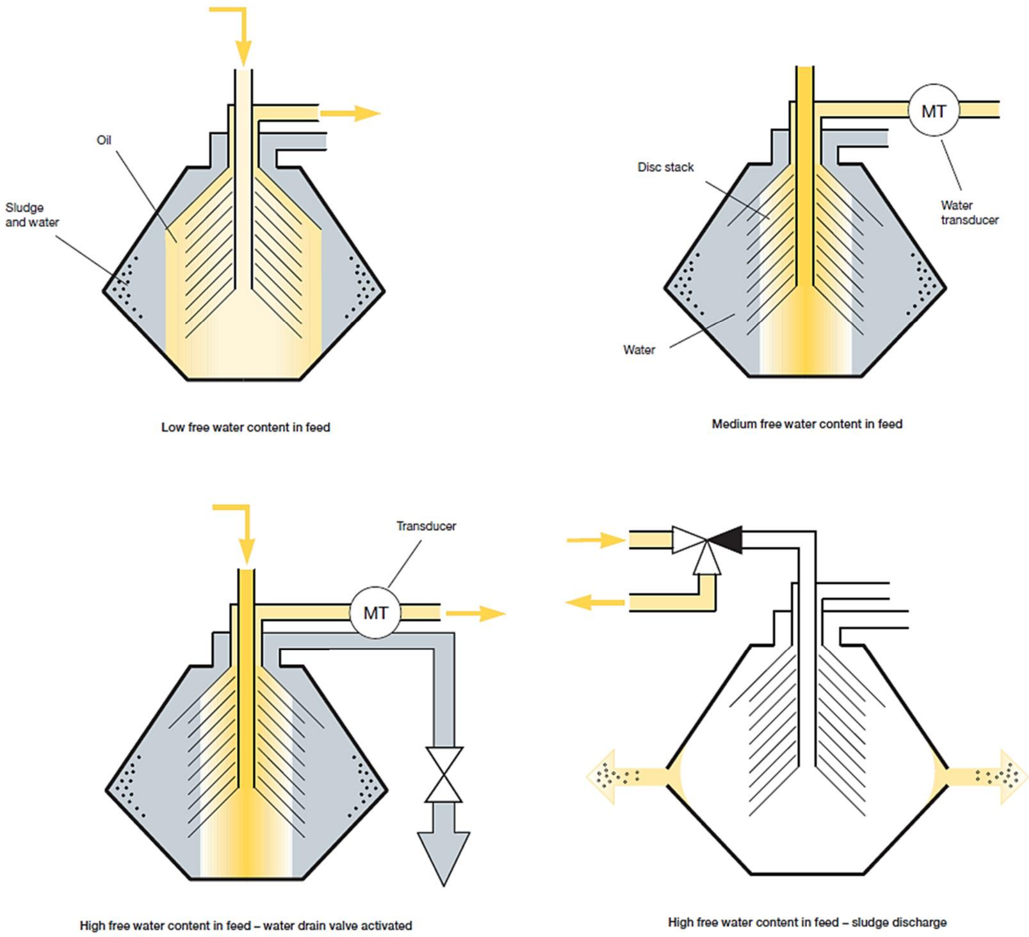


Figure 26. Alcap operation principle /26/

The transducer continuously measures changes in water content. No absolute values of water content or volume are involved. The transducer measures the deviation from a non-calibrated reference value and transmits a signal to the control unit for interpretation. Measurements that fall within the permissible deviation values are known as a trigger range. The control unit stores a new reference value after the transducer stabilization time that follows when every sludge discharge sequence has elapsed. During the reference time the best possible separation result is obtained. At the trigger point, which is when the water content in cleaned oil reaches its maximum allowable deviation of approximately 0.2 percent in water content, the control unit initiates an automatic discharge of the water that has accumulated in the separator bowl.

During normal operation vital process parameters are monitored. The control unit provides alarm functions for low oil pressure and power failure. Alarm functions are also provided for errors involving the process controller. The control unit automatically controls the water admitted to the separator for the water seal and displacement of oil prior to sludge discharge. The bowl has a simple paring tube that "floats" on the surface of the heavy water phase instead of a conventional heavy phase paring disc. /26/

3.4.3.4 Usage within Power Plant installations

Wärtsilä does not give exact rules for all cases when to use lube oil separators. Instead Wärtsilä gives engine specific requirements on the lube oil quality. If the given limits are exceeded, the lube oil must be changed. The time that it takes for the oil to exceed the limits depend on many factors and must be checked from case to case.

However Wärtsilä has experience what is the best setup in most cases. Recommendations about separator usage in Power Plant installations are given below. /16/

When the lube oil separator is needed according to power plant separation usage guideline:

- Engines using Heavy Fuel Oil (HFO)
- Engines using fuel worse than ISO-F-DMB
- Engines using Liquid Bio Fuel (LBF)
- TRI-fuel DF engines (using HFO, LFO & gas)
- GD engines using HFO, Crude Oil (CRO) (quality that is worse than LFO ISO-F-DMB)

Lube oil Separator not necessary:

- SG engines
- GD engines (only if the liquid back-up fuel is ISO-F-DMB quality or better)
- Engines using High quality LFO (ISO-F-DMB or better)
- DF engines (If using dual fuel (LFO + gas) as back-up fuel and no TRI-fuel possibility)

All installed separators are dimensioned to run continuously when the engine is running. Short stops in emergency cases are allowed (max. 48 h). However, the limiting factor is always that the lube oil quality must stay within given limits for the specific engine. /49/

3.4.3.5 Usage within marine installations

Current recommendation summarized from the Product Guides:

- Marine auxiliary engines operating on fuel having a viscosity of max 380cSt/50°C may have common lubricating oil separator, for W20 & W26L maximum of three engines may share the same separator and W26V and larger engines the maximum is two engines for separator unit.
- For main engines and for HFO operation each engine must have dedicated lubricating oil separator unit.

/39-42/, /44-48/

3.4.4 Automatic filter

The automatic filter is used to filter particles from lubricating oil in order to protect the engine components. Wärtsilä engines use Boll & Kirch Bollfilter Automatic Type self-cleaning lubricating oil filters. Automatic filters can be mounted on-engine into the lubricating oil module or off-engine into the engine auxiliary module.

This chapter covers four different filter types commonly used on current portfolio engines. Main differences between the filter types are in the self-cleaning method, filtration surface area and maximum flow rate. Filters are installed into the oil supply line after the main oil pump and lubricating oil cooler. All automatic filters use round wire mesh candle elements to capture particles until removed automatically from the filter element by the automatic continuous backflushing process with filter types 6.46 & 6.48 or intermittent process triggered by time or pressure difference with filter types 6.72 & 6.64. Filtration grades for the candle elements are stated as absolute mesh size.

3.4.4.1 Bollfilter Automatic Type 6.46

Automatic filter type 6.46 operates without any external energy or medium, as a continuous backflushing filter, all filter candle elements are installed into one big chamber. Type 6.46 filter can be mounted on-engine and backflushing oil from the filter is treated with centrifugal filter on W20, W26, W32, W34, WL38B, W46 and W50 engines. Type 6.46 has also been installed previously as an external filter in the EAM and is used on W46 & W50 power plant engines and backflushing oil is treated by a duplex filter but the current recommendation is to use newer type 6.64 model for power plant engines.

During the filter operation (see Figure 27), the lubricating oil enters through the inlet flange into the housing section (1). A partial flow of ca. 50% of the unfiltered oil is fed via the central riser pipe in the mesh insert into the upper part (2) of the filter housing and into the filter candle (3),. The candle element is open from both ends. The other half flows from below into the filter candle, the filtration flow direction through the candle is from inside to outside. The filtered lubricating oil then proceeds through the safety mesh (9) and into the filter outlet (4). /6/

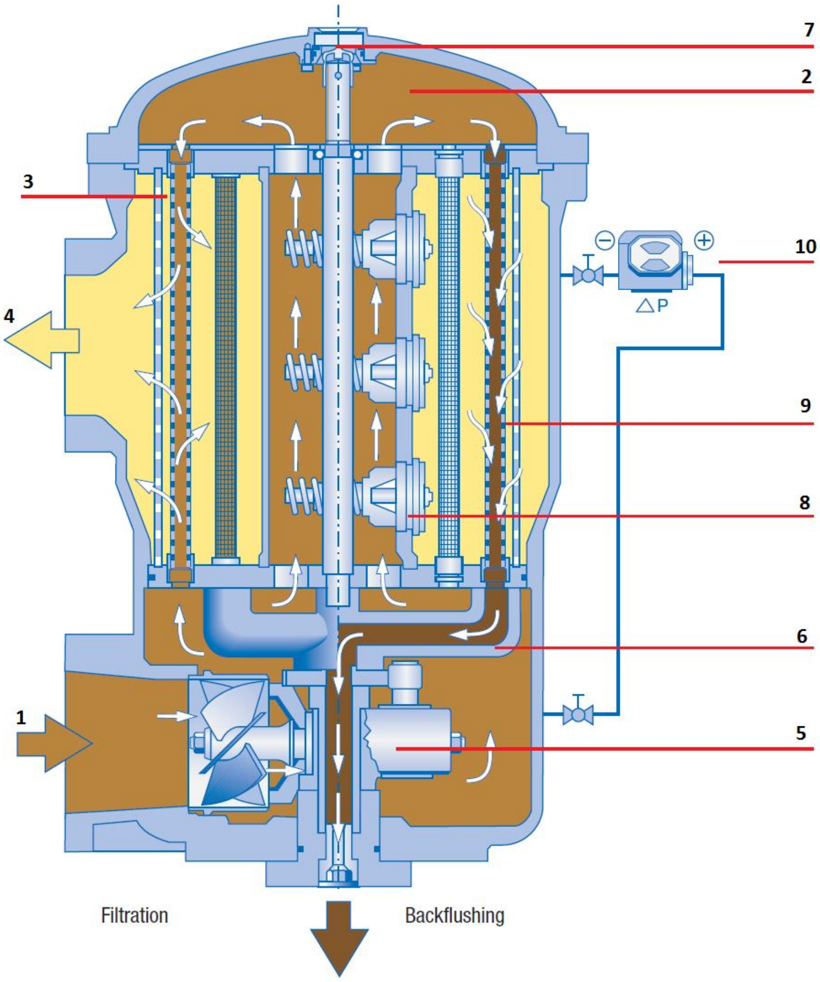


Figure 27. Bollfilter Automatic Type 6.46. /6/

The filter candles are cleaned continuously and in sequence without interruption to the filtration process. A turbine (5) mounted in the inlet flange drives the backflushing mechanism, high speed of the turbine is reduced with worm gear and toothed gear. The gear rotates the backflushing arm (6) continuously, the clearance between the arm and filter body is only 0.1-0.5mm. When the rotating arm is positioned with the filter candle, it is connected to backflush line and the pressure inside the candle drops to near atmospheric pressure and clean pressurized oil starts to flow in opposite direction through the candle and removing particles from the filter element. The oil flow from the top into the candle is limited with an orifice in order to minimize the amount of unfiltered oil flow into the backflushing line. Inspection glass (7) in the cover is provided for operating check of backflushing. /6/

If the filter candle cleaning operation is disturbed or interrupted, once the theoretical differential pressure reaches 2 bar, the overflow valves (8) open and the lubricating oil is filtered only via a safety mesh (9) incorporated as a second filter stage. However, before this status occurs, a differential pressure signal is issued by the differential pressure monitoring system (10). /6/

3.4.4.2 Bollfilter Automatic Type 6.48

Automatic filter type 6.48 operates without any external energy or medium, as a continuous backflushing filter. Type 6.48 can be mounted on-engine into lubrication oil module and off-engine into engine auxiliary module. The filter is mounted on-engine with W20, W6L26, W32 and backflushing oil is treated with centrifugal filter. On W46, W46F and W50 the filter can be mounted either on-engine or off-engine and backflushing oil is treated with centrifugal filter (rare) or Bollfilter 6.72 depending on the installation.

