Wärtsilä Finland Oy
Wärtsilä Switzerland Ltd

Wärtsilä

LOW SULPHUR GUIDELINES

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Guidelines for design, modification and operation of newbuildings and existing ships to comply with future legislation related to low sulphur content in the fuel.

Rev.	Date	Made	Approved	Explanation
a	29.09. 2005	LTH	LTH	Chapter 1 updated to reflect latest Marpol and EU rule developments
b	09.01. 2006	LTH	LTH	Minor changes in chapters 1.3.1, 1.5, 3.2.2, 3.5 and 4.2.3

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1 INTRODUCTION

1.1 General

A range of new regulations related to the sulphur content in fuel are presently being prepared or in the implementation phase. This document has been produced to assist owners, operators and shipyards in preparing technical design and operational issues for newbuildings and existing ships.

Due to new regulations, the shipping community is faced with new challenges on a large scale, especially those ships that will operate both inside and outside restricted areas, switching over from one fuel to another, in some cases to a distillate fuel. The experience of such alternating trade is limited, and some of the guidelines in this document are based on the best possible evaluation at the time of writing.

For a long time the traditional approach to operation on HFO has been “pier-to-pier”. The recommendation is not to change over between Heavy Fuel Oil and Light Fuel oil, except in emergency or in preparation for maintenance.

The portfolio of Wärtsilä engines is large, and engines and installations are different for a variety of reasons. In case of conflict between this document and the engine manual, the manual should be followed. Wärtsilä shall not be liable for any damage or injury arising from the use of information based on this document.

1.2 Marpol Annex VI

Marpol Annex VI entered into force in May 2005, providing comprehensive regulations for the prevention of air pollution from ships. This document “Wärtsilä Low Sulphur Guidelines” only covers issues related to the emission of sulphur oxides.

Marpol Annex VI defines SO_x Emission Control Areas (SECA), and the procedures for implementing new such areas. Presently the Baltic, the North Sea and the English Channel are affected, the main features being:

- Maximum permissible sulphur content 1.5 %, or alternatively exhaust gas cleaning, or “any other technological method”. This Guideline focuses on the first option.
- Fuel changeover to be recorded in log book.

Marpol Annex VI entry into force:

- 19th May 2004: Ratified.
- 19th May 2005: Entry into force as such.
    - Sulphur cap 4.5 % worldwide.
    - Bunker delivery notes required.
    - Local supplier register.
    - Statutory fuel sampling.
- 19th May 2006: Baltic Sea SECA effective.
- 22nd November 2007: North Sea and English Channel SECA effective (subject to a ratification process ending 22nd May 2006).

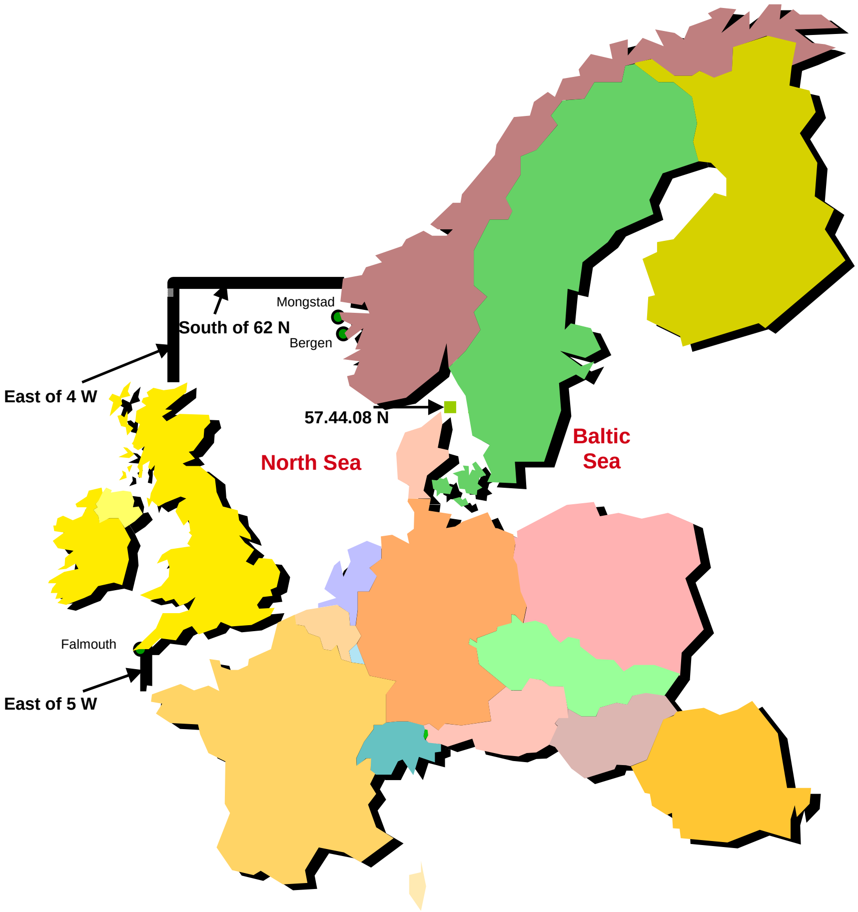


Figure 1. Marpol Annex VI SO_x Emission Control Areas (SECA).

1.3 EU directive

Presently Directive 1999/32/EC only limits the sulphur content of marine gas oils used within EU territory to 0.2 % since July 2000.

The main features of the new "**Directive 2005/33/EC** of the European Parliament and Council modifying Directive 1999/32/EC as regards the sulphur content of marine fuels" are:

1. Adopted by the EU Parliament 13.4.2005.
2. Published in the EU Official Journal L191 22.7.2005.
3. Enters into force 11.8.2005.
4. Provides new sulphur limits in marine fuels for "fuels used" and for "fuels placed on the market".
5. Permits emission abatement technology as an alternative.
6. Provides a special clause for warships.
7. Invites a new proposal to be submitted by the EU Commission by 2008, possibly with a second stage of sulphur limit values (possibly down to 0.5 %) and additional sulphur emissions control areas.

In the new directive the maximum permitted sulphur content of marine fuels is:

1.3.1 Fuels used

Ship type	Area	%	When	Note
All	Baltic SECA	1.5	11.8.2006	
All	North Sea + English Channel SECA	1.5	11.8.2007	
All	All EU ports	0.1	1.1.2010	1,2,3
Passenger ships	All EU	1.5	11.8.2006	4,3
Inland waterway vessels	All EU inland waterways	0.1	1.1.2010	

1. Except for ships due to be at berth less than 2 hours.
2. Derogation for 16 Greek ships operating within Greece until 1.1.2012.
3. Not applicable in the outermost regions of the Community (French overseas departments, Azores, Madeira, Canary Islands).
4. Operators of cruise ships making regular cruises are advised to check with relevant authorities whether their operation is affected by the definition in the Directive: “Passenger vessels on regular services to or from any Community port (= a series of passenger ship crossings operated so as to serve traffic between the same two or more ports, or a series of voyages from and to the same port without intermediate calls, either (i) according to a published timetable, or (ii) with crossings so regular or frequent that they constitute a recognisable schedule).”

Alternatively emission abatement technology may be approved.
Warships are subject to a special clause.

1.3.2 Fuels “placed on the market” within EU territory

Fuel	S-%	When
Marine diesel oils	1.5	11.8.2006
Marine gas oils	0.1	1.1.2010

1.4 “Sulphur calendar” (=Marpol+EU)

The table below is a rough summary of regulations related to the use of fuel in Marpol Annex VI and the new EU directive. The reason for the apparent overlapping is an attempt from EU to accelerate enforcement.

