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WÄRTSILÄ	Product **W-2S**	**Concept Guidance** **Fuel Oil Treatment**	
Made 14.05.2001 M.Lüthi	Main Drw.	Page 1 / 16	Material ID **107.246.880.500**
Chkd 10.07.2001 M.Lüthi	Design Group **9723**	Drawing ID **107.246.880**	Rev **C**
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1 Introduction

The purpose of this concept guidance is to show potential risks for the engine by impurities in the fuel and to provide solutions for fuel oil treatment. Please refer also to Service Bulletin ‘RT-140 – Catalyst fines in fuel oils’ as supplement to this document.

2 Fuel Contamination

Depending on the bunker, fuel oil may contain a variety of undesired solid and liquid impurities such as catalyst fines (Al+Si) and water.
The following graph (figure 1) shows that in the last few years the average fuel sulphur levels have globally decreased, while the average cat fines levels are generally increasing.

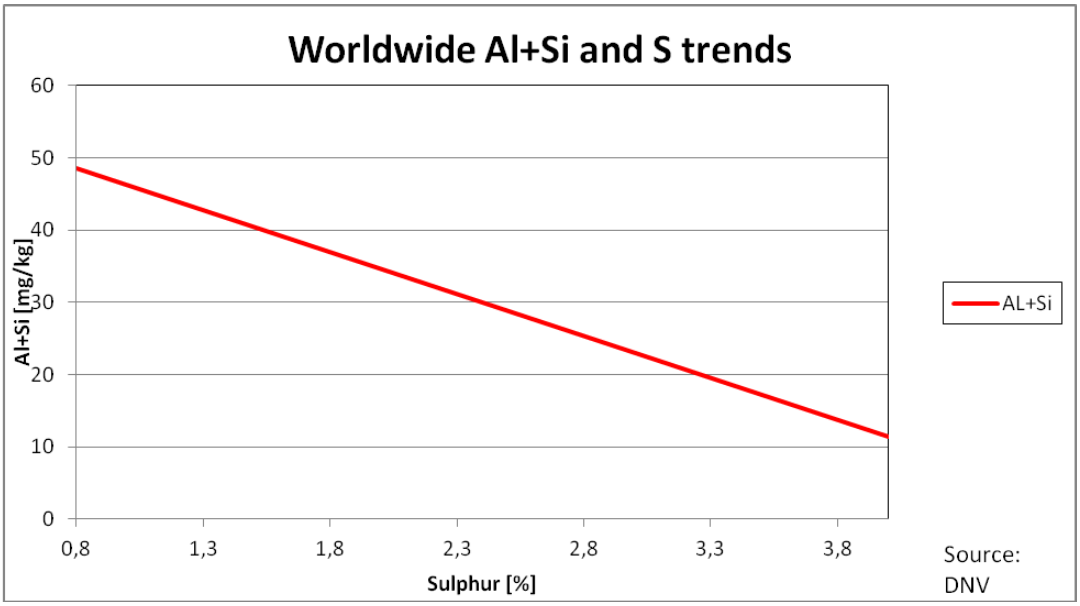

Figure 1: Al+Si and S trends according to DNV

As fuel contamination has a significant impact on engine performance and maintenance intervals, special precautions for fuel treatment are required.

2.1 Catalyst fines (cat fines)

Cat fines are found by an analysis of the aluminium (Al) and silicon (Si) content of the fuel oil. The Wärtsilä Fuel Specification allows a maximum content of 60 mg/kg combined aluminium and silicon as bunker limit (ISO 8217:2010/2012). After treatment a content of up to 15 mg/kg combined aluminium and silicon is tolerable at engine inlet, but the goal is to reach a lower value. Excessive cat fines are common in blended LSFO. These abrasive particles come from catalytic cracking processes in refineries, or from the blend components used.

The catalysts in oil refining are very hard and porous round particles. The mean particle size of fresh catalyst is 70 microns (range 20 to 200 microns) and 75 % of the particles are larger than 25 microns. But the size is reduced during circulation in the refinery, and by the time the catalyst particle reaches the fuel oil as cat fines the average size has dropped to less than 20 microns. The largest particle size in fuel oil depends on the settling history of the fuel.