Lubricating oil passes through the inlet flange (1) and turbine to the bottom end of the filter candles (see Figure 28). A partial current is fed via the connecting pipe (2) to the upper part of the housing (3), oil flows through the filter candles (4) at both ends, from the inside to the outside, and in the process larger particles of are held back on the inside of the filter candles. The filtered lubricating oil then proceeds through the safety mesh (5) and into the filter outlet (6).

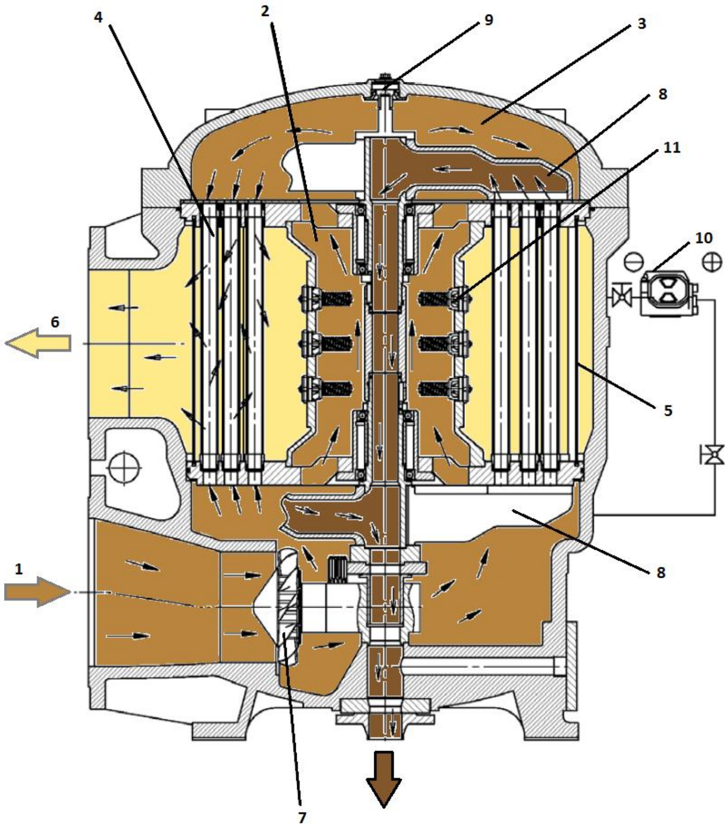


Figure 28. Bollfilter Automatic Type 6.48 /10/

The filter candles are cleaned continuously and in sequence without interruption to the filtration process. A turbine (7) mounted in the inlet flange drives the backflushing mechanism, high speed of the turbine is reduced with a worm gear and toothed gear. The gear rotates the bottom and top flushing arms (8) continuously. When the rotating arm with open connection to the backflushing line is positioned with filter candles, the opposite side rotating arm seals the other end of the filter at the same time and reduces the amount of unfiltered oil entering into the backflushing line. This type of operation does not need restrictors as used with type 6.46 on top of the filter elements. The lower pressure on the inside of the filter candles during backflushing and the higher pressure of filtered lubricating oil on outside of the filter candles generate a counter flow through the filter material, from the filter's clean side via the filter's dirty side to the backflushing line. The inspection glass (9) in the cover is provided for operating check of backflushing. /10/

If the filter candle cleaning operation is disturbed or interrupted, once the differential pressure reaches 2 bar, the overflow valves (11) open and the lubricating oil is filtered only via a protective mesh (5) incorporated as a second filter stage. However, before this status occurs, a differential pressure signal is issued by the differential pressure monitoring system (10). /10/

3.4.4.3 Bollfilter Automatic Type 6.64

Instead of the single chamber structure of Bollfilter 6.46 & 6.48, the filter candles in Bollfilter 6.64 are positioned in multiple filter chambers and backflushing operation is intermittent and it is done with compressed air instead of lubricating oil. There are no overflow valves that could mix un-filtered oil into the filtered oil and therefore there is no safety mesh after filter candles. Type 6.64 is always installed in the external lubricating oil system. Type 6.64.07 with backflush oil treatment unit is used with W46 & W50 power plant engines, type 6.64 is also a recommended filter type for marine installations where the automatic filter is to be used in the external lubricating oil system.

In filtration mode (see Figure 29) the filtered fluid enters the lower inlet connection (1) of the filter housing, then flows into the individual filter chambers (2) from the open underside of the chamber before passing from the outside of the suspended cylindrical filter elements (3) through to the inside. Contaminants are removed from the oil and retained on the external surface of the elements. The cleaned lubricating oil (4) emerges from the clean side (5) of the filter through the upper outlet connection (6). One filter chamber is always isolated from this process, held in reserve and sealed by the central selector mechanism (7). After being backflushed the chamber with cleaned filter candles is returned to the system pressure and waits to be integrated into the operating system again. /7/

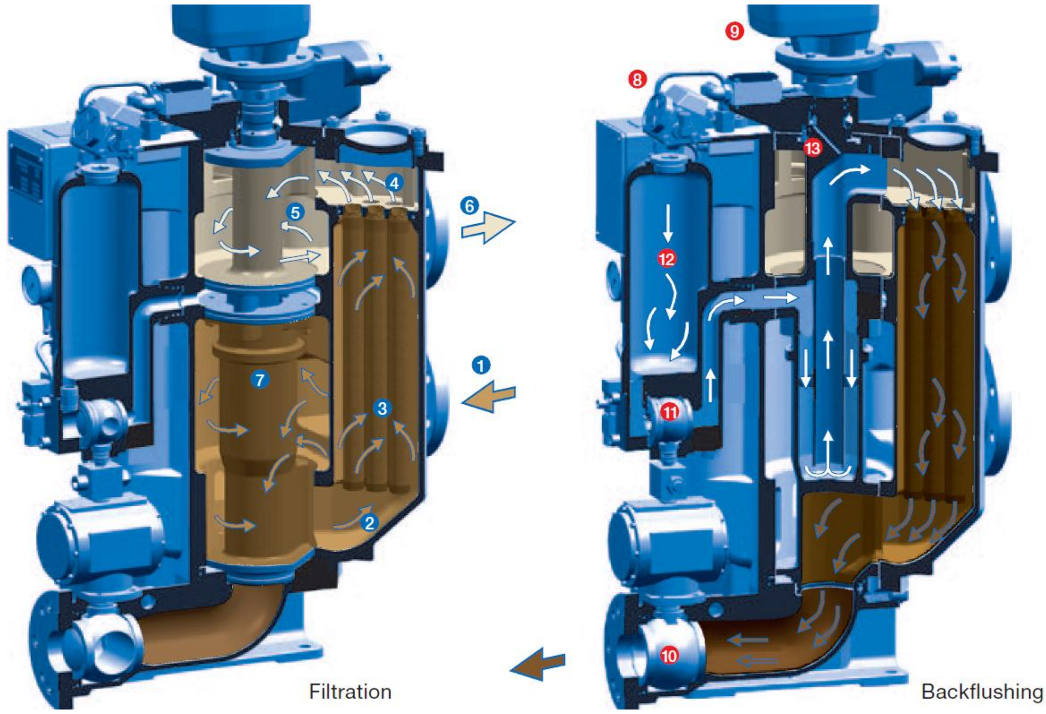


Figure 29. Bollfilter Automatic Type 6.64 /7/

Backflushing (see Figure 29) is done with compressed air and it is an intermittent process triggered by time or the differential pressure indicator (8), depending on which value is first exceeded. The control unit automatically actuates the backflushing process. An electric gear motor (9) turns the selector mechanism to the next contaminated chamber and isolates it from flow and simultaneously opens the previously cleaned and prefilled chamber back to operation. The backflush process is fast, the pneumatic drive unit activates the backflush discharge (10) and air release (11) valves. This releases a blast of compressed air from the air reservoir (12) into the isolated filter chamber via the selector mechanism. The backflush air drives a small volume of clean lubricating oil through the filter element in reverse direction and blasts the contaminants from the outer surface of the filter elements and out of the filter chamber via the backflush discharge valve. Once this process has been completed, the air and discharge valves close once again. The empty chamber is refilled with fluid via a borehole on the clean side (13) of the selector mechanism and automatically ventilated. Now this chamber takes on the role of reserve chamber waiting to be switched into the filtering process again. /7/

Bollfilter type 6.64 can also be fitted with bypass filter type 6.64.1, backflushing oil treatment unit type 6.64.07 or both combined in to type 6.64.1.7 as shown in Figure 30.

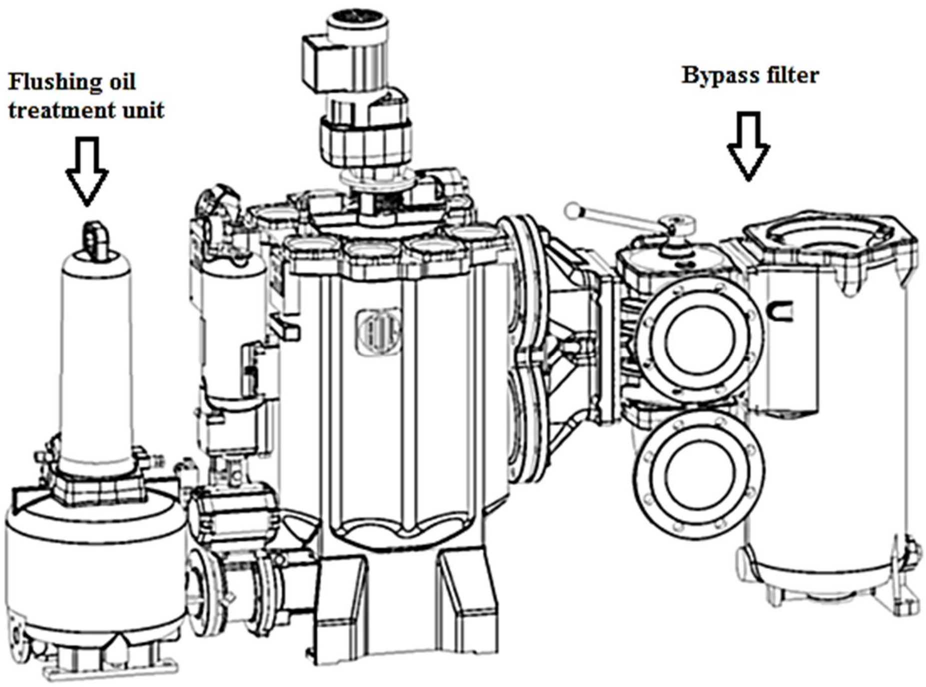


Figure 30. Bollfilter 6.64.1.7 /9/

By integrating flushing oil treatment and bypass filter into a complete lubricating oil treatment system you can save space and simplify the system and external piping to reduce costs and complexity of the complete installation.