Enforcement by flag and port states:
- Marpol regulations by states which are members of the Marpol Annex VI convention.
- EU regulations by all EU member states.

When	Ship type	Area	%	Act
19.5.2006	All	Baltic SECA	1.5	Marpol
11.8.2006	All	Baltic SECA	1.5	EU
11.8.2006	Passenger ships	All EU	1.5	EU
11.8.2007	All	North Sea + English Channel SECA	1.5	EU
22.11.2007	All	North Sea + English Channel SECA	1.5	Marpol
1.1.2010	All	All EU ports	0.1	EU
1.1.2010	Inland waterway vessels	All EU inland waterways	0.1	EU
1.1.2012	16 Greek ferries	Greek ports	0.1	EU

1.5 Other legislation

California Air Resources Board (CARB) has adopted the following limits for auxiliary diesel engines and diesel-electric engines of ocean-going vessels within Regulated California Waters (24 nautical miles from California):

		ISO 8217	Max sulfur %
1st January, 2007	Marine Gas Oil	DMA	-
	Marine Diesel Oil	DMB	0.5
1st January, 2010	Marine Gas Oil	DMA	0.1

Exhaust gas cleaning is permitted as an alternative.

Locally, ports and local authorities may offer reduction in port and fairway fees depending on the sulphur content in the fuel. In Sweden new sulphur-related fairway dues are differentiated with the following limits from 1 January 2005:

- 0.2 and 0.5 % for passenger vessels
- 0.2, 0.5 and 1.0 % for other vessels

2 DEFINITIONS

As globally standardised terminology does not exist, the following abbreviations are used in this document:

Fuel type	**Denomination**	**Sulphur content % m/m**
HFO	Heavy Fuel Oil	>1.5
LSHFO	Low Sulphur Heavy Fuel Oil	<1.5
LFO	Light Fuel Oil	0.2 … 2.0
LSLFO	Low Sulphur Light Fuel Oil	0.01 … 0.2
ULSLFO	Ultra Low Sulphur Light Fuel Oil	< 0.01

3 EFFECT OF LOW SULPHUR FUEL OPERATION ON DIESEL ENGINES

3.1 Fuel sulphur content versus lubricant BN

Ships operating inside and outside SECAs may not always use or have the optimal lubricant on board. The effect of non-optimal operation is stated below. In general, the effects on 4-stroke engines are long term - whereas for 2-stroke engines the impact is more direct.

3.1.1 2-stroke engines

Where the sulphur content in the fuel is above 1.5 %, the use of approved 70BN cylinder oil is recommended. Where the sulphur content in the fuel is below 1.5 %, approved 40BN cylinder oil is recommended. When following these target BN values, the recommended feed rate and all other operational settings can be applied irrespective of the fuel sulphur content.

3.1.1.1 Risks applying low sulphur content fuel and high BN

Using LFO or LSHFO with 70BN cylinder lubricant should be avoided, because the excessive calcium ash in BN is likely to deposit on the piston crown land. These deposits may become very hard and contact between the deposits and the cylinder liner wall can cause bore polishing and lead to SSW, particularly during load changes. Installing TriboPack (now standard on all engines) reduces the risk, in particular APRs by scraping off the deposits (Welsh/1/). Continuous operation on LFO or LSHFO with 70BN cylinder lubricant is however still advised against.

With between 1.0 and 1.5 % sulphur in the fuel, the 70BN can still be used when the feed rate is reduced to the minimum of the recommended range - below 1.0 % using the high BN must be avoided. Even though low sulphur fuels have been used in many ships with BN 70 lubricants - whenever fuel with normal sulphur content is not available – this poses a higher risk for SSW. This risk is dependent on engine design, operation and maintenance.

3.1.1.2 Risks applying high sulphur content fuel and low BN

When the BN does not suffice to neutralize the sulphuric acid, corrosion is the result. On the other hand attempts to counteract by increased feed rate of low BN lubricant would lead to over lubrication.

Modern Sulzer 2-stroke engines run with liner wall temperatures that are optimized along the full stroke to be above the dew point of water. The result is that less water condenses, and less harmful sulphuric acid needs to be neutralized. Therefore less BN is required for neutralization, so the low BN lubricants can be used with a wider sulphur range. Certainly up to 2 % sulphur, and although above that experience is lacking, with increased feed rate up to at least 3 % should be possible.

3.1.2 4-stroke engines

3.1.2.1 Risks applying low sulphur content and high BN

LSHFO qualities are generally expected to contain rather low amounts of ash constituents, like vanadium, sodium, nickel, etc. When operating on such fuel qualities, risk of deposit formation on engine component surfaces is not considered significant. This is especially valid if the engines are equipped with anti-polishing rings resulting in low lubricating oil consumption, and so preventing also excessive calcium amounts from entering the combustion chamber.

However, if LSHFO qualities have high ash content and if the lubricating oil consumption is on the higher side (e.g. no anti-polishing ring), there may be a risk for excessive ash deposit formation in the combustion chamber, exhaust valves and turbocharger.

Possible mitigation:

1. HFO engines starting to alternate between HFO and LSHFO or LFO can typically continue with the same lubricating oil as before.
2. HFO engines starting to operate continuously on LSHFO can often start using lubricating oil with lower BN.
3. HFO engines starting to operate continuously on LFO should start using lubricating oil with lower BN.

3.1.2.2 Risks applying high sulphur content and low BN

A ship operating continuously in SECAs with LSHFO will possibly select a lubricant with lower BN than for conventional HFO for technical and economical reasons. It is therefore important for these ships to carefully monitor the BN level (or in justified cases change the lubricant) if and when occasionally bunkering conventional HFO, as there otherwise is a clear risk of corrosive wear.

Possible mitigation:

1. Avoid operation with high-sulphur fuel and too low BN.
2. Arrange lube oil systems with more flexibility.
3. Establish lubricating oil BN monitoring equipment and routines.

3.2 Fuel Injection

3.2.1 General

LSHFO and HFO typically have similar properties from the fuel injection point of view. However, some vessels may change over from HFO to LFO before arrival in SECAs. On these ships the effect on a HFO engine when operated on LFO needs to be considered.

3.2.2 Low viscosity

The minimum viscosity of the fuel supplied to diesel engines is in the range 1.8…3.0 cSt. Due to differences in the injection equipment this limit depends on the engine type.

Engine type, 4-stroke	**Minimum fuel injection viscosity, cSt**	
	Jerk pump	**Common rail**
Wärtsilä 20	1.8	1.8
Wärtsilä 26	2.0	
Wärtsilä Vaasa 32/32LN	2.0	
Wärtsilä 32	2.0	2.0
Wärtsilä 38	2.0	2.0
Wärtsilä 46	2.8	2.0
Wärtsilä 64	2.8	
Sulzer S20	3.0	
Sulzer Z40, ZA40, ZA40S	2.0	

The minimum kinematic viscosity (cSt) at 40 °C as per ISO 8217 is 1.5 for DMA and 2.5 for DMB type distillate fuel.

For 4-stroke engines low fuel viscosity is generally speaking not a severe problem, but in severe cases with too low viscosity damage to the fuel injection equipment may occur, and the running parameters of the engine are affected. In exceptional cases there may be a risk of loss of capability to produce full power, black-out and starting problems.

The effect of low viscosity on Sulzer RTA and RT-Flex engines is typically minor.

Possible mitigation:

1. When ordering LFO, specify minimum viscosity.
2. Design / modify systems to maintain appropriate viscosity.

3.2.3 Low density

The main issue is the energy content of the fuel, and the question may be how to handle low density fuels from the automation point of view.