2.1.1 Detection of catalyst fines

The presence of cat fines in fuel is determined by burning the fuel and roasting the ash at 550 °C. The ash is then dissolved in very strong acid and the solution analysed for the two elements aluminium and silicon, which are constituents of catalyst fines (ISO 10478:1994).
Another but less common test method is measuring the quantity of centrifuge sediment and its microscopic examination.
In microscopic examination the presence of catalyst fines can be identified by the replicas showing the particles found embedded in the graphite flakes on the running surfaces of rings and liners. As an example, figure 2 to figure 5 show the analysis results of an older ring and liner surface which were worn down by cat fines with a size of 10 microns and a hardness of 800-1000HV.

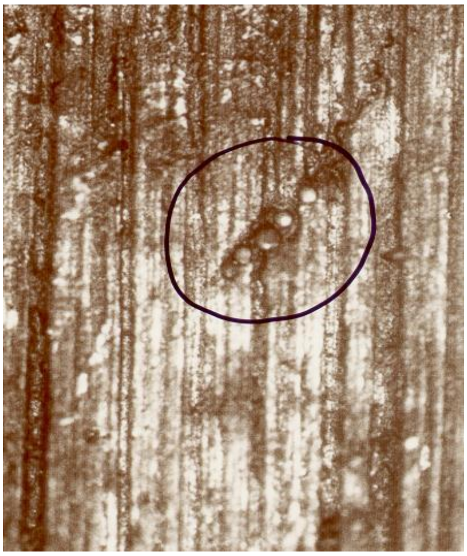

Figure 2:
Piston ring surface with cat fines trapped in graphite flakes magnification 280:1

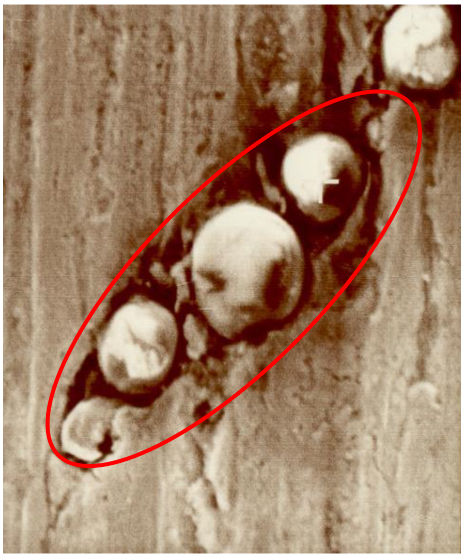

Figure 3:
Piston ring surface with cat fines trapped in graphite flakes magnification 1200:1

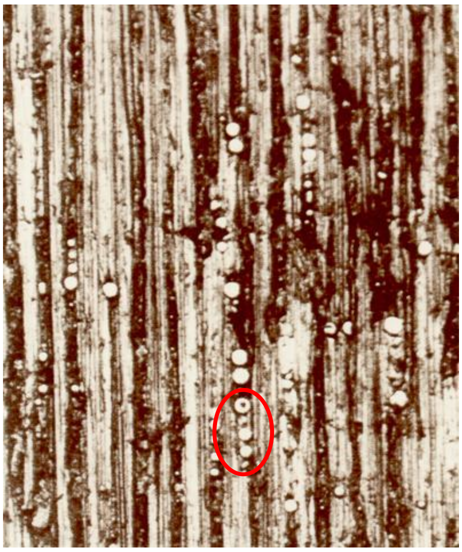

Figure 4:
Cylinder liner surface at TDC with cat fines trapped in graphite flakes magnification 84:1

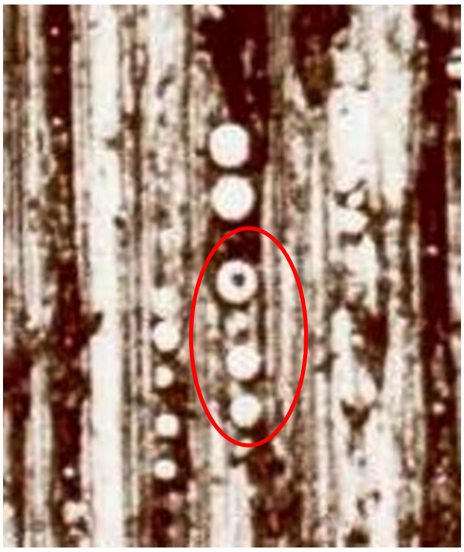

Figure 5:
Cylinder liner surface at TDC with cat fines trapped in graphite flakes

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2.1.2 Effects of catalyst fines on engine components

Cat fines are hard abrasive particles. These particles of 10 to 15 microns in size are the most dangerous, as they are most readily caught in the oil film and in the fine graphite structure of the liners.
They will also increase the abrasive wear rate of the piston rings independently of the coating execution. This will eventually lead to severe scuffing of the unit. Smaller particles do not tend to cause wear and larger particles are not easily held in the oil film. If the fuel oil is heavily contaminated with cat fines, then there may be problems on all exposed surfaces.