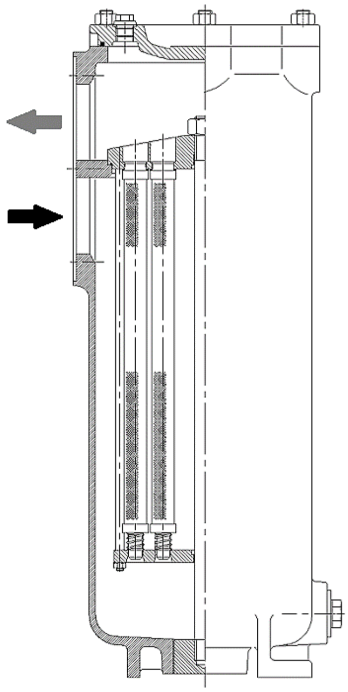


Figure 31. Bollfilter bypass filter used with filter type 6.64. /9/

The bypass filter (Figure 31) is used to filter particles lubrication oil in order to protect the downstream engine components. The bypass filter is used in situations in which the filtering process must not be stopped even whilst maintenance or repairs are being performed on the automatic filter. The oil being filtered flows through the lower inlet flange into the housing, from where it flows into the filter chambers. Oil flows through the filter element from the outside to the inside and the particles in the oil are held back on the filter material of the filter element. The cleaned oil proceeds to the filter outlet above. The condition of the bypass filter is monitored by differential pressure monitoring system and cleaning the filter elements is done manually by removing the elements from the casing. /9/

A segmented plug valve is used to switch between the connected automatic and bypass filter. The special shape of the plug valve prevents interruptions in the flow of medium and pressure surges when switching over and guarantees freedom of movement due to lower levels of frictional force. The switch-over is performed manually using the attachable lever. The construction of the circuit prevents both filters from being shut down at the same time. A pressure compensation valve is fitted to the segmented plug valve to compensate pressure between the two connected filters. It is opened and closed manually. /9/

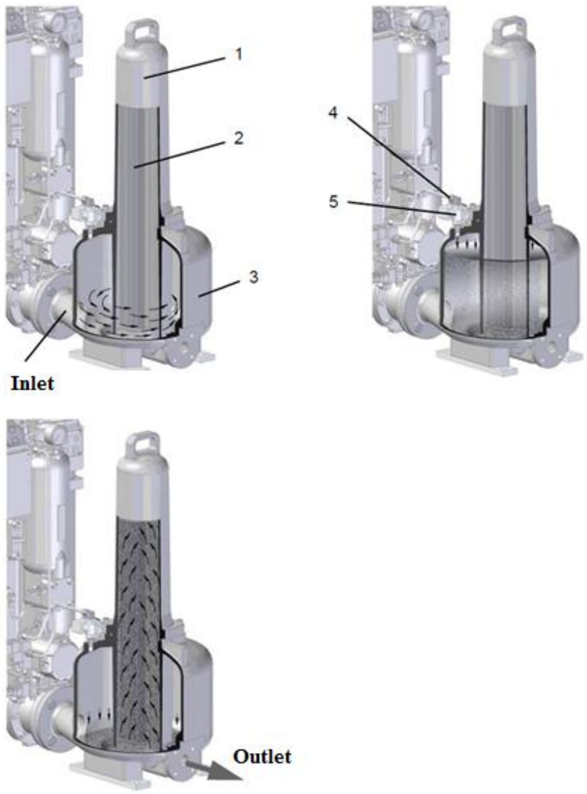


Figure 32. Bollfilter backflushing oil treatment unit used with filter type 6.64. /9/

The flushing oil treatment unit, presented in Figure 31, is used to regenerate the dirty backflushing oil from the automatic filter and pass the usable oil back to circulation. When the automatic filter is backflushing, the backflush oil from the automatic filter flows into the depressurized flushing oil treatment filter (1). It is collected in the sludge chamber (3). Once the flushing of the automatic filter is complete and the flushing valve is closed, the solenoid valve (5) on the flushing oil treatment filter is activated and the compressed air supply valve is opened (4). The compressed air in the system now enters into the flushing oil treatment filter. The admission of pressure causes the backflushing medium in the system to be forced through the filter element (2). The backflushing medium, which is filtered in this way, flows out through the flushing oil outlet and is fed back into the oil circulation. The medium flows through the filter element from the outside to the inside. The filter element is attached to the filter support and fastened in place due to the shape of the filter housing. The dirty side is sealed off from the clean side by a seal on the filter element. The particles of dirt held back on the filter element generates a growing differential pressure between the flushing oil inlet and outlet. This is detected by the differential pressure monitoring system and evaluated by the operator. /9/

3.4.4.4 Bollfilter Automatic Type 6.72

Bollfilter type 6.72 (see Figure 33) has two filter chambers which are mounted on top of the filter housing. Each of these chambers is fitted with a vertically positioned filter element and includes between 1 and 16 filter candles depending on the filter size. The filtering work is divided up in such a way that one of the filter chambers can regenerate while the other carries on filtering.

There are no overflow valves that could mix un-filtered oil in to the filtered oil and therefore there is also no safety mesh. In the event of the capacity of the filter candles in the filter chamber that is currently operating is contaminated, the regenerated reserve element will take over. The indicator for the contamination is the pressure differential between the dirty and the clean side. Type 6.72 can also be fitted with flushing oil treatment unit similar to solution used with 6.64 and the filter type number is also indicated similarly as 6.72.07. /8/

Type 6.72.07 filter with flushing oil treatment filter is used with Wärtsilä engines as an externally mounted backflushing filter instead of the centrifugal filter or duplex filter. It is typically mounted on the backflushing line of type 6.46 or 6.48 and used with W46F or W50 engines.

During the filtration process, the lubricating oil to be filtered flows through the inlet opening (1) into the filter housing. The oil is fed into the chamber that is engaged (2) passing through the filter candles (3) from the outside to the inside. The filtered contaminants out are held back by the mesh. The cleaned liquid (4) passes through the inside of the candle to the filter outlet in the lower part of the housing. During this filtration process, one filter element with clean filter candles will be on hold as a reserve in the chamber that is not involved in the current operation. The backflush discharge valve is shut and compressed air is available in the air reservoir. /8/

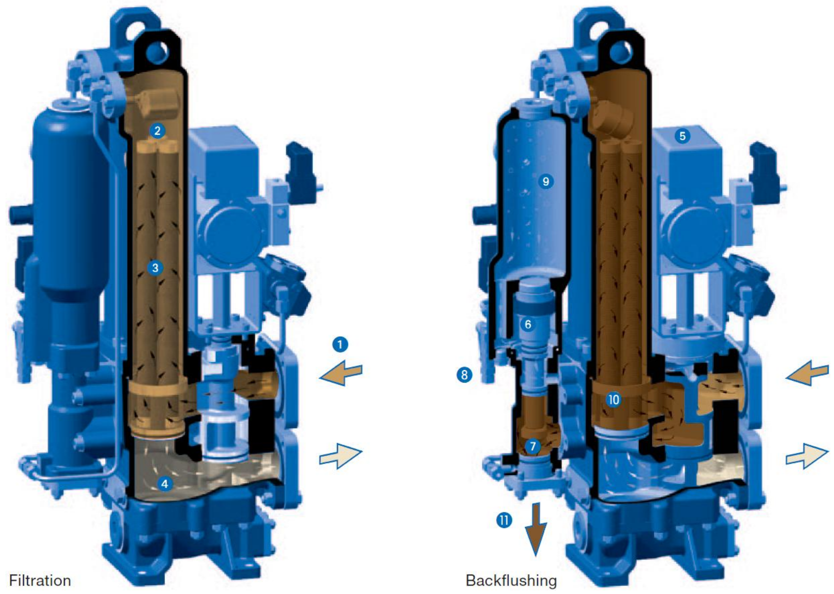


Figure 33. Bollfilter Automatic Type 6.72 /8/

Once the differential pressure between the dirty and clean sides of the filter has reached a predetermined value, the filter element cleaning process is actuated automatically. The pneumatic drive (5) will then swivel the actuating device to a point where the inflow of unfiltered lubricating oil into the contaminated filter chamber is blocked while the inflow into the previously cleaned chamber with the reserve candles is enabled at the same time. This will cause the differential pressure to drop immediately. And at the same time a double-acting tappet (6) opens the opening for the flushing oil outlet (7) and the infeed for the flushing air (8). The flushing air from the air reservoir (9) presses clean liquid at a high speed in reverse direction (10) through the filter candle. The particles on the outside of the candle are thereby removed and flushed out of the filter via the open backflush discharge valve (11).

After a short after-blowing time, the backflush discharge valve will close again. The emptied chamber will be filled with clean liquid via a refill bore. The candles in this chamber are now the reserve that is ready and waiting to be once again switched into the filtering process. /8/

3.4.5 Lubricating Oil Cooler

Lubricating oil has to be cooled from normal operating temperature at full load 75-80°C to nominal inlet temperature of 56-68°C, depending on the engine type. Too low oil temperature will cause increased viscosity which will increase the flow resistance and reduce the flow. Too high temperature will reduce viscosity and reduce the oil film thickness in high load areas and also will cause ageing of the oil. The cooling media for LO cooler is taken from the low temperature circuit and it is positioned in the cooling system circuit after the charge air cooler. The cooler can be built on engine or into the engine auxiliary module. /4/, /29/

Tube heat exchangers (Figure 34) are used with engines which have on-engine mounted lubricating oil module with self-acting wax-type thermostatic valves to provide compact solution for LO temperature handling. The only exception is with W20 where the brazed plate heat exchanger is installed into the lubrication oil module.

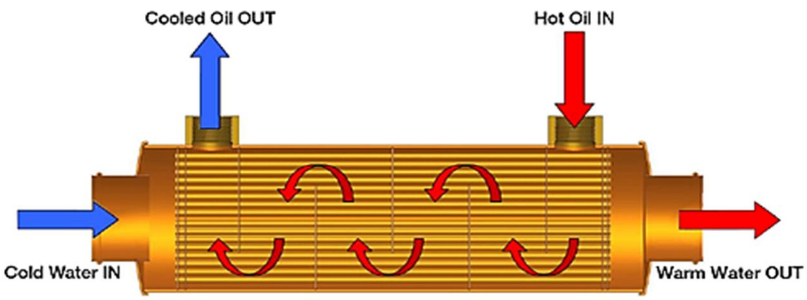


Figure 34. Basic functionality of tube heat exchanger /2/

There are many different sizes of tube stacks for the lubrication oil cooler available and the decision about the used stack size depends on engine use and design stage and LT water temperature.

The brazed plate heat exchanger (Figure 35) is used with W20 engine and mounted into the lubrication oil module. The heat exchanger consists of pack of corrugated metal plates, a thin metal foil is placed between layers and melted in a high temperature furnace to join plates together and form a permanent seal between different layers. /1/

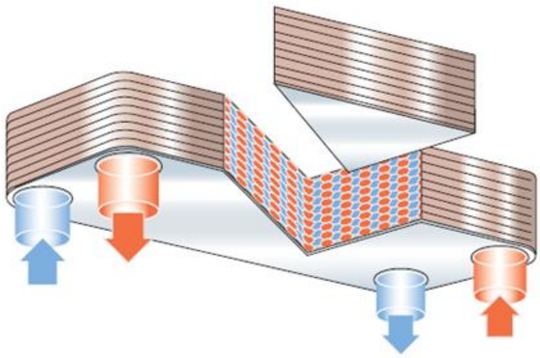


Figure 35. Brazed plate heat exchanger flow principle. /1/

The plate heat exchanger (Figure 36) consists of a package of thin corrugated metal plates with openings to allow the passage of fluids between them. The plates have gaskets between each other and they are arranged in such a way that a channel is formed between neighbouring plates. Every second channel is open to the same fluid. The actual heat transfer takes place between two adjacent channels, from hot fluid to cold fluid. The corrugation of the plates supports them against differential pressure and creates a turbulent flow in the channels. In turn, the turbulent flow provides high heat transfer efficiency. The high pressure drop is required in the plate heat exchanger to enable that efficient heat transfer. The flow of fluids is counter current and this in combination with a good heat transfer capacity makes it possible to design the plate heat exchanger with a small temperature approach. The advantages of plate type heat exchanger are:

- Leakage from one fluid to another is unlikely and external leaks through the seals can be easily detected.

- Easy to clean internally.
- Better heat transfer than other heat exchanger types means clean advantages in size and price.
- The capacity of the heat exchanger can be increased after installation just by adding more plates.