1. **4-stroke:** Reduced energy content per stroke of fuel pump, reduced output at any fuel rack position. Depending on the 4-stroke engine type, the actual difference in output between LFO and HFO can typically be approx. 6…15 %, considering also the leakage due to low viscosity. This tendency may be further aggravated in older engines due to wear in the injection pumps.
2. **2-stroke:** On 2-stroke engines in general, pump index limitations are not an issue regarding application of different fuel qualities. But when running on distillate fuel a slightly higher pump index can be expected compared to HFO operation. This adaptation is made automatically by the speed governor. The injection pumps typically have sufficient capacity to cover this need. During normal circumstances also the torque limiter and charge air limiter have sufficient margin for safe engine operation. However, during exceptional conditions, such as a combination of an old engine with worn injection pumps, inappropriate adjustments, extreme weather and distillate fuel, these limiting devices may limit the available power. In case of doubt it is prudent to check the engine in case operation on distillate fuel in rough sea areas is foreseen (especially in case of small container ships).

Possible mitigation:

1. Generally: Check fuel rack parameters for increased pump wear more frequently.
2. Engines driving FP-propellers: Check the possible need for governor adjustments, permanent or temporary with switch-over and/or override arrangements.

3.2.4 Poor lubricity

Based on Wärtsilä's experience lubricity is not considered a problem for 4-stroke fuel injection components as long as the sulphur content is above 100 ppm (= 0.01 %) S-content. At the time of writing documented experience about fuels with lower sulphur content than 100 ppm is not available. However, in extreme cases a lubricity additive can be added to very low sulphur fuel by a fuel manufacturer / marketer.

3.2.5 Switching between LFO and HFO

Continuous operation with HFO is recommended for engines and plants designed for running on HFO. Changing to LFO is only recommended when absolutely necessary, for example:

- For flushing the engine before maintenance.
- When the heating plant is not available.
- Due to environmental reasons.

When changing the fuel temperature too quickly in 2- and 4-stroke engines, uneven temperature changes may cause uncontrolled clearance adaptation in the injection pump with risk of seizure (thermal shock), fuel leakages in high pressure pipe joints etc.

Possible mitigation:

1. Arrange fuel system to permit a controlled slow change in fuel temperature.
2. Where necessary, introduce appropriate manual switchover procedures.

3.3 Fuel incompatibility

When two different fuels are mixed there is a risk of incompatibility, which may cause clogging of fuel filters and separators and sticking of fuel injection pumps (asphaltene deposits on plunger and barrel). Compatibility problems are related to the fuel's stability reserve. HFOs are rather aromatic and do contain asphaltenes. If the stability reserve of such a HFO is low, it cannot stand mixing more paraffinic LFO into it, and as a consequence asphaltenes will precipitate out of the blend. The risk is generally not very high, but incompatibility may occur e.g. if two fuels originate from different crude oils or have gone through different refining processes. Incompatibility problems can also occur during steady-state, e.g. when blending fuels.

Possible mitigation:

1. As much as possible avoid mixing two different fuels.
2. Perform a compatibility test onboard before mixing the fuels in question.
3. Schedule permitting, make a compatibility test in a laboratory before mixing the fuels in question.
4. The size of tanks where different fuels are mixed and duration of the mixing should be minimised. This requirement is not compatible with the target of minimising thermal shocks (e.g. by maximising size of mixing tank).

3.4 LSHFO

In recent years the availability of LSHFO has been satisfied from crude oils with low sulphur content. In the near future the increased demand for LSHFO will also mean mapping of other alternatives. Technically construction of desulphurization units is possible but the investment costs are very high. Also blending of HFO with lower sulphur streams in refineries or with LFO on board the vessels are under discussion.

Depending on which approach will be taken to achieve the required sulphur content, the density of LSHFO can be affected (and therefore separator adjustments may be required).

If LSHFOs are processed by using a desulphurization unit, fuel aromaticity is decreased. This means a lower stability reserve and, depending on refining process severity, fuel stability can reach its limit. Density and viscosity are not expected to be influenced significantly, since by varying the amount and quality of diluents, those properties can be kept at their original level. The influence of the desulphurization process on fuel's ignition properties is not yet known in detail.

If LSHFOs are manufactured by blending HFOs with different lower sulphur products, like light cycle oil, vacuum gas oil, kerosene, heavy naphtha, gas / diesel oil, etc., it is not possible to give a clear answer on how different fuel properties are influenced, but on the other hand it can be noted that many of these products have already been used to some extent for decades. However, it's important to follow the fuel quality trends and look at the essential physical and chemical properties as well as gather field experience.

DNV Petroleum Services has already seen indications that the low sulphur processing of fuel oils may lead to additional quality problems such as instability, incompatibility, ignition and combustion difficulties and an increase of catalytic fines levels /2/.

3.5 Exhaust valves (4-stroke)

This chapter applies to some modern highly loaded HFO 4-stroke engines.

Some constituents of HFO have a tendency to cause hot corrosion on exhaust valves. Such constituents are e.g. vanadium, sodium, nickel, calcium and sulphur, especially with high contents as well as in certain unfavourable proportions. The risk for corrosion is depending on the temperature in the combustion chamber. This tendency is mitigated by specifying Nimonic exhaust valves for modern, highly loaded HFO engines. Nimonic has a high resistance against hot corrosion, and also against high temperatures.

Some constituents of HFO may have a positive lubricating effect on the exhaust valve seats. When operating a diesel engine on LFO or LSLFO, this lubricating effect can be clearly lower, which may cause increased wear of the exhaust valve seats. To mitigate such wear, exhaust valves with Stellite facing (a harder material) are selected for engines specified to operate on LFO/LSLFO only. Unfortunately such valves do not have the same resistance against hot corrosion and high temperatures as Nimonic, and are therefore not used in these engines.

Changing exhaust valves when changing fuel quality is not feasible for practical reasons.

The conclusion is that these engines alternating between HFO and LFO/LSLFO operation should have Nimonic exhaust valves, with the unfortunate consequence of a possible risk of increased wear when operating on LFO/LSLFO. If the operation of an engine is changed from HFO to continuous LFO/LSLFO operation, a change of exhaust valves from Nimonic to Stellite is recommended.

4 SYSTEM SOLUTIONS AND OPERATIONAL RECOMMENDATIONS

4.1 General

These recommendations are general guidelines and by no means universally applicable. Engines and installations are different for a variety of reasons, and it is important to closely monitor the performance and behaviour of the plant once it starts operating in a new fuel mode.

The emphasis in this chapter is on fuel and lubricating oil tank and system arrangements for ships expected to operate inside and outside SECAs.

For newbuildings expected to operate purely within SECAs, fuel and lubricating oil filling, storage, transfer, separation, and supply systems can in principle be arranged as on a traditional HFO ship. However, to enhance the flexibility and second-hand value of the ship, consideration could be given to designing these systems also for alternating operation inside and outside SECAs, as outlined below.

4.2 Fuel systems

4.2.1 HFO system layout aspects

4.2.1.1 Mixing vs. segregating fuels

Ships generally have two or more HFO storage tanks, and SOLAS rules have required double day tanks for all fuel types used onboard since July 1998. Some ships also have double HFO settling tanks to further reduce the risk of fuel incompatibility, and enhance settling.