- RTA fuel pumps:
  Seizure and wear (if particle size equals clearance between barrel and plunger)
- RTA fuel injection valves:
  Wear on nozzle holes and needle seat
- RT-flex and W-X fuel oil pumps:
  Abrasive wear and seizure
- RT-flex injection control units:
  Erosion that can lead to loss of injection control
- W-X injection valves:
  Excessive wear
- Piston rod, piston rod gland boxes:
  Excessive wear and excessive oil leakage at gland box

Primarily, the abrasion of ring and liner surfaces is caused directly, but some cat fines are retained in the graphite flakes of the metal surface and continue to abrade the running partners for a long time after they have entered the engine.

2.2 Water emulsions

The presence of used lubricants in the fuel oil is known to cause water to emulsify (due to detergent), making cat fine removal more difficult.
Cat fines are highly hydrophilic and if water is present they are incorporated into water droplets. When the water is separated from the oil the cat fines are also removed. The density of fresh water is close to that of high density fuel at separation temperature. If water, in particular fresh water, cannot be removed in the fuel oil separator then the cat fines may not be removed. When the fuel oil is stirred, water is mixed in. It forms an emulsion and becomes more difficult to separate. A decanter or homogeniser upstream from the separator hinders cat fine removal because of the stirring effect.

For the same reason the centrifuge should be arranged as close as possible to the settling tank. Additional treatment of fuel containing emulsified water with a demulsifying fuel additive can improve cat fine removal.

3 Fuel oil treatment

To protect the engine from serious damages, reduce cylinder liner wear, avoid cold corrosion and improve combustion, the fuel oil must be treated by removing undesired solid and liquid particles (e.g. cat fines and water) before entering the combustion chamber. For this purpose an accurate configuration of the fuel treatment system is essential. As proper fuel oil treatment is connected with a good centrifugal separation, the centrifugal separators are the main components of the fuel oil treatment system. Good separation performance depends on the proper selection, installation and operation of the separators. Other equipment, e.g. decanters, homogenisers, etc., are not a substitute for the application of centrifugal separators.

3.1 System layout

The standard fuel oil treatment system, shown as proposal in the Marine Installation Drawing Set (MIDS) and in figure 6 of this document, mainly consists of:

- the storage system: settling tanks (015, 019, 020) and service tanks (021, 022, 023) with transfer pumps
- the separator supply pumps (025)
- the self-cleaning HFO separator (027)
- the self-cleaning MDO separator (033)
- the fuel filters (006 and 014)

3.2 Fuel tanks

Pre-cleaning of the fuel is effected in the tanks, especially in the settling tank(s), where water and sediment settle out by gravity. The tanks should have inclined bottoms for easier removal of cat fines and other solid particles from the fuel and provide possibility for draining.

However, the gravitational settling out of water and sediment in heavy fuel oils is an extremely slow process due to the small difference in densities.
The settling process is a function of the fuel surface area in the tank, the viscosity, the temperature and the density difference. Heated large surface area tanks enable better settling than heated small surface area tanks.

Most design features of the service tank are similar to those of the settling tank, having self-closing sludge valves, inclined bottoms, level monitoring sensors and remote closing valves in the discharge leading to the separators and engine systems. The service tank is to be equipped with a drain valve arrangement at its lowest point, an overflow pipe to the overflow tank and a re-circulating piping to the settling tank. The inlet of this recirculation pipe should be close to the bottom of the service tank to drain water which may still be present in the fuel after leaving the separators (e.g. due to condensation or coil leakage).

The fuel is cleaned either during transfer from settling tank (015, 019, 020) to service tank (021, 022, 023), or by re-circulating from and to the service tank. Ideally, with the main engine operating at CMCR, the fuel oil separator(s) should be able to maintain a flow rate from the settling tank to the service tank including a continuous overflow back to the settling tank. The sludge valve is to be operated at regular intervals to check the presence of water, being an important indication of the condition of the separator(s) and heating coils.