/4/, /25/

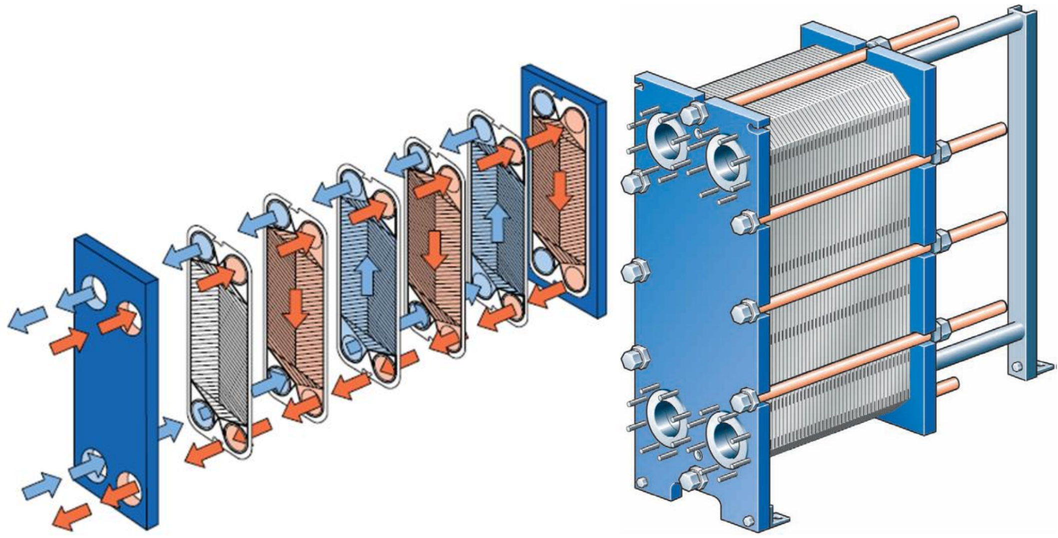


Figure 36. Flow principle of plate heat exchanger /4/

3.4.6 Thermostatic valves

Thermostatic valves are used to handle lubricating oil temperature by mixing warm lubricating oil from the engine into cooled lubricating oil from the LO cooler to meet engine specific lubrication oil temperature requirements. Valves used within Wärtsilä engines can be divided into self-acting temperature control valves and valves with actuators. When lubrication oil is still cold, temperature control valves directs oil back to the engine, when oil starts to get warmer the valves start to mix cooled lubrication oil from the LO cooler into warm oil which is coming from the engine.

3.4.6.1 Self-acting valves

Self-acting thermostatic valves are controlled by expansion of wax mixture, which is highly heat sensitive to temperature changes. Forces created by the expansion of the mixture start to open the valve and act as a sliding valve. The valve starts to open few degrees before the stated nominal temperature and is fully open few degrees above the nominal temperature, for example, if the nominal stated temperature is 63°C, the valve starts to open at 60°C and is fully open at 69°C. These type of valves are installed into lubricating oil module and used in the external system only with Vasa type engines. /33/

3.4.6.2 Externally controlled temperature control valves

Temperature control valves used in the external lubricating oil system are electrically (Figure 37) or pneumatically controlled to provide more precise temperature control than self-acting thermostatic valves. The temperature control valve is an integral part of the electric, pneumatic or electro-pneumatic system. The pneumatically controlled valves are ideal when there is a lack of electricity or when a fail-safe system is needed. The electro-pneumatic system combines the features and functionality of electronic control system with the fail-safe action benefits of a pneumatically actuated valve. /33/, /16/

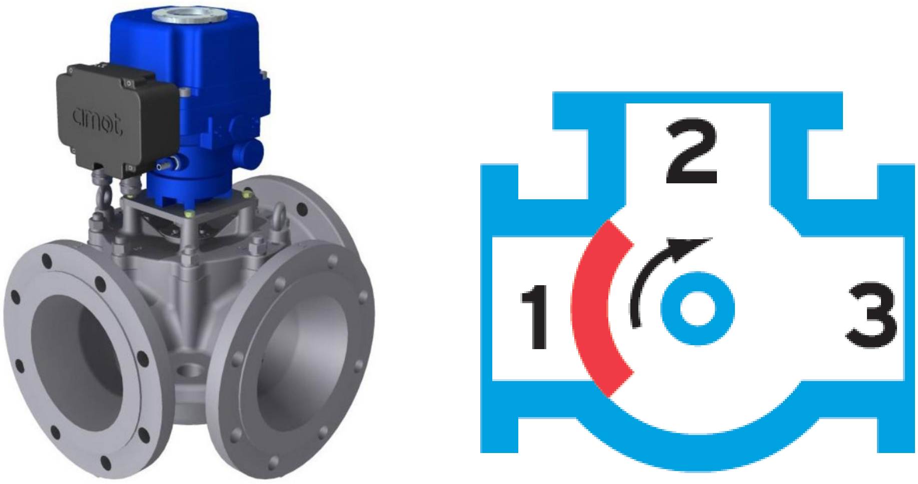


Figure 37. Amot electrically controlled rotary valve. /33/

3.4.7 Centrifugal Filter

The function of centrifugal filters is based on a clarification process. It separates contaminants into a filter paper insert placed on the outer wall of the bowl and must be manually cleaned. This type of process cannot remove water from the lubricating oil. The centrifugal filter (Figure 38) is connected to the lube oil system as a by-pass filter, its duty is to gather dirt particles out from the backflushing oil flow from the automatic filter and to act as an indicator of engine lube oil cleanliness.

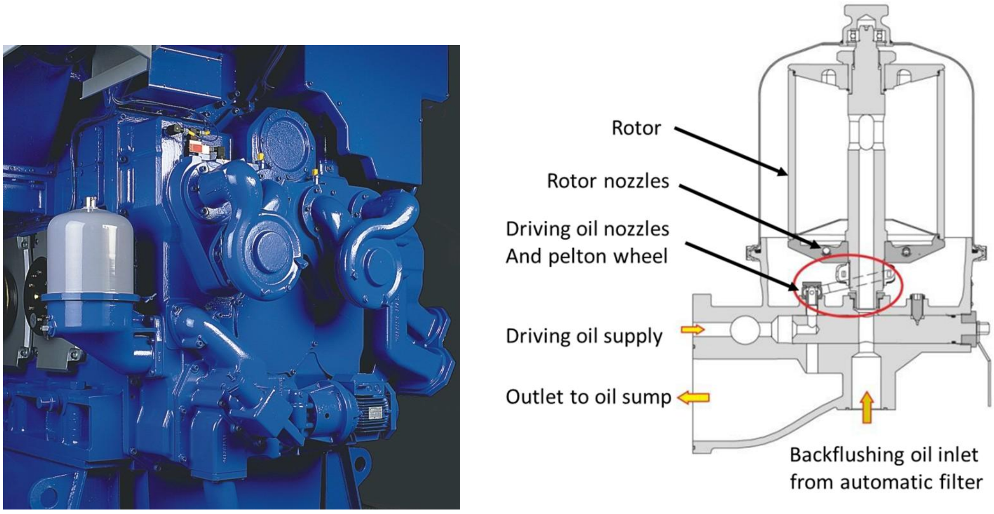


Figure 38. W32L Centrifugal filter. /36/, /30/

The centrifugal filter includes a housing containing a hardened steel spindle rotor comprised of two compartments, a cleaning chamber and a driving chamber with driving oil supply from the main lube oil pump. Dirty backflushing oil from the automatic filter is directed through the hollow spindle into the cleaning chamber of the rotor where centrifugal forces drive heavier particles into the periphery of the bowl and in time particles will form a dense layer of impurities inside of the bowl into the paper filter insert from where it has to be manually removed. The rotor gets its power from two sources, the exiting oil from the rotor nozzles and driving oil nozzles driving the rotor via a Pelton wheel. The filter can be shut off for inspection or cleaning while engine is running.

3.4.8 Crankcase Ventilation

Because the combustion chamber cannot be completely sealed, a small part of the gas escapes as blow-by via the piston and the cylinder liner gap and the piston rings into the crankcase. In turbo-charged engines there is also blow-by gas coming through the shaft sealing in the turbocharger. Since the crankcase is not designed for high pressures, it requires a ventilation pipe to prevent pressure from building up inside. Because the gas pressure is very high during the piston blow-by, it tears the lube oil off the walls breaking it into very small oil droplets forming a fine oil mist gas. These small oil droplets escape the crankcase via the crankcase ventilation which leads to oil pollution in the close surroundings and to increased lube oil consumption. /40/

The purpose of the crankcase ventilation is to evacuate gases from the crankcase in order to keep pressure in the crankcase within acceptable limits. Each engine must have its own vent pipe and crankcase ventilation pipes may not be combined with other ventilation pipes. V-engines are equipped with two ventilation pipes and it is permitted to join pipes from the same engine. Piping must be large enough to avoid excessive back pressure and possible equipment in the piping must also be designed and dimensioned to avoid excessive flow resistance. The connection between engine and piping must be flexible. /13/

3.4.8.1 Condensate trap

With the open crankcase ventilating system the gases from the crankcase are led to the free atmosphere. A condensate trap (Figure 39) is used to collect condensate water and oil from the crank case piping in order to prevent condensate from entering the engine's lube oil system. Condensate water and oil are guided into the sludge tank. For optimal performance the condensate trap must be fitted on the vent pipe near the engine. The condensate trap is used mainly on Ship Power installations. /48/

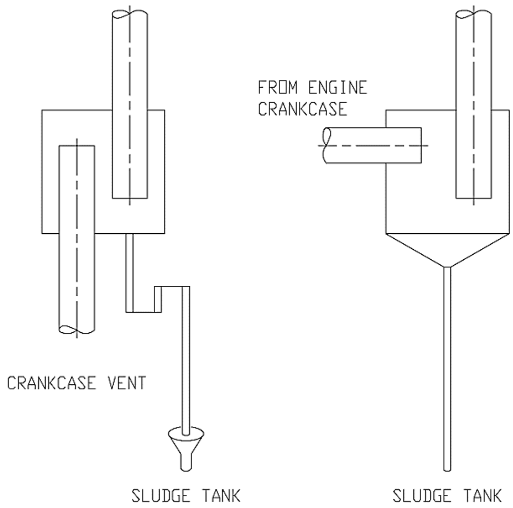


Figure 39. Condensate trap operation principle. /48/

3.4.8.2 Oil Mist Coalescer

Power Plants recommends using a roof coalescer on the outlet pipe that takes care of the biggest droplets. Due to technical, environmental and safety reasons, the traces of lubricating oil have to be removed from the gas. In order to remove this oil an oil mist coalescer (Figure 40) is to be installed. Power Plants recommends using the oil mist coalescer even if the oil mist separator is installed in case that the oil mist separator does not work for some reason. The oil mist coalescer is used on Power Plant installations and is available in two sizes DN100 & DN150.

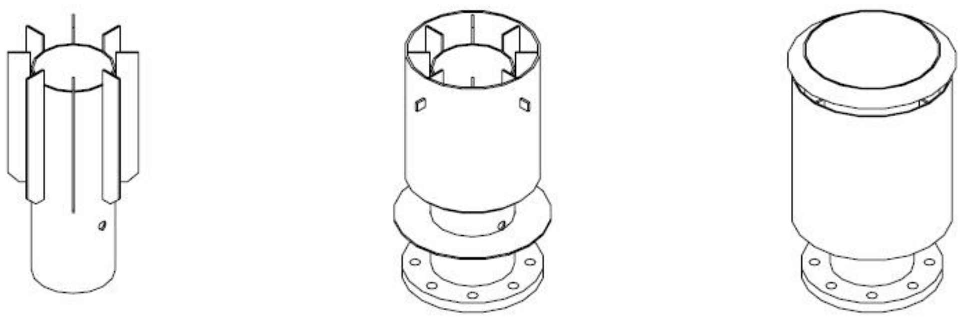


Figure 40. Oil mist coalescer structure. /16/

In the oil mist coalescer design, the following features should be involved in the design process.

- Low pressure drop is required, since the engine crankcase cannot withstand a high backpressure.

- The gas from the crankcase ventilation will in some occasions contain fuel and therefore the filter should be designed in the way that a gas explosion will not cause danger for personnel in the vicinity of the coalescer.

- The gas may be slightly corrosive owing to containing some traces of exhaust gas. This should be kept in mind while choosing materials. Also soot and other contaminants may pollute the filter.

- Crankcase ventilation materials should also withstand high temperature; temperature can vary between 50-90°C but normally it's around 70-80°C.