In case the intention is to operate on different HFO qualities inside and outside SECAs it is now beneficial to install (or retrofit) double HFO settling and service tanks, for operational convenience, economy and safety. The benefits of double HFO systems compared with mixing fuels in the settling tank (or in the service tank if the settling tank is completely drained before changing to another fuel) are:

- To facilitate verification of compliance with the Marpol Annex VI clause "…shall allow sufficient time for the fuel oil service system to be fully flushed of all fuels exceeding 1.5 % m/m sulphur content prior to entry into a SECA".
- To avoid consuming expensive LSHFO during the mixing phase before entering and after exiting the SECA.
- To avoid possible incompatibility problems.

In the example below the level in the settling tank is permitted to fall to about 20 % before filling up. Several days are needed to reach the new S-level before entry into a SECA as well as upon exit from a SECA.

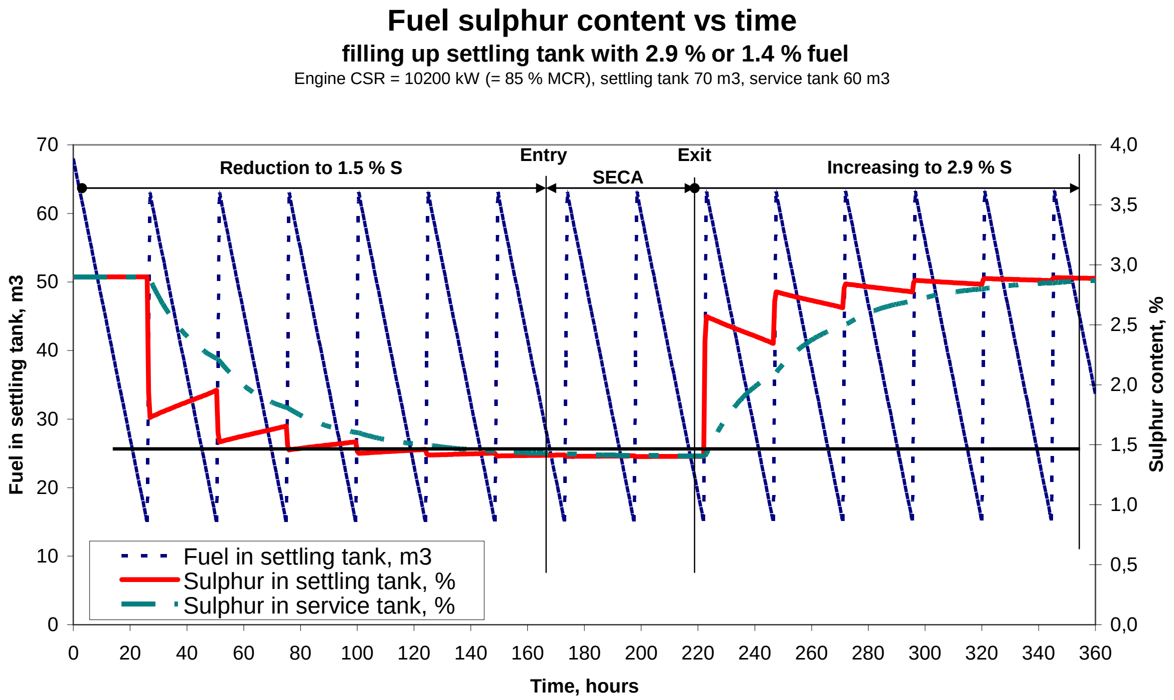


Figure 2. Example: Fuel sulphur content vs time when alternating between 2.9 % and 1.4 % sulphur.

The benefits of double HFO systems compared with switching between HFO and LFO in the supply piping are:

- To avoid the hazard of switching between completely different fuels at sea (especially in congested areas like the English Channel or potentially rough areas like the North Sea or Bay of Biscay).
- To simplify the switch-over procedure generally.

4.2.1.2 Switching between HFO and LFO

If double HFO systems are not provided and the ship does not have LSHFO available when entering a SECA, the only alternative will be to switch over all HFO engines to LFO at sea. In such a case the LFO temperature and the temperature change gradient need to be considered.

For **2-stroke engines** a controlled temperature gradient is recommended, with a reduced engine load. For **4-stroke engines** the fuel change-over can generally be performed via the mixing tank at any load.

Procedures and/or arrangements for switching from HFO to LFO may include fuel pre-heaters, fuel pipe trace heating, a 3-way valve in the suction line from the service tanks, redirecting the return fuel to the LFO service tank, LFO cooler, possible need to control engine load, and monitoring pressure difference of fuel filter (indication of incompatibility).

If light fuel oil is mixed in while the fuel temperature is still very high, there is a possibility of gassing in the fuel oil service system with subsequent loss of power.

4.2.1.3 Switching between HFO and LSHFO

If the ship has only one HFO service and one HFO settling tank, and assuming that it is possible to completely drain them with a transfer pump, and the operator deems it feasible to do so even at sea, the switchover procedure may include the following phases:

- Switching from HFO to LFO operation
- stopping the separator
- perhaps draining the bottom sludge to the sludge tank
- draining the HFO service and HFO settling tanks completely with the transfer pump to a storage tank with the same fuel quality
- filling the settling tank with the new quality
- possibly changing the gravity disc of the separator
- restarting the separator
- filling up the service tank via the separator (at least partly to a safe level), and
- switching over to this new fuel

Depending on the ship this procedure may take perhaps 15 hours in case the service tank is filled to 50 % before taken into use.

4.2.1.4 Fuel separators

Until the mid 1980s fuel separators typically were equipped with gravity discs, the purpose of which was to control the interface between the water and the fuel in the separator bowl. The gravity disc has to be selected according to prevailing parameters, including the fuel density. A new bunker delivery may require the gravity disc to be replaced. Finding a suitable disc sometimes requires some patience.

From the mid 1980s a new type of separator with water monitoring in the clean fuel outlet gradually became the dominating type to be installed on new ships.

Typically separators of the old type are still in operation on old ships. These old ships are now in a new situation, and could benefit from fuel separators of the new type, in case the ship is alternating between HFO and LSHFO with different density. Such a difference is more likely if the LSHFO is based on blending at the refinery rather than on low sulphur crude oil.

4.2.2 Fuel systems for different categories of ships

4.2.2.1 New buildings

It is beneficial to arrange double HFO settling and service tanks. The preferred minimum number of storage tanks is four, to permit the ship to bunker HFO and LSHFO in empty tanks anytime even if both fuel qualities are available in other tanks. Thus different bunker deliveries do not have to be mixed.

Since January 2003 a new DNV voluntary class notation “FUEL” is available. The system design criteria of this class notation are suitable for ships which due to their operational pattern benefit from using two different HFO qualities.

4.2.2.2 Existing ships with double HFO service tanks (> 1998)

SOLAS rules have required double service tanks for all types of fuels used onboard for ships, the keel of which has been laid 1st July 1998 or later. These ships have the possibility to dedicate one service tank permanently for HFO and the other for LSHFO.

There are, however, ships built with an “equivalent” arrangement, where a LFO service tank of suitable capacity has been approved as the second tank.

If the ship has only one HFO settling tank, consideration could be given to installing another settling tank for complete segregation and proper functionality of the settling tank.

4.2.2.3 Existing ships with single HFO service tanks (< 1998) – double tank option

Consideration could be given to installing another HFO service tank. If the ship has only one HFO settling tank, installing another settling tank would provide additional benefits.