<u>Summary:</u>

- To achieve the best settling results, the surface area of the settling tank should be as large as possible with low depth.
- Tanks should have inclined bottoms for easier removal of impurities and need to be equipped with drains for regular draining.
- To keep a suitable oil temperature in the settling tank, the installation of a tank heating system is required.
- The re-circulating pipe from the bottom of the service tank must be led to the bottom of the settling tank.

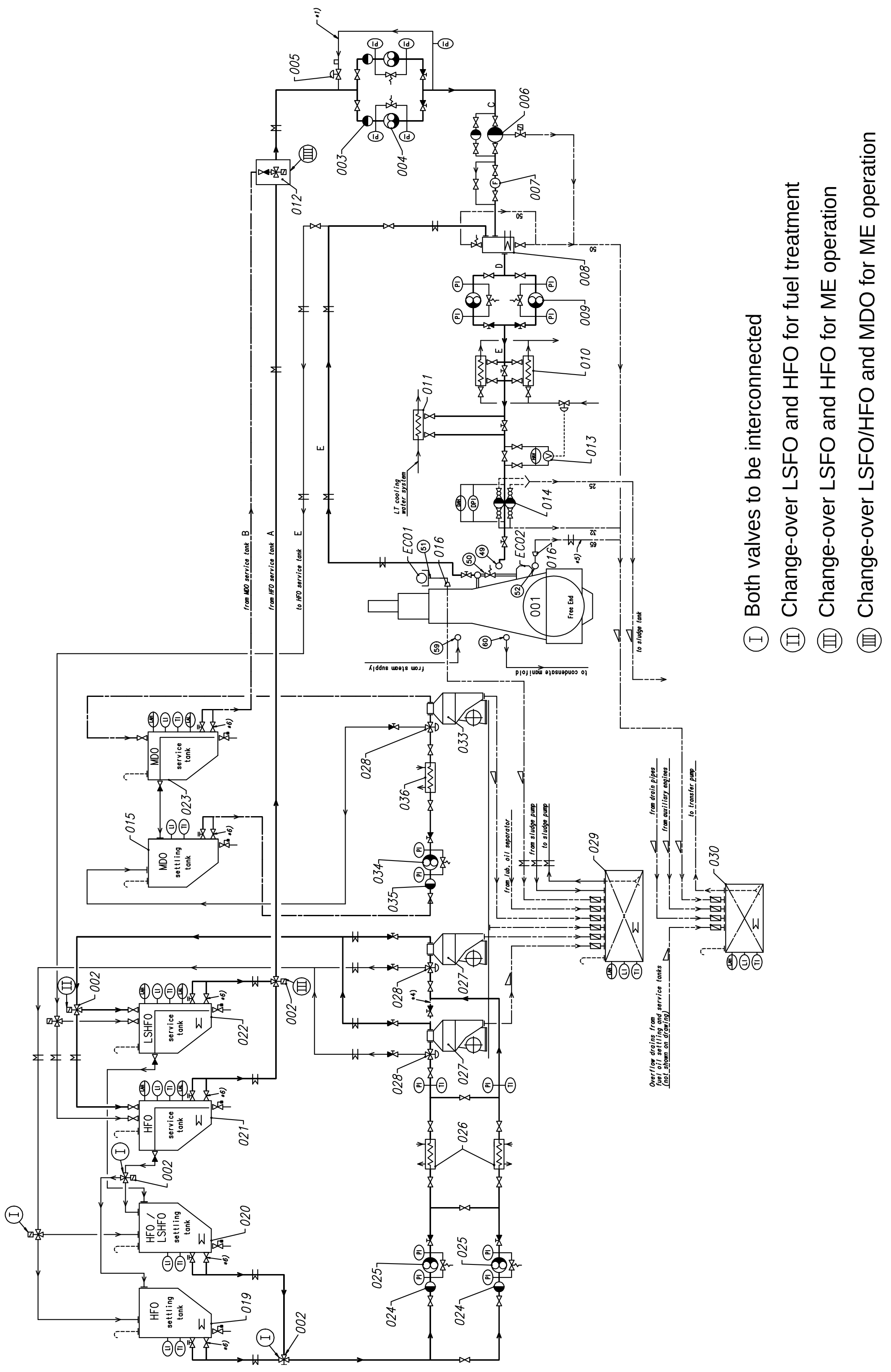

Figure 6: System proposal of fuel oil system

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Fuel oil system components

001. Main engine
002. Three-way valve, manually or remotely operated
003. Fuel oil suction filter, heated (trace heating acceptable)
004. Low-pressure feed pump
005. Pressure regulating valve
006. Automatic self-cleaning filter, 10 micron, heated (trace heating acceptable)
007. Flowmeter
008. Mixing unit, heated and insulated (according to separate drawing)
009. High-pressure booster pump
010. Fuel oil end-heater
011. Fuel oil cooler
012 Automatic fuel change-over unit
013. Viscometer
014. Fuel oil filter, heated (trace heating acceptable)
015. MDO settling tank
016. Pipe reduction
019. HFO settling tank, heated and insulated
020. LSHFO settling tank, heated and insulated
021. HFO service tank, heated and insulated
022. LSHFO settling tank, heated and insulated
023. MDO service tank
024. Suction filter
025. HFO/LSHFO separator supply pump, with safety valve
026. HFO/LSHFO pre-heater
027. Self-cleaning HFO/LSHFO separator
028. Three-way valve, diaphragm operated
029. Sludge tank
030. Fuel oil overflow tank
033. Self-cleaning MDO separator
034. Separator supply pump, with safety valve
035. MDO suction filter MDO
036. MDO pre-heater

3.3 Centrifugal separators