/16/

3.4.8.3 Oil Mist Separator

The oil mist separator is developed to reduce the oil mist emissions coming out from the crank case ventilation. It typically removes 95-98% of the oil mist which means that in warm climate there is no visible smoke coming out of the crankcase ventilation pipe and also eliminates the problem with surroundings close to crank case outlet getting dirty. The oil mist looks like smoke because the droplets are very small in size, between 0.1 and 2 μm, which is why till now it has been difficult to remove them effectively.

The basic function of the oil mist separator module can be seen in Figure 41. The oil mist separator is based on the centrifugal separation principle. Oily gas enters at the bottom of the separator and because of the centrifugal forces, the air is driven to the periphery of the disc stack separating the heavier oil droplets from the lighter gases by centrifugal separation. The process also decreases odor and smoke emissions as well. The separated oil is collected through a specially designed draining system which prevents already separated oil from re-entering the clean air outlet. The drained oil can be re-used by the engine to minimize lube oil consumption. The oil mist separator unit has a balancing pipe to ensure constant crank case pressure. The balancing pipe works also as an automatic bypass line in case of any separator disturbances. This is a safety function, which prevents the crank case pressure from rising too high. The oil mist separator module should be installed minimum 10 meter from the engine.

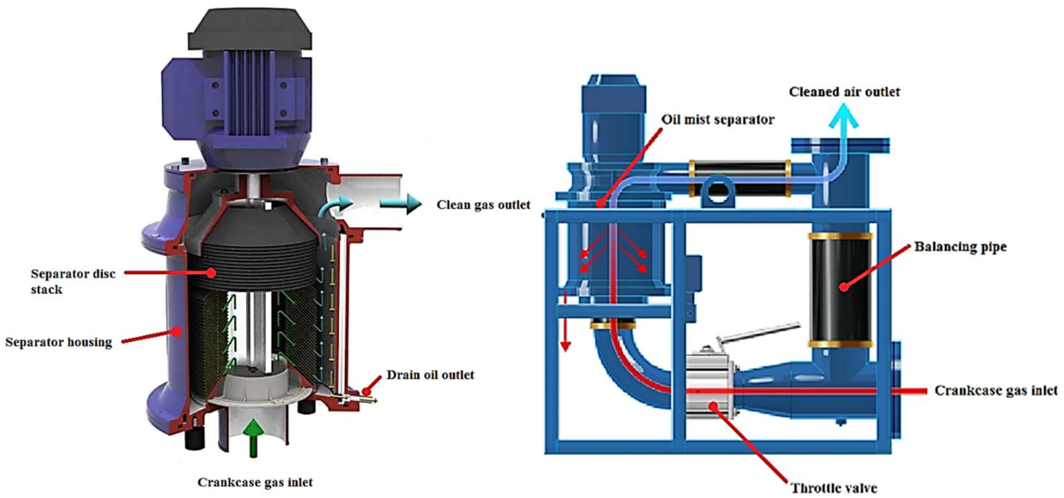


Figure 41. Oil mist separator functional principle. /40/

The connection pipe from the engine crankcase ventilation connection to the crankcase gas inlet connection in the oil mist separator unit is recommended to be constantly rising. If the oil mist separator is installed below the engine crankcase ventilation connection level, the crankcase gas inlet pipe must have a drain to remove condensate water and oil from the piping. There are two different type of oil mist separator systems available:

Open system (Figure 42) is designed for liquid fuel and gas engines, standard on all engines. The open system reduces efficiently the oil mist coming out from the crank case ventilation and the cleaned gases are directed back into the atmosphere.

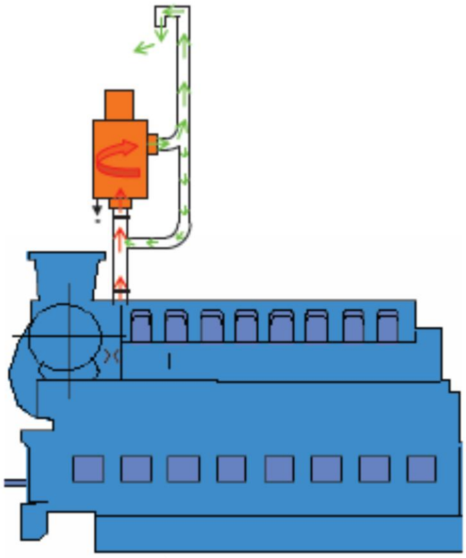


Figure 42. Open oil mist separator system principle. /16/

Closed system (Figure 43) is an option for gas engines in special cases where separated gases are directed back to the turbocharger air inlet. This type of solution is used only to eliminate the emissions coming out from the crank case ventilation.

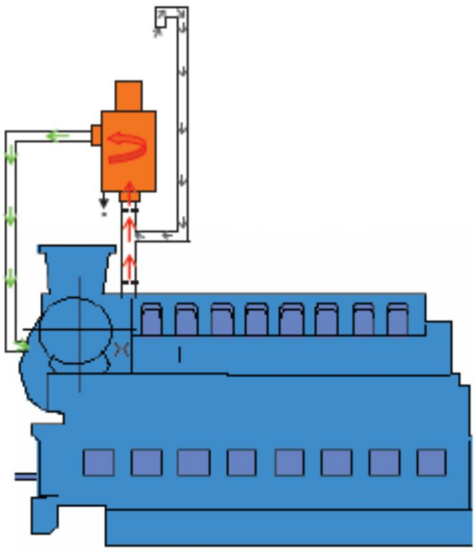


Figure 43. Closed oil mist separator system principle. /16/

Oil mist separation units are available in three sizes, DN100, DN150 and DN150 double with two oil mist separators in one unit and all models are available with UL certification. /16/; /40/; /11/

3.4.9 Suction Strainers and Screens

Suction strainers and screens are used to protect downstream components from larger particles by trapping or blocking solids from flowing fluid. Suction strainers and screens are installed before the pump in the suction line. The fineness of the strainer is a compromise between minimizing pressure drop to avoid pump cavitation and to provide adequate protection to avoid damaging the pump. The suction strainers must always be provided with an alarm for high differential pressure to avoid cavitation of the pump and since maximum pressure drop in the suction line is rated typically 30-40kPa the strainers are relatively coarse. There are two types of strainers used within Wartsila products, Y-type and basket strainer.

Suction screens (Figure 44) are used to block large particles from entering to the pump. The screens are used with in the main lubricating oil pump suction line and are very coarse to minimize pressure drop to avoid pump cavitation. This type of suction screen has no dirt holding capacity and blocks only large particles

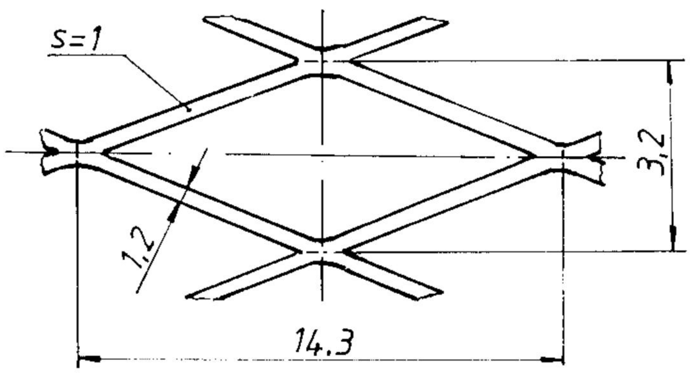


Figure 44. Screen plate mesh size.

Y-type strainers are always of single type. The strainer must be installed so that it is located at the lowest possible position and the screen must be positioned downward to trap sediment in the debris collection chamber. Typically Y-type strainers are used where only a low concentration of contaminants is expected and due to that has a lower pressure drop compared to the basket type strainer. The filter element can be removed from the housing and serviced only when the system is not in operation. /12/

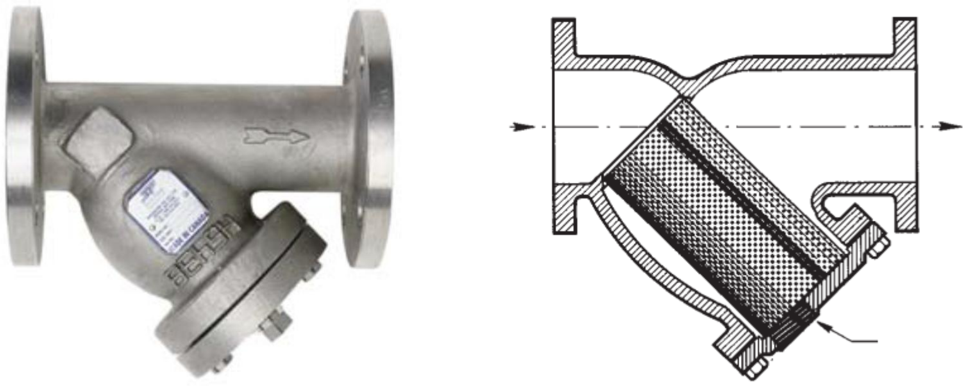


Figure 45. Y-type suction strainer /12/

The basket type (Figure 46) can be either of duplex or single type and most basket strainers are intended for horizontal or slightly inclined installation. Typically basket type strainers offer a larger dirt holding capacity but a higher pressure drop compared to Y-type strainers. The duplex type is designed with two identical baskets and equipped with a switchover-valve so that the filter can be serviced while the system is in operation.

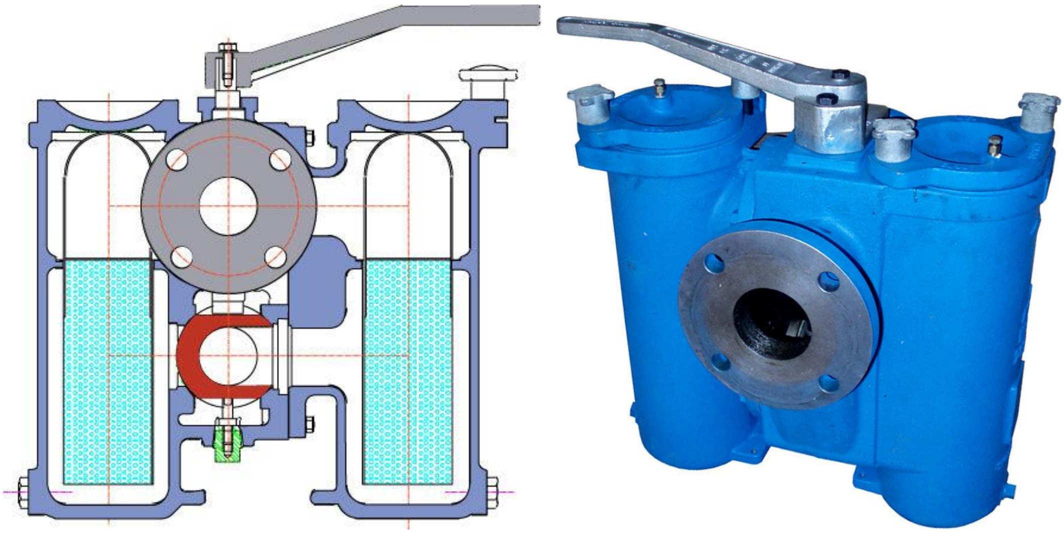


Figure 46. Duplex basket suction strainer. /12/

3.4.10 Safety Filter

The safety filter is a full flow filter installed after the automatic filter to protect engine components if there are particles flowing through automatic filter, for example because of damaged filter candle. Safety filters are of duplex type and equipped with a pressure differential indicator and a change-over valve that permits the change-over in operation without pressure shocks.