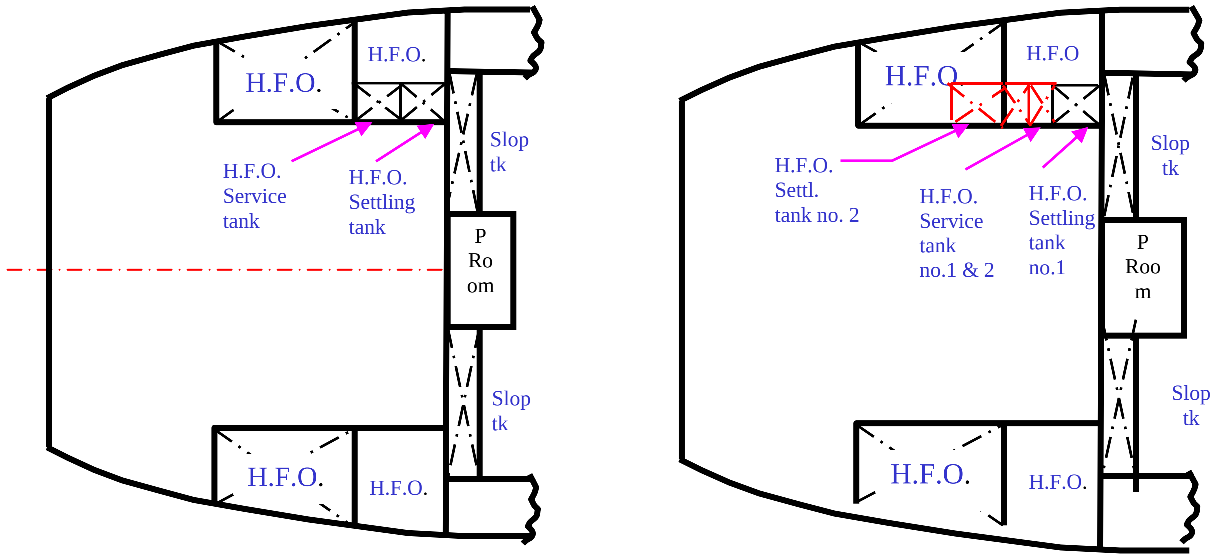


Figure 3. Example of doubling HFO settling and service tanks as proposed by DNV /2/.

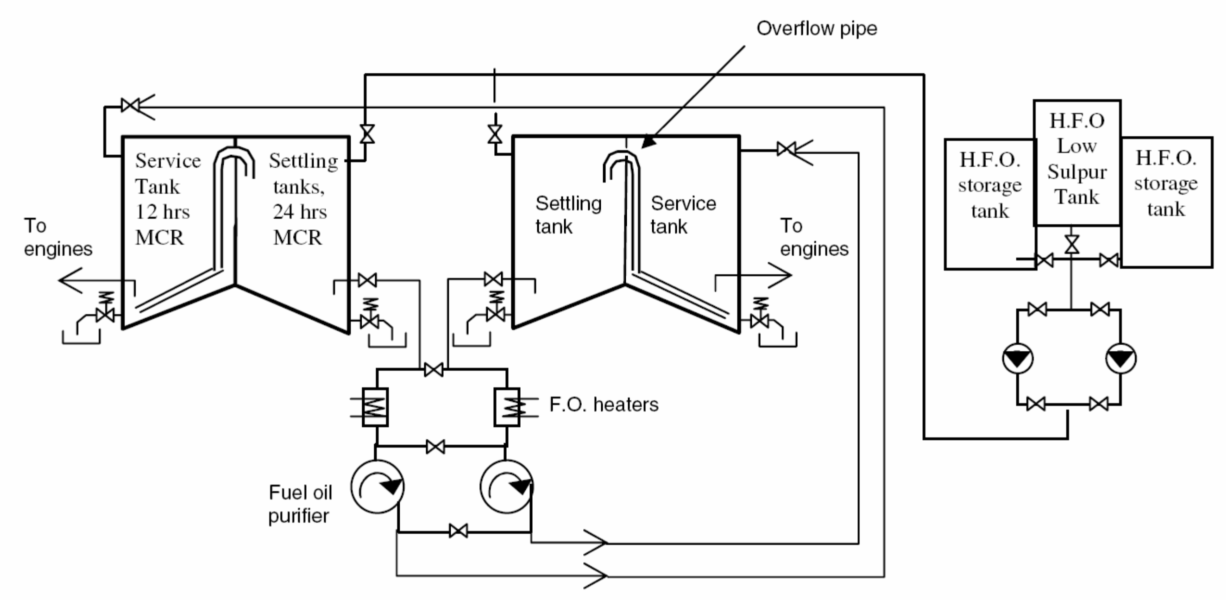


Figure 4. Simplified fuel piping diagram for double HFO settling and service tanks /2/.

4.2.2.4 Existing ships with single HFO service tanks (< 1998) – blending unit option

As an alternative to installing double tanks, a blending unit can be retrofitted, however with the risk of incompatibility. The unit is used to inject LFO (with low sulphur content) into the fuel booster system to reach the required S-content of 1.5 %.

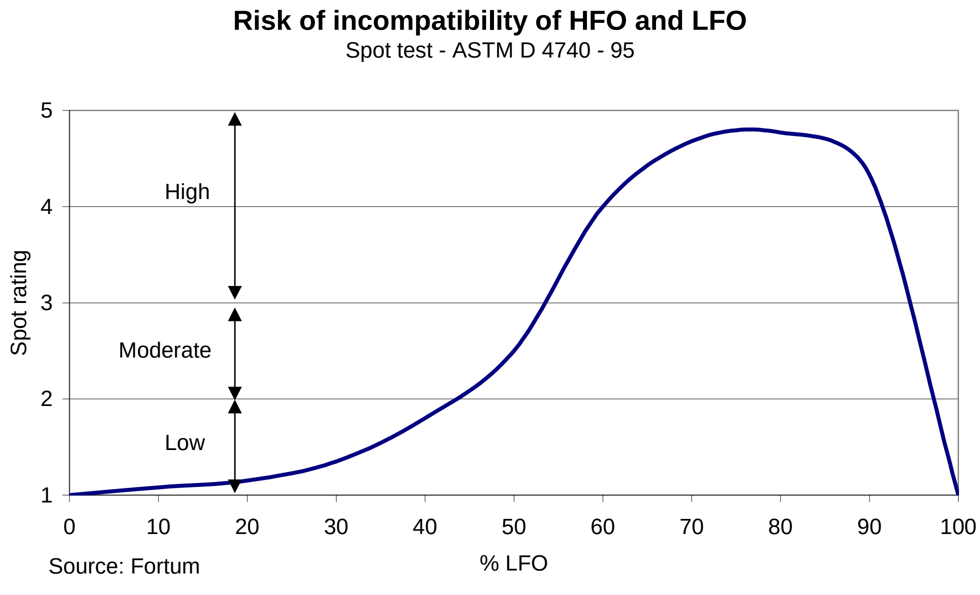


Figure 5. Example of compatibility risk level of HFO and LFO versus percentage of LFO in the blend. The shape of the curve may vary depending on the fuel qualities in question in each specific case.