Centrifugal separators as the main components of the fuel oil treatment system cannot get superseded by filters or other additional treatment solutions. The function of the separators is to remove water and solid particles like cat fines from the fuel oil. The fuel reaching the engine should not contain more than 15 mg/kg aluminium plus silicon. Particles of 10 to 15 microns in size are the most dangerous for the engine as they are most readily caught in the oil film and in the fine graphite structure of the liners.
Consequently, cat fines of a diameter larger than 10 microns must be removed by the separators.

3.3.1 Separation efficiency

In general, a minimum separation efficiency of 80 % should be achieved, i.e. 80 % by weight of the impurities removed. For the separator capacity determination it is recommended to refer to the throughput rates which are provided according to the certified flow rate definition. This ensures sufficient separation efficiency.
For a rough estimation of the effective throughput capacity, which is connected to the maximum fuel oil consumption of the diesel engine plant plus a safety margin of about 20 %, the following formula can be applied:

$$Throughput\,capacity = \frac{1.2 \cdot CMCR \cdot BSFC}{1000} \left[{}^{l}\!/_{h} \right]$$

$BSFC$	$\left[{}^{g}\!/_{kWh} \right]$	brake specific fuel consumption at CMCR
$CMCR$	$[kW]$	contracted maximum continuous rating

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As shown in figure 7 the separation efficiency is inversely proportional to the flow rate.

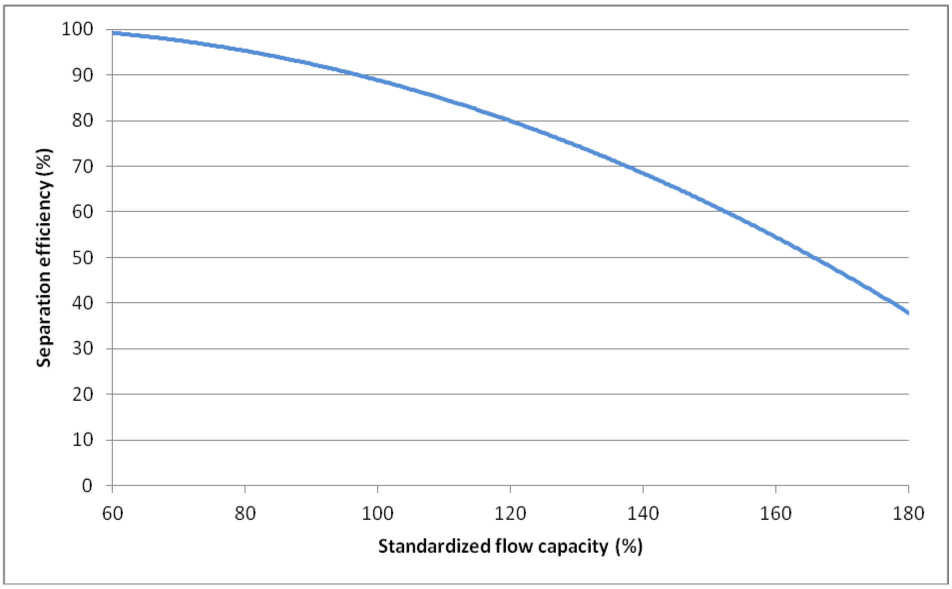

Figure 7: Separation efficiency versus separator throughput (source: Alfa Laval)

The higher the flow rate, the less time is available for separation. It is therefore essential to match the centrifuge capacity to the total fuel consumption (main engine, auxiliary engines and boiler). Additionally, to ensure an optimum separation efficiency the fuel oil inlet temperature should be at least 98 °C (please refer to figure 8). Operating at lower inlet temperatures seriously hinders the separation process.