Since Bollfilter 6.46 and 6.48 have an integrated mesh installed around the candle chamber to act as a safety filter, there is no immediate need to have an external safety filter installed but the Bollfilter 6.64 does not have integrated safety filter to act as a back-up filter and it is recommended to install a safety filter to protect the engine components. /33/

4 LUBRICATING OIL

Modern engines with low lubricating oil consumption are setting a need for more advanced lubricating oils. Engines which are consuming less lubricating oil the same volume of the oil has to be able to maintain its properties for longer interval and therefore engines require high quality lubricating oil to keep the quality above the engine and fuel type specific requirements. With older engines the lubricating oil volume was naturally refreshed with periodical re-fills to compensate higher lube oil consumption. Even if the lubricating oil system is feeding the lubricating oil to the engine with correct pressure and temperature if the oils properties are below the requirements, problems will occur with the engine and with functionality of lubricating oil system components. /13/, /20/

Lubricating oil is needed to:

- Reduce friction between moving surfaces
- Act as a sealing media for seals, and for piston and liner
- Reduce wear by preventing metal-to-metal contact between moving parts
- Transfer heat from piston crown and loaded bearing connections
- Transport harmful particles from the engine to filtration system
- Neutralize corrosive combustion acids
- For control purposes, the lubricating oil of the engine is used in VIC (Variable Inlet Closing) hydraulic system as the hydraulic medium
- Remove sludge to prevent deposit formation. Sludge originates from:
    - Water
    - Liquid fuel

    - Solid residues

- Protect the engine from deposits and lacquer damages which appear from:
    - Combustion products of fuel
    - Combustion products of lubricants
    - Oxidized lubricants & fuel
    - Cracked lubricants & fuel
    - Polymerized lubricants & fuel

4.1 Engine Specific Lubricating Oil Requirements

Engine specific “lubrication oil requirements and quality” documents define the required characteristics for the lubrication oil according to the standard of the used fuel type. Also condemning limits for used lubricating oil is defined in these documents. Engine specific documents can be found in Table 2.

Table 2. Engine specific lubrication oil requirements and quality documents

Vasa 14 & 24	XXXXXX
Vasa 22, 22/26	XXXXXX
Vasa 32	XXXXXX
WA20, W20	XXXXXX
WA26, W26, W38	XXXXXX
W32, W32GD	XXXXXX
W46	XXXXXX
W46F	XXXXXX
W64	XXXXXX
W34SG, W50SG	XXXXXX
W20DF, W32DF, W34DF, W50DF	XXXXXX

4.2 Lubricating Oil Sampling

When taking lubricating oil samples on a regular basis, it is possible to determine suitable oil changing intervals and in general the changes in analyses can give a better basis of estimation than absolute values and also fast and great values can indicate abnormal operation of the engine or of a system malfunction.

Lubricating oil samples should be taken from circulating oil when the engine is in operation and the sample should be taken before the engine components, and after separation and filtration of the oil. It is recommended to take the sample before adding new oil to the system. The sampling line has to be rinsed before filling the sampling bottles to ensure that no deposits from the sampling line will end up with the oil to be analysed. Also the background data needed to evaluate the sample must be provided with the sample. During the first year of operation it is advisable to take samples at 500hrs intervals. Frequent sampling and analysing every 500-1000hrs is also recommendable after first year of operation. /19/, /18/, /23/

4.2.1 Base Number

The Base number (BN) is a measure of the alkalinity of lubricating oil, expressed in mg KOH/g oil. The sulphur level in the fuel oil used determines the required degree of alkalinity of lubricating oil. The fuel sulphur is during the combustion process converted into acidic combustion products, mainly sulphur oxides. These acidic compounds will attack the combustion space and other engine components unless neutralized.

Too low base number levels in lubricating oil will lead to acidic corrosion, increased engine wear, reduced component lifetime and thus increased maintenance costs. Too high base number may theoretically lead to an increased risk of excessive deposit formations, but with modern lubricating oils and engines this is however a very rarely met problem. Typically the BN of lubricating oil drops faster in the beginning but gradually levels out towards a balanced level.

It is recommended to use BN 50 - 55 oils when operating on HFO with sulphur levels > 2 w-%, especially for engines with the wet sump. BN 30 oils are recommended only for special applications, for example for installations equipped with SCR units, where high BN oils could contribute to deposit formations in the catalyst layers.

For SG engines operated continuously on gas it is recommended to use low ash gas engine oils, with a BN of 4 – 7 for fresh oils. For DF engines the lubricating oil quality and BN should be chosen according to the used fuel quality and operating hours on the different fuel qualities. See more detailed info and recommendations for the lubricating oil in Table 2 "Engine specific lubrication oil requirements & quality". /19/, /18/

4.2.2 Viscosity

Typically the viscosity of lubricating oil is expected to increase gradually during operation, due to oxidation, nitration and ageing of the lubricating oil compounds, emulsified water, increase of solid contents in the oil, also HFO leakage to lube oil will increase the viscosity. And too high viscosity can cause:

- Cavitation, in the pump suction line or in the bearings
- Oil whip in journal bearings
- Excess heat generation and energy consumption
- Starvation due to a reduced flow

Possible reasons for unexpected viscosity decreases could be for example LFO contamination of the lubricating oil or thermal cracking of oil molecules. Too low viscosity can cause:

- Increased friction and therefore increased heat generation

- Loss of oil film at high temperature or high loads and causing excessive wear
- Higher risk of oil film failure with particle contamination

It is important to notice that in some cases it might be possible that two different factors are acting in opposite directions and the viscosity stays in acceptable limits and therefore viscosity analysis alone is insufficient. Viscosity in general has been covered in Chapter 2.4.1 Viscosity and Temperature. /19/

Viscosity Index (VI) is an arbitrary comparison value of the resistance of oil to viscosity change with temperature (see Figure 47). The higher the viscosity-index, the smaller the relative change in viscosity with temperature. Most medium speed gas and diesel engine oils have a VI between 95 and 110. /19/, /17/

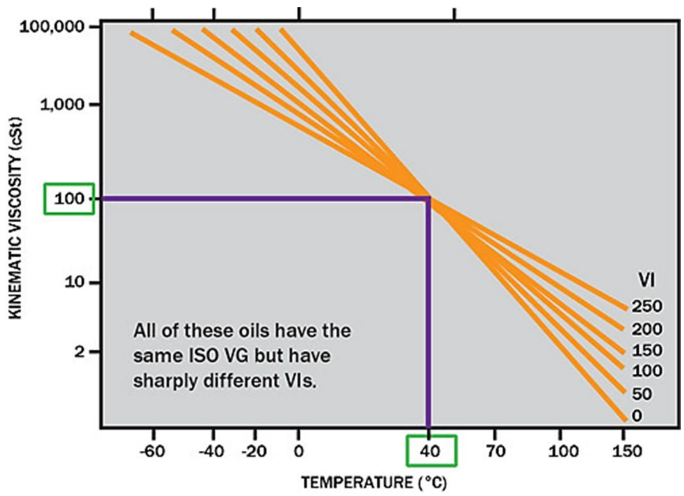


Figure 47. Viscosity-temperature comparison graph between oils with same grade (SAE 30) but with different viscosity index. /17/

4.2.3 Water

Water in oil is harmful to lubrication, both physically and chemically. Water is slightly soluble in base oils and slightly more soluble in formulated oils. Generally the solubility of water in lubricating oils is however low, if increased amounts of water molecules are present, the oil gets saturated and free water appears and hazy oil is most often a result of not dissolved water droplets.

Water corrodes many common metals and may thus also contribute to various forms of corrosive and cavitation damages on bearing surfaces. Bearings consisting mostly of lead and tin are quite easily oxidized in the presence of water and oxygen. Corrosion products may also contribute to the solid debris in the oil and pit formation in the metal surfaces. Another indication of water contamination in lubricating oils may be increased sodium and chlorine contents, especially in marine applications.

Water also catalyzes oil oxidation and acid formation and may react with or precipitate the oil additive compounds, the base oil and with suspended contaminants. The effects of all these reactions are undesirable by-products, such as varnish, lacquer, sludge, organic and inorganic acids, surface deposits and lubricant thickening due to polymerization. These reaction products also consume the oxidation inhibitors of the lubricating oil. /19/, /18/

4.2.4 Insolubles

Hard solid particles, which may be present in lubricating oil systems are for example shop debris, such as welding or grinding splatter, sand, clay, etc. earth materials and wear fragments. If their size is close to the oil film thickness, they may embed or abrade surfaces and therefore reduce component lifetime. Abrasion can be detected on a worn part by observation of parallel scratches in the direction of sliding or by microchips and abrasive particles presence in the used oil.

Semi-solid contaminants are generally oxidation and/or thermal polymerisation products, carbonaceous material, microorganisms and oil/ additive/water reaction products, etc. In lubricating oil systems, these and other small particulates contribute to sludge, which collects and plugs pipes, pumps and orifices possibly resulting in too low oil flow. If there are oxidation products present, they can be measured by an increase in total acid number (TAN), pentane- and toluene insolubles.

4.2.5 Oxidation and Nitration

Oxidation and nitration are indicators of the ageing of the lubricating oil compounds and molecules. Oxidation occurs when oxygen molecules chemically join the oil molecules. The oxidation causes oil to form acids and increases the viscosity. Oxidised oil can cause deposits to piston and valve are and also may result in bore polishing.

Nitration occurs in all engine oils but is specially a problem with gas engines where nitrogen compounds from the piston blow- by increases the viscosity and can result in heavy piston deposits and lacquering of valves and pistons. They are measured with infrared spectroscopy and are together with viscosity and BN one of the important measures of the gas engine lubricating oil service condition. /19/, /18/

4.2.6 Elemental Sources

Elements are divided into three groups according to their possible origin. However, note that some elements belong to several groups and that different construction materials may be used in different engine types, component specifications should be checked in each case, before making any detailed conclusions.

Wear metals

The most common wear metals in lubricating oil analyses are iron (Fe), chromium (Cr), lead (Pb), copper (Cu) and tin (Sn). In the engine components there can also be smaller amounts of aluminum (Al), molybdenum (Mo), nickel (Ni) and antimony (Sb) present. The iron content in lubricating oils reflects mainly piston and cylinder liner wear. Fresh oil may also contain small amounts (< 15 ppm) of iron, originating from transfer pipelines or tanks, if the oil is not delivered as a bulk. Note that iron may also be used as an additive in some lubricating oil formulations.

The chromium content in lubricating oils indicates mainly piston ring wear. Lead can be present in the overlays of gudgeon pin bearing bushings, camshaft bearings, bearing bushing for camshaft end and thrust washer. Copper can enter the lubricating oil from lubricating oil pump bearings, bronze bearings of rocker arms, roller pins for tappets and gudgeon pin bearing bushings. If the Cu content is abnormally high (> 10 - 15 *ppm*), one possible reason is the presence of exhaust gases in the inlet air, for example from some nearby located external sources. If there are exhaust gases present in the inlet air, the sulphur compounds from the exhaust gases may gradually corrode the charge air cooler material, which contains copper. The copper will then enter the lubricant via the combustion space and blow-by gases to the crankcase. In these cases the Cu content of the lubricating oil can be even as high as 30 - 50 ppm.

Some lubricating oil systems may also include couplings, coolers, etc. components of the engines and thus introduce significant amounts of for example Cu to the lubricating oil. Lube oil analyses from such systems should always be judged with special attention and carefulness. In such cases these elements cannot be directly used to evaluate engine component condition.

Possible sources for tin are big end bearings, main bearings, gudgeon pin bearing bushings, camshaft bearings, bearing bushing of camshaft end and thrust washer. The most probable source for aluminium and nickel is the fuel (HFO), but they may enter the lubricating oil from engine parts, (Al + Si) may also enter the lubricating oil from engine parts.

External source elements

The source of vanadium (V) and nickel (Ni) is normally HFO. There may also be small amounts of these elements present in LFO. The lubricating oil vanadium and nickel contents normally achieve an equilibrium, which are 1 - 2 times the V and Ni contents of the fuel.

The source of aluminium (Al) and silicon (Si) is normally HFO. Oil refineries equipped with a fluid catalytic cracker (FCC) unit use zeolites (aluminium and silicon compounds) as catalysts. Occasionally some catalyst rests ("cat fines" = Al +

Si) can be present in fuels and thus enter the lubricating oil during operation. Silicon is also typically used as an antifoaming component in lubricating oils.

The source of sodium (Na) is normally HFO, but the presence of sodium can also indicate sea water leakage, through the central coolers or water leakage in the closed cooling water system. The most commonly used cooling water additives are sodium nitrite + sodium borate and sodium molybdate based products.