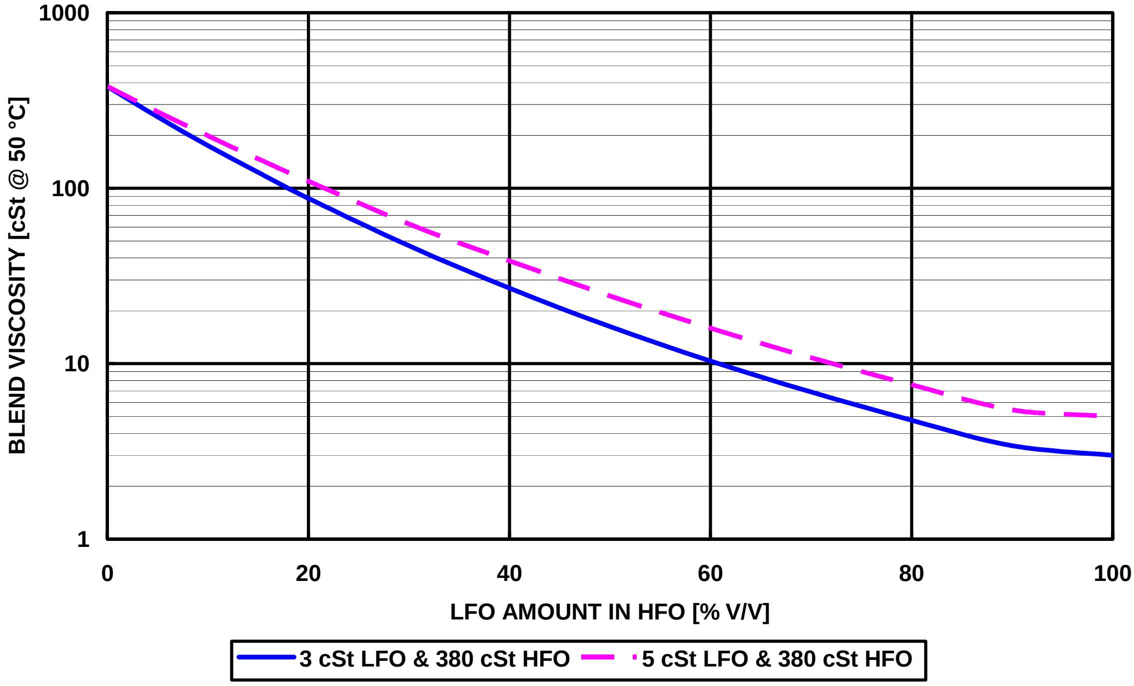


Figure 6. Example of viscosity of blended fuel.

4.2.3 LFO system layout for EU ports (or sea-going, if applicable)

The fuel system needs to be suitable to avoid too low viscosities of the LFO for generator engines in EU ports, also in warm conditions, even if the system has been designed for HFO. Heat is introduced into the system from the diesel engines and possibly from fuel separators and adjacent tanks. In some cases a fuel cooler may be required. It may be prudent to review the fuel system thermal balance if and when larger amounts of LFO are beginning to be consumed in a continuous operating mode. This applies especially if LFO operation is foreseen also for the main engine in SECAs.

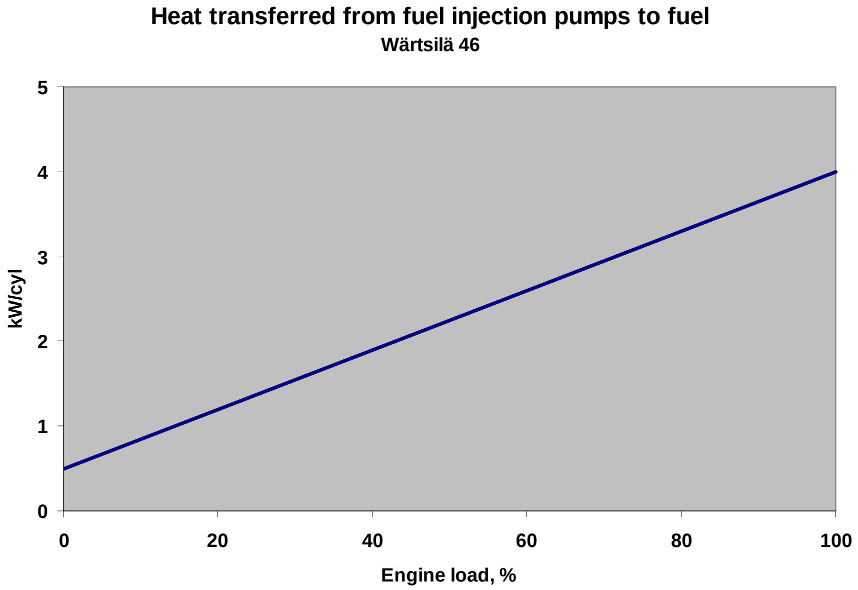


Figure 7. Example of heat transfer from fuel injection pumps to fuel.

Main engines are not affected by EU rule limiting the fuel used in ports.

DNV has identified a range of technical challenges when operating HFO oil-fired boilers on low viscosity distillates /2/. Double HFO settling and service tanks are beneficial also for this reason.

4.3 Lubricating oil systems

4.3.1 System layout aspects

For **new buildings** and **existing ships** the following could be considered:

- Double cylinder oil storage and daily service tanks for 2-stroke engines regardless of fuel tank arrangement.
- Double system oil storage tanks for 4-stroke HFO auxiliary engines and main generator engines, in case one or some of the engines are to be operated (more or less) permanently on LFO. Also arrangements for proper drainage of the 4-stroke lubricating oil circulating oil system for installations where a (e.g. seasonal) change of oil quality is deemed justified.

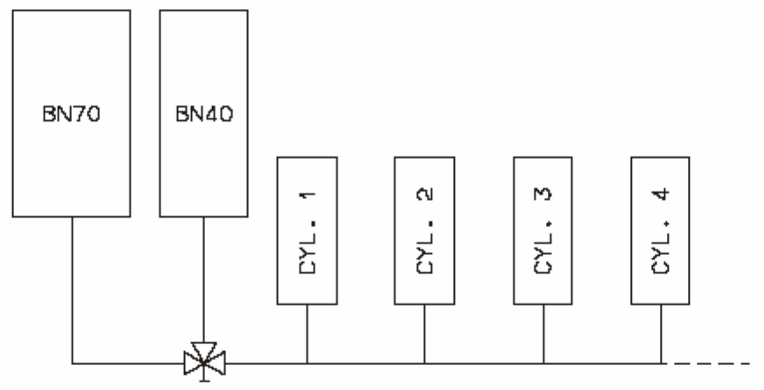


Figure 8. DNV proposes double cylinder oil systems for 2-stroke engines /2/.

4.3.2 Lubricants

The basic rule is to select the BN of the lubricant (cylinder oil for 2-stroke and system oil for 4-stroke engines) in accordance with the higher sulphur content.

4.3.2.1 2-stroke engines

Select the cylinder lubricant in accordance with the fuel sulphur content. The crankcase lubricant is not affected by the fuel quality and cylinder oil.

Currently all global suppliers offer 40BN cylinder lubricants, so availability should be no problem.

In general analysis of the piston underside drain oil to find the optimal cylinder oil feed rate is recommended.

Fuel sulphur %	Cylinder oil BN	Feed rate	Recommendation
> 1.5	70	Normal	Ok
< 1.5	40	Normal	Ok
< 1.5	70	Normal	Not ok
1… 1.5	70	Reduced	Ok
< 1	70	Reduced	Not ok
< 2	40	Normal	Ok with Tribopack
< 3	40	Increased	Ok with Tribopack

4.3.2.2 4-stroke engines

Wärtsilä can assist the operator in selecting a suitable lubricant (a questionnaire is available for 4-stroke engines).

If both distillate fuel and residual fuel are used periodically as fuel, the lubricating oil quality has to be chosen according to instructions valid for residual fuel operation, i.e. BN 30 is the minimum. Optimum BN in this kind of operation depends on the duration of operating periods on both fuel qualities as well as of the sulphur content of the fuels in question. Thus in particular cases BN 40 or even higher BN lubricating oils should be used. Note that higher alkali reserve (BN) in lubricating oil also offers better detergency.