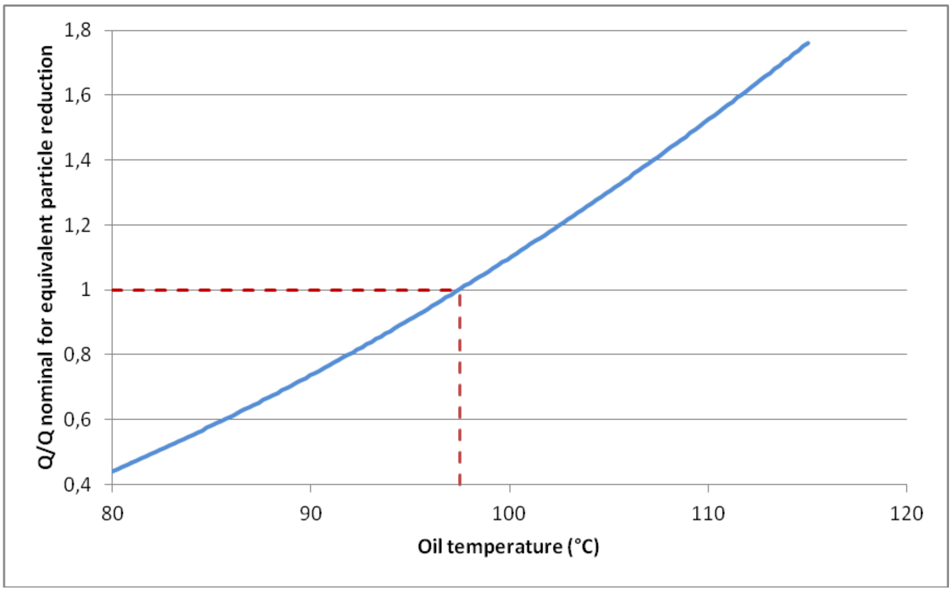

Figure 8: Throughput versus oil temperature at constant separation efficiency (source: Alfa Laval)

For correct separator arrangement and setting the manufacturer's instructions should be observed.

3.3.2 Separator types

- Self-cleaning separators without gravity disc
  For new and retrofit installations, self-adjusting separators without gravity discs are recommended. Since they are self-adjusting they do not require gravity discs to be changed for different fuel densities.
- Self-cleaning separators with gravity disc
  As the use of separators with gravity discs comprises certain disadvantages the installation in new buildings is not recommended.

Summary:

- An optimal performance of the separator is given by
  - a separation efficiency of 80 %
  - adjusting the capacity in accordance with the actual total fuel consumption (observe the certified flow rates)
  - keeping a fuel oil temperature of at least 98 °C

3.4 Homogeniser

Homogenisers are able to improve the system performance and to reduce the NO_x emissions by supplemental fuel oil treatment.
A homogeniser supports the same function as an emulsifier by stabilising the water-fuel emulsion.
In addition it reduces the size of agglomerated asphaltenes and disperses them throughout the fuel. Therefore, homogenisers may also act as safeguard by preventing clogging of the fuel oil filter.
According to our latest state of knowledge, homogenisers should be installed on the high-temperature side of the fuel oil system, after the separators. An installation of homogenisers before the separators is not recommended, since an operation in this position comprises the risk of forming water-fuel emulsions, which can hardly be separated. In general, to ensure a trouble-free operation of the homogeniser, suppliers´ instructions and recommendations have to be observed.

3.5 Filter

The fuel oil filters serve as additional protection for the engine by removing residues and catalytic fines which were not removed from the fuel by the separators.
As shown in the following graph (figure 9) the efficiency in removing catalytic fines can be significantly improved by combining centrifugal cleaning and fine filtration in series.