Oil additives

Calcium (Ca), phosphorus (P) and zinc (Zn) are normally used in lubricating oil additive packages. The calcium content is depending on the BN, the higher the BN the higher the Ca content.

The phosphorus and zinc contents are depending on the additive chemistry used in each specific case and can vary significantly. In most low ash lubricating oils used in the gas engines the P content of the fresh oil used with gas engines is around 200 - 300 ppm and 200-1000 with diesel engines, the Zn content is around 200 - 300 ppm with gas engines and 200-1100 with diesel engines. In used lubricating oils these values can be somewhat lower. Silicon (Si) is typically used as an antifoaming component in lubricating oils. Typical sources of elements found in the lubricating oil analysis can be found in Table 3. /19/, /18/, /15/

Table 3. Sources of elements. /15/

	ENGINE				EXTERNAL SOURCES					
	PISTON / PISTON RINGS	CYLINDER LINERS	BEARINGS	OTHER ENG. PARTS	HEAVY FUEL	LIGHT FUEL	COOLING WATER	SEA WATER	BASE OILS & ADDITIVES	LUBE OIL SYSTEM
IRON, Fe	Possible	Probable		Probable	Probable	Possible			Probable	Probable
CHROMIUM, Cr	Probable			Possible						
MOLYBDENUM, Mo				Possible			Probable			
COPPER, Cu			Probable							Probable
TIN, Sn			Probable							
LEAD, Pb			Probable							
ANTIMONY, Sb			Probable							
ALUMINIUM, Al			Probable	Possible	Probable					
VANADIUM, V					Probable	Possible				
NICKEL, Ni				Probable	Probable	Possible				Probable
SILICON, Si		Possible			Probable		Possible		Probable	
SODIUM, Na					Probable	Possible	Probable	Probable		
MAGNESIUM, Mg					Possible				Probable	
PHOSPHORUS, P		Possible							Probable	
ZINC, Zn									Probable	
CALCIUM, Ca					Possible				Probable	
BORON, B									Probable	
CHLORINE, Cl								Probable		
SULPHUR, S									Probable	

PROBABLE (cyan) POSSIBLE (green)

Table 4 presents typical contents of different elements in used lubricating oils for gas engines. The table also shows guidance values for what can be considered abnormal levels for different elements in used oils. The limits in Table 6 should be kept as guidelines only. Elemental concentrations above the abnormal levels call for attention and indicate that something abnormal is obviously happening in the engine or in the lubricating oil system. An engine inspection is worth to consider especially if the values above the abnormal levels show a continuously increasing trend.

Table 4. Element content in used lubricating oil for gas engines.

Element	Unit	Typical values	Abnormal level
Iron, Fe	ppm	5 - 15	> 25
Chromium, Cr	ppm	0 - 3	> 5
Tin, Sn	ppm	0 - 3	> 5
Lead, Pb	ppm	0 - 3	> 5
Copper, Cu [1)]	ppm	0 - 5	> 15
Silicon, Si	ppm	1 - 15	> 20
Sodium, Na	ppm	0 - 10	> 20
Aluminium, Al	ppm	0 - 5	> 10
Nickel, Ni	ppm	0 - 3	> 5

It should be noted that typical elemental concentrations may be slightly different for different engine types. Differences can also be found depending on engine application, power plant, main engine, auxiliary engine, etc. and lubricating oil system configuration if couplings included or not, etc.

Table 5 presents the typical contents of different elements in used lubricating oils, recorded from both HFO and LFO operated engines. The table also shows guidance values for what can be considered abnormal levels for different elements in used oils.

The limits in Table 5 should be kept as guidelines only. Elemental concentrations above the abnormal levels call for attention and indicate that something abnormal is obviously happening in the engine or in the lubricating oil system. An engine inspection is worth to consider especially if the values being above the abnormal levels show a continuously increasing trend.

Table 5. Element content in used lubricating oil for HFO & LFO engines.

Element	Unit	HFO, Typical values	HFO, Abnormal level	LFO, Typical values	LFO, Abnormal level
Iron, Fe	ppm	10 - 40	> 50	5 - 15	> 25
Chromium, Cr	ppm	0 - 3	> 5	0 - 3	> 5
Tin, Sn	ppm	0 - 3	> 5	0 - 3	> 5
Lead, Pb	ppm	0 - 3	> 5	0 - 3	> 5
Copper, Cu	ppm	0 - 5	> 10	0 - 3	> 5
Silicon, Si	ppm	10 - 40	< 5 or > 50	1 - 15	> 20
Sodium, Na	ppm	10 - 50	> 100	0 - 10	> 20
Aluminium, Al	ppm	0 - 10	> 20	0 - 5	> 10
Vanadium, V	ppm	1 - 2 * fuel V	> 2 * fuel V	0 - 3	> 5
Nickel, Ni	ppm	1 - 2 * fuel Ni	> 2 * fuel Ni	0 - 3	> 5

It should be noted that typical elemental concentrations may be slightly different for different engine types. Differences can also be found depending on engine application, power plant, main engine, auxiliary engine, etc. The fuel quality and the fuel elemental composition also influence on the concentration of fuel originated elements in used lubricating oils. /19/, /18/, /15/

4.3 Adding Lubricating Oil

When topping up to compensate consumption, adding large amounts of fresh lubricating oil into the system can disturb the balance of used oil and can cause the precipitation of insolubles and therefore it is recommended to add maximum of 10% of the complete volume at a time. The amount of oil added should be measured and recorded since the lubricating oil consumption can give valuable information about the engine condition. A continuous increase may indicate that piston rings, pistons and liners are getting worn.

Top-up with another lubricating oil brand than being filled to the system is not allowed, except if the both two lubricating oils originate from the same manufacturer. E.g. if company A’s BN 40 oil is filled into the oil system and top-up with same company A’s BN 50 oil is desired, that can be done provided that both products are based on the same base oils and additive technology. Otherwise the lubricating oil system has to be drained and then filled with another brand. /18/, /23/

Also a process called "sweetening" is used where lubricating oil is removed from the system and replaced with fresh oil to extend life-time of the oil and to avoid changing the complete volume of the system is an option which can be considered with low SLOC engines and with systems having small total lubricating oil volume to decrease oil contamination rate.

4.4 Oil Change

Guidance values for oil change intervals can be found in the engine manual. Intervals between changes are influenced by system size, operating conditions, fuel quality, separation efficiency and total oil consumption.

Change the lubricating oil according to the following:

- When the lubricating oil analysis result exceeds any of the condemning limits for used lubricating oil.
- At every piston overhaul.
- At the latest every fourth year.

/20/

Changing the lubricating oil brand:

In order to minimize the risk of lubricating oil foaming, deposit formation, blocking of lubricating oil filters, damage of engine components, etc., the following procedure should be followed when lubricating oil brand is changed from one to another:

- If possible, change the lubricating oil brand in connection with an engine (piston) overhaul.
- Drain the old lubricating oil from the lubricating oil system, preferably while the oil is still hot.

- Clean the lubricating oil system in case of an excessive amounts of deposits on the surfaces of the engine components, like crankcase, camshaft compartment, etc. Only high quality fibre free cloth should be used for cleaning in order to maintain filters and automatic filter candles lifetime.
- Fill a small quantity of new oil in the oil sump and circulate with the pre-lubricating pump and drain again.
- Insert new filter elements and/or clean the automatic filter candles.
- Fill the lubricating oil system with fresh lubricating oil.

/19/

5 TROUBLESHOOTING

This chapter presents typical issues when lubricating oil system is not properly serviced and how it affects the components and lubricating oil and possible harms caused to the engine. Some typical changes in the sensor and indicator readings and the matrix of available service bulletins considering lubricating oil and the components are also listed in this chapter.

5.1 Effects of Lack of Proper Maintenance

To maintain the functionality of the components used in the lubricating oil system, and the required quality of the lubricating oil, there are pre-defined inspections defined in the engine manual, based on operating hours or time. The periods stated in the engine manual should be used for guidance purposes only, but must not be exceeded during the warranty period. The actual operating conditions and the quality of the used fuel will largely determine necessary maintenance for the engine because of the difficulty in anticipating the various operating conditions that may be encountered in the field.

Where any indications are encountered that the performance of a maintenance procedure is required in advance of the recommended time period, prudent industry practice dictates that the suggested maintenance procedure be performed. Additionally, where inspection or observation reveals that a part shows wear or use beyond the prescribed tolerances, that part should be renewed immediately. /43/

5.1.1 Components

If the system components are not serviced according to the specified need, problems will occur, not only with the neglected component but with the lubricating oil quality, other components and in extreme cases safety of the engine and personnel can be compromised. Typical issues are listed below and effects to the lubricating oil and the system, which can occur if components are not properly serviced. /43/

5.1.1.1 Automatic filter

High differential pressure between the LO inlet and the LO outlet is caused by filter candles being blocked with particles. If differential pressure between the LO inlet and the LO outlet exceeds predefined pressure the safety valves inside the filter are open and filtration is done only with a coarse safety mesh and large particles are passed through the filter and can cause wear to the engine components.

If the filter candles have been operating too long or with too high a pressure differential or the candle elements have been damaged with incorrect cleaning procedure, it is possible that the filtering mesh between the supporting meshes can be damaged and therefore larger particles can flow through the filter candles without any increase of the differential pressure between the LO inlet and the LO outlet. If the automatic filter backflushing efficiency is low, the filter candles will quickly be clogged with dirt. /14/

5.1.1.2 Centrifugal filter

Too thick a deposit layer inside the filter can cause excessive vibrations and the vibration can cause accelerated bearing bush wear, damage the bearing journals and even cause cracks to the filter body. /14/

5.1.1.3 Separator

If the separator is not serviced properly, the amount of water and dirt particles in the lubricating oil will grow or in worst case the traces of water start to escape with the cleaned oil and the amount of water in the lubricating oil increases. A poorly maintained separator is just an expensive pump. /14/

5.1.1.4 Components increasing the risk of cavitation

Cavitation is one of the biggest problems with lubricating oil pumps. Suction strainers, -screens and non-return valves installed in the pump suction line are protecting the pump but at the same time they are creating pressure drop in the suction line and by that increasing the risk of cavitation. Geodetic height and pressure losses in the piping, suction speed in the inlet of the pump, tip speed of the gears and flow passage design also increase the risk of cavitation.

There are two different phenomena that are considered as cavitation. Real cavitation is when the pressure decreases below liquid vapour pressure, vapour bubbles begin to form and these bubbles implode. Another phenomena which is not real cavitation but which causes similar problems is air separation where dissolved air separates from liquid. Air separation can be detected by letting an oil sample stand in an open container and monitoring oil level changes. The difference between air separation and cavitation can also be noticed during the start-up with cold oil. If noise in the pump decreases when the oil warms up and viscosity decreases, it is cavitation. If noise increases together with the temperature or stays at the same level, it is air separation. Normally air separation should be no problem. If air separation is detected, it is often caused by excessive blow-by from turbochargers, leakage in suction side, problems with oil properties, too small sump capacity when compared to pump suction capacity or even piston jet-cooling.

Oil normally contains 2 %...6 % of air, depending of oil type, viscosity and temperature. The air separates from oil when the oil has calmed down in the sump. This has to be made so that the air is no longer being primed by the pump. Factors affecting cavitation are density, viscosity, vapour pressure and suction pressure. Usually SAE 40 oil is used and the first three properties are fixed at operating point. /28/, /27/

5.2 Causes for Lubricating Oil Pressure and Temperature Deviations

Since the sensors and indicators monitoring the lubricating oil system are measuring only pressure or temperature and there are multiple causes that can cause changes to the lubricating oil temperature or pressure, common reason for changes in these parameters are listed below.