Fuel type	Fresh oil BN	BN condemning limit
HFO	30-55	20
LSHFO	30-40	20
HFO+LSHFO	30-55	20
HFO+LSHFO+LFO	30-55	20
HFO+LSHFO+LSLFO	30-55	20
DMC	30-40	20
LFO+LSLFO *	15-30	-50 %
LSLFO **	10-30	-50 %

Depending on the fuel sulphur content and lubricating oil consumption, the optimum BN can be selected from the upper or the lower end of the BN range.

* For LFO qualities meeting the DMX / DMA specification, the minimum BN of lubricating oil is 10.

** Also for LSLFO having a low sulphur content of 0.01 …0.2 % a lubricating oil with BN of minimum 10 is needed to ensure an adequate alkali reserve to neutralize acid oxides of sulphur as well as nitrogen.

4.4 Engine components

For new engines there is basically no change due to low fuel sulphur content. All new 2-stroke engines have TriboPack as standard. All new Wärtsilä 4-stroke engines have Anti-Polishing Rings.

For existing 2-stroke engines it is recommended to retrofit Anti-Polishing Rings to prepare the engine for operation on low sulphur fuel.

For the exhaust valves of existing 4-stroke engines, see chapter 3.5.

4.5 Check list

There are several items to check, adjust, install, develop guidelines and arrange crew training for, depending on the preferred solution for operating inside and outside SECAs. For each solution only a part of the items listed below are valid. When evaluating several alternative options the check list is a rather complex matrix.

SYSTEMS
HFO settling tanks
HFO service tanks
HFO bunker tanks
LFO tanks
HFO separators
LFO separators
HFO/LFO blending unit
LFO cooler
Fuel return line to LFO service tank
HFO/LFO switch-over arrangements
Cylinder oil storage / daily service tanks (2-stroke)
Fuel filter differential pressure monitoring

DIESEL ENGINES
Anti-Polishing Rings (2-stroke)
Tribopack (2-stroke)
Exhaust valves (4-stroke)
Check of fuel rack adjustment
ME speed governor
Start fuel limiter
Load increase rate (2-stroke)

OPERATIONAL GUIDELINES / TRAINING
Selection of lubricants (for ordering)
Cylinder oil change at SECA border (2-stroke)
Cylinder oil feed rate (2-stroke)
Analysis of piston underside drain oil (2-stroke)
Flash point and viscosity analysis of lube oil (4-stroke)
Minimum LFO viscosity when ordering
Maximum LFO temperature
HFO/LSHFO switch-over procedures
HFO/LFO switch-over procedures
Onboard fuel compatibility tests

5 OPERATIONAL ECONOMY

A case study of a ship with a 12 MW main engine serves to illustrate the economy of different fuel system options available for an existing ship with single HFO settling and service tanks. Option 1 is included as reference to show the present cost level.

The table below lists some more or less possible options, indicating also drawbacks and possible technical risks.

#	Low Sulphur Package	Drawback	Possible risk
1	HFO only (reference)	Non-compliant	
2	HFO & LSHFO, slow blending in settling tank	Opex	Incompatibility
3	HFO & LSHFO, slow blending in service tank, settling tank drained	Opex	Incompatibility
4	HFO & LSHFO, settling & service tank drained, pure LFO during switch-over	Opex	Change-over
5	HFO & LSHFO slow blending in settling tank, LFO blending unit during switch-over	Opex + small capex	Incompatibility
6	HFO & LSHFO & double tanks	Capex	
7	HFO & LFO, LFO in SECA	Opex	Change-over
8	HFO & LFO, blending unit in SECA	Opex + small capex	Incompatibility
9	LSHFO only	Opex	

Opex = Operating expenses
Capex = Capital expenses

For newbuildings this case study has less relevance, assuming that double HFO settling and service tanks will be installed. The capital expenses of double tanks are much smaller in a newbuilding compared with a later modification. The operating expenses of the other possible system solutions are of course valid for newbuildings as well.

For existing ships, the result of the economical analysis varies depending on ship, route, duration of SECA visits, etc.

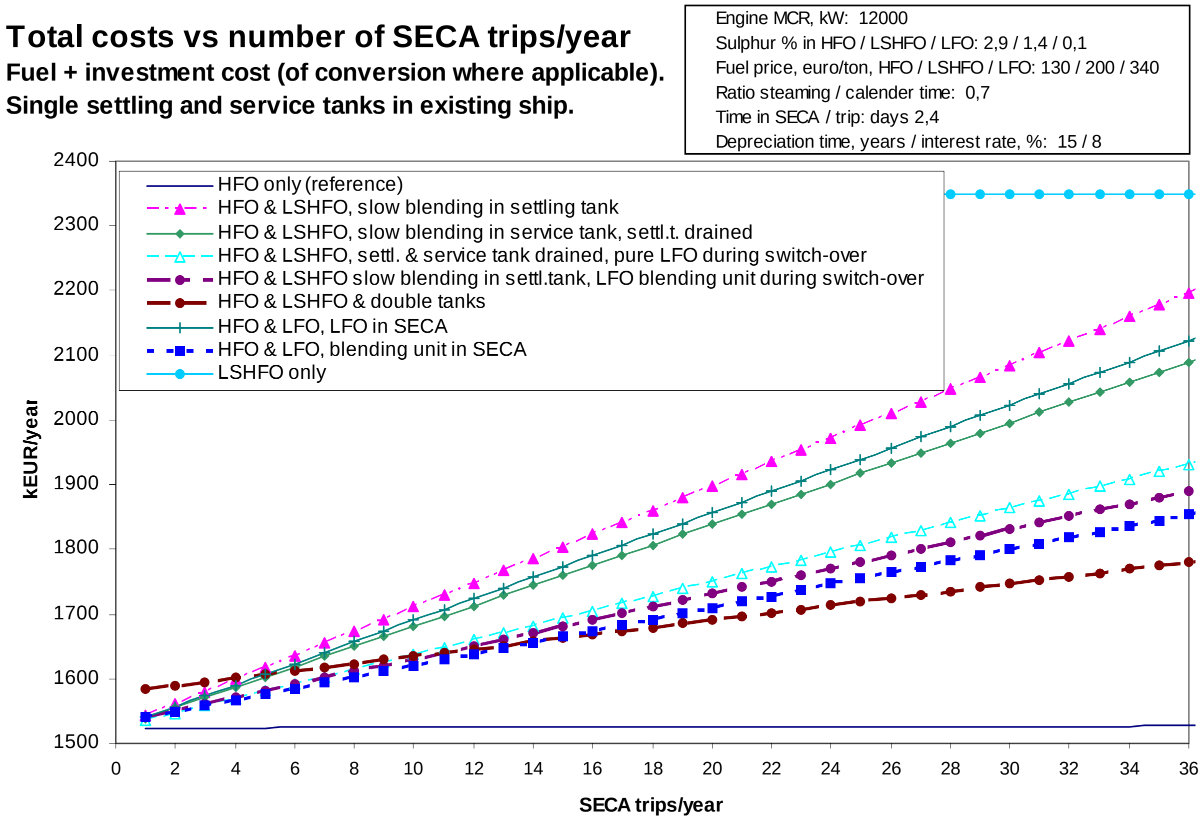


Figure 9. Total economy of different fuel system solutions. Case study, engine 12 MW.