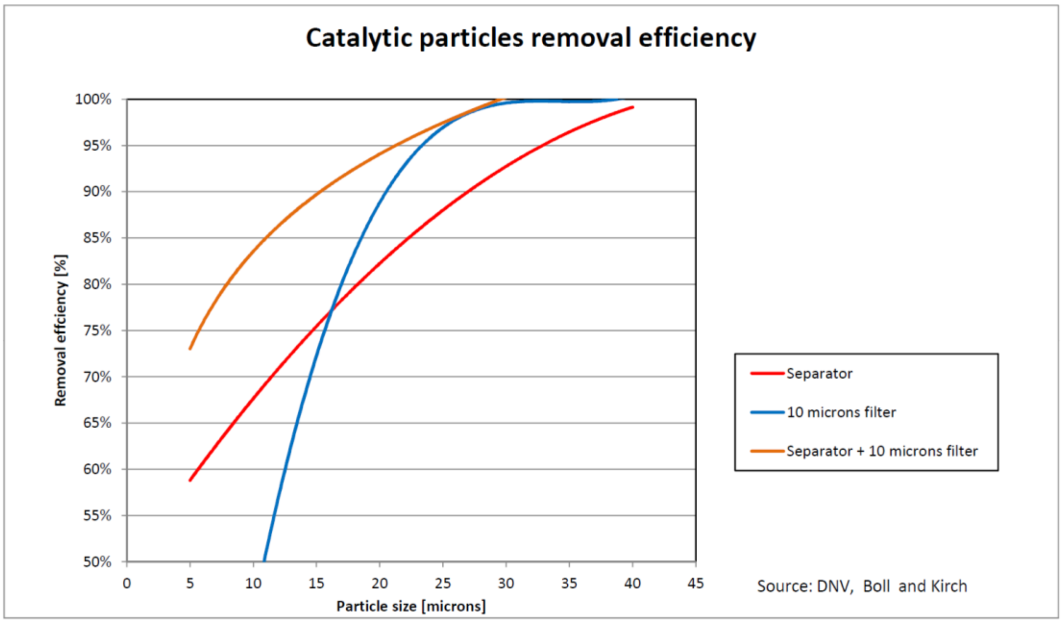

Figure 9: Removal efficiency with separator and filter in series

Additionally, a fine filter in the system provides a good indication whether the separator efficiency is sufficient or improvements are required.

3.5.1 Filter installation and requirements

The arrangements of the fuel oil filters are shown in the fuel oil system proposal in the Marine Installation Drawing Set (MIDS) and in figure 6 of this document. Cat fines and other residues are primarily removed by the fuel oil separators but not by the filters.

However, a minimum of one filter set close to the engine inlet is required for additional protection of the engine against foreign particles. At least one filter set needs to follow the sphere passing mesh size requirement which is valid at the time of installation (refer to table 1).

Engine delivery date	Mesh size – absolute
Before summer 2005	50 micron
After summer 2005	34 micron
After spring 2012	10 micron

Table 1: Required absolute filter mesh size used in Wärtsilä 2-stroke engines

For all new buildings after spring 2012 the required absolute sphere mesh size filtration of 10 microns can be achieved by the following system arrangements:

Recommendation:
Fine filter in the feed system with additional filter in the booster system
(figure 10**)**

A 10 micron (absolute sphere passing mesh size) fine filter is installed in the 'cold' feed system. This installation position is recommended as the flow rate in the feed system is lower compared to that in the booster system and the risk of filter clogging is limited due to the lower fuel oil temperature. The filter protects the engine against serious damages as it catches most of the cat fines which were not removed by the separator. In addition such a filter provides a good indication if the separator efficiency is sufficient or if improvements are required.
Under consideration of the filter fineness, an automatic filter with good self-cleaning performance should be selected.

Additionally a filter of maximum 60 microns (absolute sphere passing mesh size) is installed in the booster system close to the engine inlet. Its function is to protect the engine against foreign particles coming from the system. A duplex filter is sufficient as most particles are already kept by the fine filter in the feed line.