Low lubricating oil pressure: the lubricating oil pressure in the supply line after the LO filter has dropped below the alarm set-point. The reason for low LO pressure can be:

- Engine is overloaded.
- Worn bearings.
- Low oil level.
- Leak in LO system.
- LO temperature is too high.
- Oil is diluted by fuel or coolant.
- Wrong grade of oil.
- Temperature control valve is operating improperly.
- LO cooler is dirty.
- LO filter is clogged or in the wrong position (all filters must be in use).
- LO pump is defective.
- Pressure switch is broken.
- Cut-off valves are not fully open.
- If no corrective action is taken the following breakdowns are possible: bearings, crankshaft, and pistons.

Lubricating oil inlet pressure to turbocharger low: lubricating oil pressure to the turbocharger has dropped below the alarm set point. The reason for low LO inlet pressure can be:

- Oil filter is choked with dirt.
- Damaged lubricating oil pump.
- Axial or radial play of the rotor too large.
- Pressure transmitter failure.

Lubricating oil high temperature: the lubricating oil temperature in the inlet line to the engine has reached the high temperature set-point, the reason for high temperature can be:

- Engine is overloaded.
- Worn cylinders, pistons and piston rings (blow by).
- Bad injection timing.
- Cooling system is not working properly.
- Abnormally high ambient temperature.
- Valves in the LO system are in the wrong position.
- Oil level is high or low.
- Temperature control valve is operating improperly.
- LO cooler is dirty, check the inlet/outlet temperatures on the LO cooler and compare with the temperatures in the test run report and logbook.
- Inadequate aspirating air pressure.

/22/

5.3 Lubricating Oil System Service Bulletins

The Service Bulletin is an official document that is delivered directly to involved customers. It concerns a technical issue and it is directed mainly to technical person using technical language. A Service Bulletin contains information that will improve the lifecycle of the product.

Bulletins considering the lubricating oil system are listed in Table 6 and categorized between the component and the engine type.

Table 6. Bulletins for lubricating oil system.

	W20	W26	W32	W32DF / W34SG	W38B	W46	W46F	W50DF / W50SG	W64
Main pump			B3	B3	B6, B7				
Pre-lube pump									
Stand-by pump									
LO Separator	B8, B9								
Automatic filter	B1, B2, B3	B1	B1, B4, B5	B1, B4, B5	B1	B1	B1	B1	
LO cooler									
Thermostatic valves									
Centrifugal filter	B10	B11	B12, B13, B14	B12, B13, B14					
Oil mist separator	B15, B16								
Suction strainers									
Safety filter									
LO analysis and quality	HFO & LFO: B17 GAS: B18		HFO & LFO: B17 GAS: B18	HFO & LFO: B17 GAS: B18		HFO & LFO: B17 GAS: B18	HFO & LFO: B17 GAS: B18	HFO & LFO: B17 GAS: B18	

5.4 Relevant Report Summaries

Relevant lubricating oil system service reports were read and analysed and results are summarized in Table 7, one report form each category was chosen and arranged in the table showing related component(s) and relevant engine type. The used summary template can be found in the appendixes.

Table 7. Relevant report summaries

	Engine type								
	1	2	3	4	5	6	7	8	9
Main pump							C		
Pre-lube pump									
Stand-by pump									
Automatic filter		A		B	I				
Lo separator								H	
LO cooler							C		
Thermostatic valves									
Centrifugal filter									
Crankcase vent.			E						
Suction strainers					I				
Safety filter									

6 SUMMARY

Lubricating oil is a crucial component for engine operation, modern engines with low lubricating oil consumption are setting a need for more advanced lubricating oils. Engines are consuming less lubricating oil and the same volume of the lubricating oil has to be able to maintain its properties for longer interval and therefore engines require high quality lubricating oil to keep the quality above the engine- and fuel type specific requirements.

The longer lubricating oil lifetime sets a need for functional lubricating oil conditioning systems since the volume of the lubricating oil system is not refreshed naturally with periodical re-fills to compensate high lube oil consumption. Even if the lubricating oil system is feeding the oil to the engine with correct pressure and temperature if the lubricating oil conditioning system cannot maintain the required quality for the oil problems will occur with the engine and with functionality of lubricating oil system components.

The actual operating conditions and the quality of the used fuel will largely determine necessary system requirements for the engine. Even if the system is designed according to installation needs but the system components are not serviced according the specified need, problems will occur, not only with the neglected component but with the lubricating oil quality, other components and in extreme cases safety of the engine and personnel can be compromised and therefore operation should be rather pro-active than reactive. One concern with the lubricating oil systems is the fact that some cases the system is not built according to Wärtsiläs recommendations and this can cause various problems with the functionality of the lubricating oil system.

REFERENCES

/1/ Alfa Laval, Brazed Plate Heat Exchanger. Accessed 21.3.2015. http://www.alfalaval.com/solution-finder/products/doc-dedicated-oil-cooler-line/Documents/Environmentaldeclaration_brazed.pdf

/2/ Alfa Laval, Brazed Shell and Tube Heat Exchangers. Accessed 18.3.2015. http://www.alfalaval.com/solution-finder/products/brazed-shell-and-tube/Documents/Brazed_shell-and-tube_heat_exchangers.pdf

/3/ Alfa Laval, Flex separation systems, P-separators. Accessed 17.2.2015. http://www.alfalaval.com/industries/marine/oil-treatment/s-pflexrange/Documents/Flex%20separation%20systems

/4/ Alfa Laval, Instruction Manual Plate Heat Exchangers. Wärtsilä intranet, Access rights required.

/5/ Alfa Laval, S and P separation systems. Accessed 14.2.2015. http://local.alfalaval.com/ko-kr/key-technologies/marine-essentials/s-p-felx-separator-sytstems/

/6/ Bollfilter Automatic Type 6.46 brochure. Accessed 2.12.2014. http://www.bollfilter.com/fileadmin/bollfilter/down-loads/prospekte/Prospekt_6_46_engl_klein.pdf

/7/ Bollfilter Automatic Type 6.64 brochure. Accessed 3.12.2014. http://www.bollfilter.com/fileadmin/bollfilter/down-loads/prospekte/BUK218797P_Prospekt_6_64_eng-web.pdf

/8/ Bollfilter Automatic Type 6.72 brochure. Accessed 4.12.2014. http://www.bollfilter.com/fileadmin/bollfilter/down-loads/prospekte/6_72_eng.pdf

/9/ Bollfilter operating instructions for automatic filter type 6.64.1.07. Wärtsilä intranet, access right required.

/10/ Bollfilter protection systems, operating instructions for automatic filter type 6.48. Wärtsilä intranet, access right required.

/11/ Compass, Power Plants Products & Solutions / MECHWIS. Wärtsilä intra-net, access right required.

/12/ Fluid Controls Institute, Inc. Technical resources. Accessed 11.2.2015. http://www.fluidcontrolsinstitute.org/resource/resources.asp

/13/ Handbook for auxiliary systems, issue 1/2013. Wärtsilä intranet. Access rights required.

/14/ Interviews with Wärtsilä Technical Services Engine Auxiliary Systems team. October 2014 – April 2015

/15/ Liquids Training for WFI-TS, Lubricants. Wärtsilä intranet, access right required.

/16/ Lube oil system design handbook update 2013, Power Plant. Wärtsilä intranet, access right required.

/17/ Machine Lubrication, VI When Selecting a Lubricant, accessed 21.3.2015. http://www.machinerylubrication.com/Read/28956/lubricant-viscosity-index

/18/ Operating Instruction "Gas engine lubricating oil analyzing and quality follow-up". Wärtsilä intranet, access right required.

/19/ Operating Instruction "Lubricating oil analyzing and quality follow-up", HFO & LFO. Wärtsilä intranet, access right required

/20/ Operating Instruction "Revised lubricating oil change recommendations". Wärtsilä intranet, access right required.

/21/ Power Plant training PPT. Wärtsilä intranet, access right required.

/22/ Power Plant training PPT2. Wärtsilä intranet, access right required.

/23/ Power Plant training, lubricants. Wärtsilä intranet, access rights required.

/24/ Power Plants Products and Solutions, MECHWIS. Accessed 15.3.2015. Wärtsilä intranet, access right required

/25/ Power Plants, Cooling Water System – Central Cooler System. Wärtsilä intranet, access right required.

/26/ Pump School, 2012 External Gear Pumps. Accessed 18.2.2015. http://www.pumpschool.com/principles/external.asp#Overview

/27/ R&D design guide, "Lubricating oil gear pump" Wärtsilä intranet, access right required.

/28/ R&D design guide, "Lubricating oil screw pump". Wärtsilä intranet, access right required.

/29/ R&D Design Handbook, Heat Recovery from Cooling Water and Lubrication Oil. Wärtsilä intranet, access right required.

/30/ Service letter, “Driving oil supply for centrifugal filter.” Wärtsilä intranet, access right required.

/31/ Stachowiak, G & Batchelor, A. Engineering Tribology 3rd Ed. 2005

/32/ Sutherland, K, Filters and Filtration Handbook 5th Ed. 2008

/33/ TERPS, Total Engine Room Package for auxiliary Systems. Wärtsilä intranet, access right required

/34/ Viscosity conversion charts and typical viscosity values. Accessed 19.11.2014. http://www.vp-scientific.com/Viscosity_Tables.htm

/35/ Viscosity: A lubricant’s most important characteristic. Accessed 25.11.2014. http://www.kittiwake.com/sites/default/files/2%20-%20Viscosity%20Dec12_0.pdf

/36/ W32 engine presentation. Wärtsilä intranet, access right required.

/37/ W32 oil plant system. Accessed 4.11.2014. Wärtsilä intranet, access right required.

/38/ W46 oil plant system. Accessed 5.11.2014. Wärtsilä intranet, access right required.

/39/ Wärtsilä Auxpac Product guide, issue 2/2014. http://www.wartsila.fi/file/Wartsila/en/1278529610621a1267106724867-wartsila-o-g-w-auxpac-pg.pdf

/40/ Wärtsilä Environmental Product guide, issue 1/2014. http://www.wartsila.com/file/Wartsila/en/1278528485383a1267106724867-wartsila-o-env-product-guide.pdf

/41/ Wärtsilä W20DF Product guide, issue 1/2013. http://www.wartsila.fi/file/Wartsila/en/1278536759563a1267106724867-wartsila-o-e-w-20df-pg.pdf

/42/ Wärtsilä W26 Product guide, issue 1/2013. http://www.wartsila.fi/file/Wartsila/en/1278529591949a1267106724867-wartsila-o-e-w-26-pg.pdf

/43/ Wärtsilä W32 Instruction manual. Wärtsilä intranet, access right required.

/44/ Wärtsilä W32 Product Guide, issue 1/2014. http://www.wartsila.fi/file/Wartsila/en/1278529592702a1267106724867-wartsila-o-e-w-32-pg.pdf

/45/ Wärtsilä W34DF Product Guide, issue 1/2013. http://www.wartsila.fi/file/Wartsila/en/1278529594746a1267106724867-wartsila-o-e-w-34df-pg.pdf

/46/ Wärtsilä W38 Product guide, issue 1/2014. http://www.wartsila.fi/file/Wartsila/en/1278529597188a1267106724867-wartsila-o-e-w-38-pg.pdf

/47/ Wärtsilä W46F Product Guide, issue 1/2013. http://www.wartsila.fi/file/Wartsila/en/1278529607805a1267106724867-wartsila-o-e-w-46f-pg.pdf

/48/ Wärtsilä W50DF Product Guide, issue 1/2014. http://www.wartsila.fi/file/Wartsila/en/1278529608815a1267106724867-wartsila-o-e-w-50df-pg.pdf

/49/ Wärtsiläs policy regarding the use of lube oil separators in Power Plant installations. Wärtsilä intranet, access right required.

/50/ Wärtsilä Corporation This Is Wärtsilä. Accessed 25.4.2015. http://www.wartsila.com/about

/51/ Wikipedia, Screw pump. Accessed 16.2.2015, http://en.wikipedia.org/wiki/Screw_pump

APPENDICES

Model template for report summaries:

Report name:	Report type Engine type Installation Issue
DocID:	DBAXXXXXXX

Background
Short description about the backgrounds of the work
Conclusions
Description of actions taken
Recommendations
Results

Collection of drawing symbols used in drawings. /44/