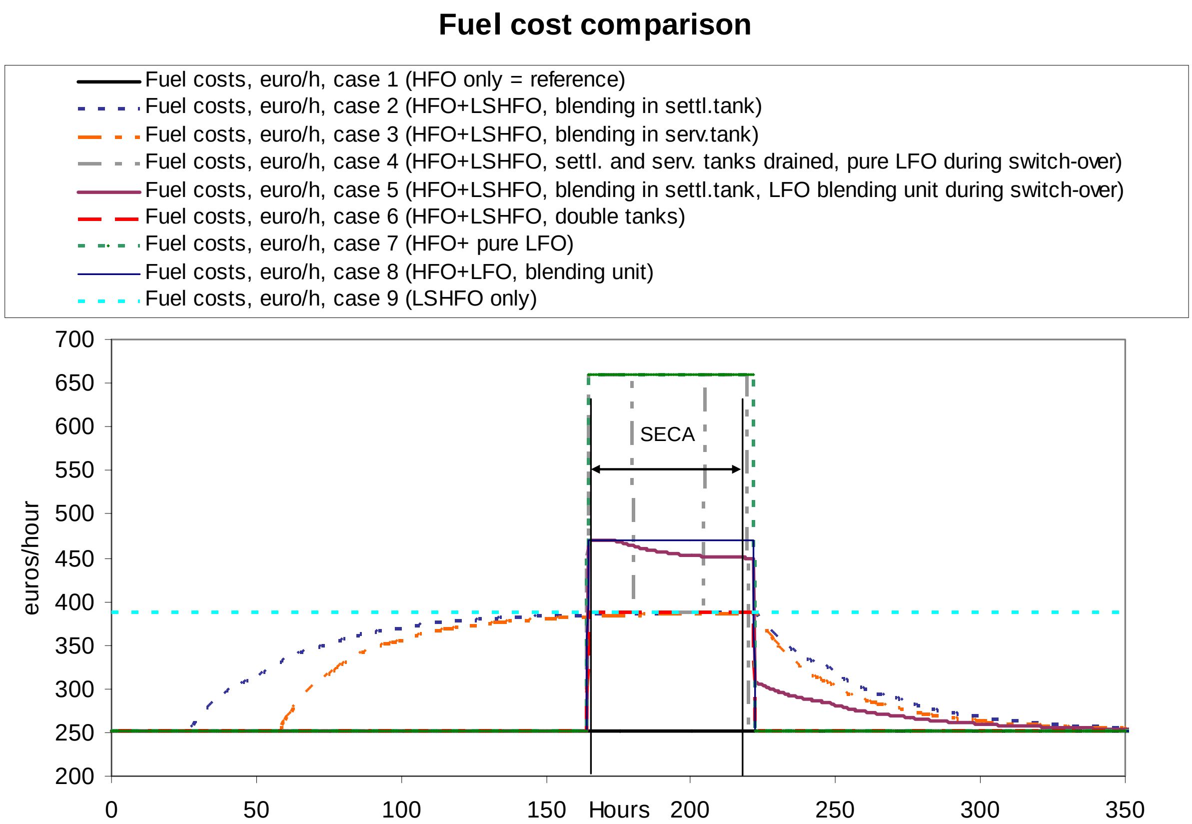


Figure 10. Fuel cost / hour with different fuel system solutions. Case study, engine 12 MW.

6 ASSISTANCE OFFERED BY WÄRTSILÄ

For existing ships, Wärtsilä including the Ciserv organisation can offer engine checks and modifications, as well as tank and system modifications onboard (see check list in chapter 4.5).

7 ATTACHMENTS

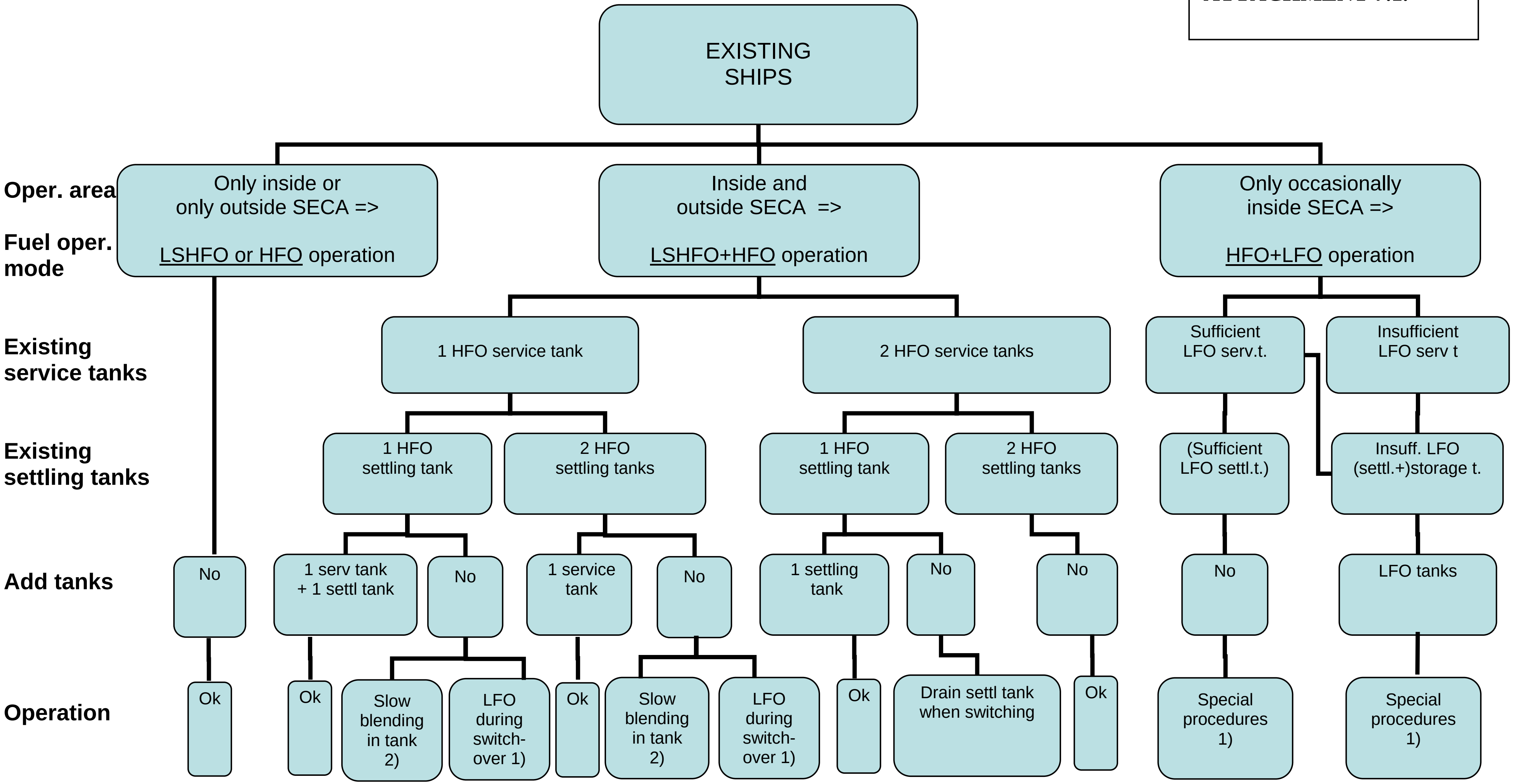
7.1 Tank selection chart for existing ships – main options

8 REFERENCES

1. Michael Welsh, Wärtsilä Switzerland Ltd, "Considerations for using low-sulphur fuel", March 2002.
2. DNV, "Regulations for the Prevention of Air Pollution from Ships, Technical and Operational Implications", 21 February 2005.

LOW SULPHUR TANK SELECTION CHART FOR EXISTING SHIPS – MAIN OPTIONS

ATTACHMENT 7.1.



Notes:

1) Special procedures as to switchover HFO-LFO-HFO, temperature changes, lube oil BN, available power with lower energy density, etc
2) Risk of fuel incompatibility