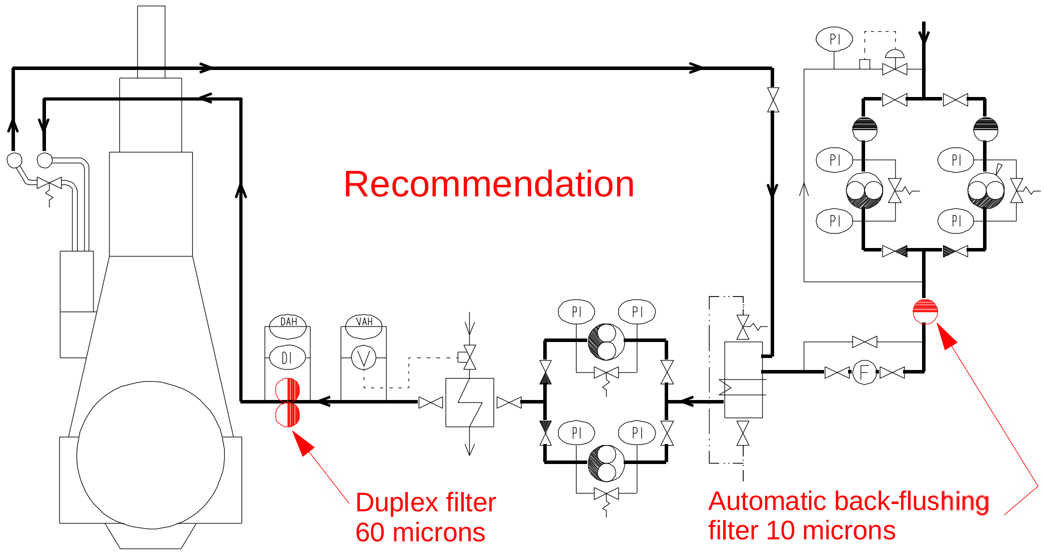

Figure 10: Recommendation for fuel oil filter arrangement

Minimum Requirement:

Fine filter in the booster system as single arrangement (figure 11**)**

A 10 micron (absolute sphere passing mesh size) fine filter is installed in the booster circuit close to engine inlet. The high temperature in this circuit might increase the risk of filter clogging due to agglomeration of asphaltenes. The filter needs to be laid out for a maximum working temperature of 150 °C (special high-temperature gaskets are required).

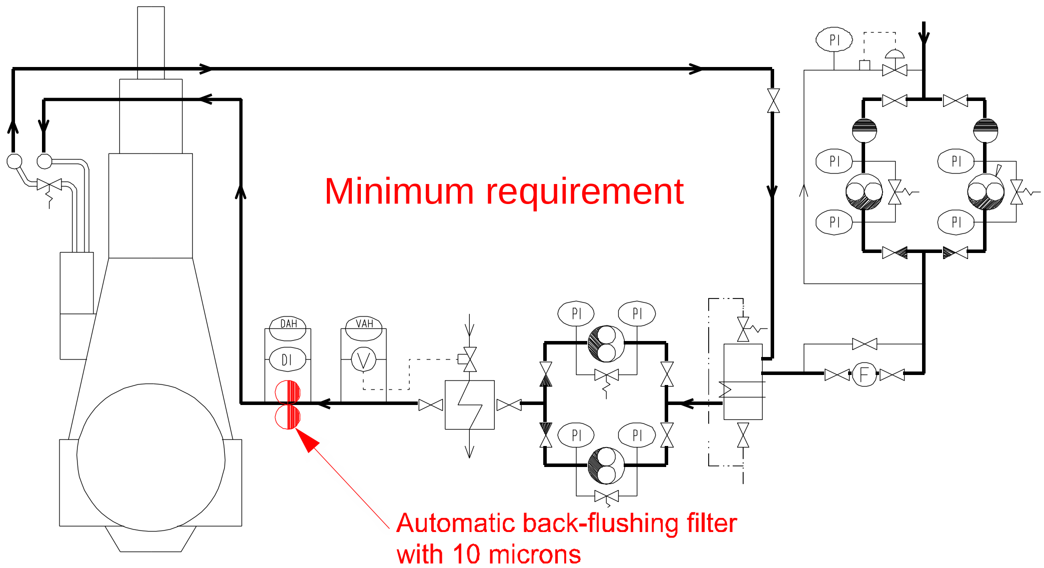

Figure 11: Minimum requirement for fuel oil filter arrangement

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3.5.2 Filter cleaning during normal ship service

The finer the mesh size, the more difficult it is to clean the filter elements. Well-proven cleaning methods are back-flushing supported by compressed air, or back-flushing by cross-flow of a process medium through a special nozzle. The drain pipe from the filter is to be sized and fitted to allow free flow into the overflow tank.

Summary:

- Filters serve as additional protection of the engine against foreign particles which were not removed by the separators.
- At least one filter set close to engine inlet needs to fulfil the current requirement with an absolute sphere mesh size filtration grade of 10 microns.
- Filters need to be cleaned by a proven cleaning method to avoid clogging.

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TRACK CHANGES

DATE	SUBJECT	DESCRIPTION
2016-10-25	GUIDANCE	First web upload