The Alfa Laval Adaptive Fuel Line BlueBook

Technical reference booklet – 2018 Edition

A technical reference booklet on catalytic fines, sulphur emission legislation, oil compatibility issues
and how to handle these challenges with modern fuel treatment systems

The Alfa Laval Adaptive Fuel Line

This BlueBook provides an overview of the Alfa Laval Adaptive Fuel Line concept and the rationale behind its development. The BlueBook serves as an introduction to fuel handling in general, a technical reference for those interested in the function and relevance of specific components, and a guide to how the entire fuel chain can be designed to improve fuel handling efficiency and reduce operating costs.

Niclas Dahl
Head of Marine Separation

Summary

The shipping industry today faces many challenges. Stricter sulphur emission regulations are driving the transition towards new low-sulphur fuels. While the changes are necessary for environmental reasons, they increase the challenges and uncertainties for ship operators and owners. This book describes the background and implications of the change underway and explains how the Alfa Laval Adaptive Fuel Line has been designed to meet the fuel handling and treatment needs of ships in the low-sulphur era.

Alfa Laval Adaptive Fuel Line

Producing low-sulphur fuel oils often requires a process called catalytic cracking. This process leaves behind residues of particulate matter, usually containing aluminium and silicon compounds, called catalytic fines or cat fines for short. These cat fines are very hard and range in size from 100 microns down to submicrons. If not properly removed from the fuel, cat fines can wear down engine components and cause severe engine damage.

Furthermore, uncertainty surrounding the nature of future low-sulphur fuels raises concerns for onboard fuel handling operations.

In a competitive market, there are always demands for cost reductions and increased efficiency. Alfa Laval offers market-leading equipment for fuel handling and fuel processing on board ships. The concept behind the Alfa Laval Adaptive Fuel Line is to take advantage of Alfa Laval's range of equipment throughout the entire fuel handling system. Enhanced communications among individual components, helps optimize fuel treatment performance, delivering higher separation efficiency, cleaner fuel, and fewer cat fines.

For the operator, the result is lower operational costs, lower engine maintenance costs, and more secure ship operations.

This publication is divided into four chapters

Chapter 1: Marine bunker fuels
This section deals with the process of producing marine fuel oils, provides an introduction to catalytic fines, and discusses cat fine trends in heavy fuel oil today, as well as other fuel quality properties.

Chapter 2: Fuel treatment – Engine performance
This section describes how cat fines influence engine performance and how other parameters influence separation efficiency.

Chapter 3: Legislative impact on ship operation
This section provides a summary of current sulphur emissions legislation. It discusses the establishment of new emission control areas (ECAs) and the increasingly stringent emissions regulations, which have led to multi-fuel operation. It also addresses the consequences of changeover between residual and distillate fuels.

Chapter 4: Fuel oil treatment – The modern approach
This section describes the fuel treatment system of tomorrow and highlights six different areas where efforts can be made to optimize a plant or onboard equipment in order to improve energy efficiency, fuel quality and environmental compliance. Interconnecting components and adding intelligence may yield great advantages. This is the Alfa Laval Adaptive Fuel Line.

Inside view

What you need to know about catalytic fines, sulphur emissions legislation, oil compatibility issues and how to handle these challenges with modern fuel treatment systems.

1 Marine bunker fuels

When using marine fuel oils, onboard fuel treatment and fuel cleaning is critical for efficient ship operation. Here, some aspects and challenges of marine fuel treatment are described, with particular focus on the increasingly important issue of cat fines content in fuel oils.

Bunker fuel is used on board vessels both by the main engines, which generate propeller thrust, and by the auxiliary engines, which provide electrical energy for onboard systems. A broad range of fuels is used for marine transport. ISO 8217 is the current international standard regarding specifications for petroleum products for use in marine diesel engines and boilers, prior to appropriate treatment. Environmental regulations, described in Chapter 3, “Legislative impact on ship operation”, increasingly have an effect on global bunker demands. Heavy residual fuels dominate demand today but will most likely be replaced by lower-viscosity residual blends and distillates in the future. Figure 1 shows a view of the global bunker demand post 2020.

The implementation of MARPOL Annex VI will shift marine fuel demand to:

• Very-Low Sulphur Fuel Oil (VLSFO) with a maximum sulphur content of 0.50%.

• Ultra-Low Sulphur Fuel Oil (ULSFO) with a maximum sulphur content of 0.10% for use in emission control areas (ECA) that were introduced in 2015. Today, the majority of ULSFO is based on MGO; however, the use of low-viscosity residual fuels, such as ISO RMD80 is growing.

• High-Sulphur Fuel Oil (HSFO) which can be used in combination with an exhaust gas cleaning system (scrubber). The installation of scrubbers is expected to grow in the global fleet, as it appears to be the lowest-cost compliance option.

• Liquefied Natural Gas (LNG). While demand for LNG is expected to grow, lack of infrastructure and high investment costs mean LNG-fuelled vessels are unlikely to be a significant part of the global fleet in the medium term.

Sucessful implementation of the new regulations will depend on the availability of both VLSFO and HSFO in 2020. In July 2016, a consortium led by the independent research and consultancy organization CE Delft published a report that supports the decision-making process of the Marine Environment Protection Committee (MEPC) of the International Maritime Organization.

“The main result of the assessment is that, in all scenarios, the refinery sector has the capability to supply sufficient quantities of marine fuels with a sulphur content of 0.50% m/m or less and with a sulphur content of 0.10% m/m or less to meet demand for these products, while also meeting demand for non-marine fuels.”

Based on this assessment, the IMO announced in October 2016 that the global sulphur cap of 0.50% on marine fuels would enter into force on January 1, 2020. Several industrial stakeholders have been critical of the decision, expressing concern that the transition will be problematic and that the regional fuel supply may not be able to match the demand.

The marine industry represents about one-tenth of global petroleum consumption (Figure 2). When the sulphur cap is introduced in 2020, the global demand for distillates is forecast to increase by 85 million tonnes per year, from about 1.2 to 1.3

billion tonnes, because most vessels will have to switch from HFO to MDO or another compliant fuel blend (IBIA, 2016).

The use of scrubbers and liquefied natural gas (LNG) may decrease the use of MDO and fuel blends at the transition, but forecasts indicate that availability of such equipment and fuel will not cover the demand (DNV GL, 2016).

Different types of fuels used within shipping and the refining processes are briefly described in the following sections.

1.1 Marine fuel oils

Ship operations require the use of different types of fuel, which are commonly referred to as marine fuel oils. Ship engines are flexible machines capable of consuming everything from heavy fuel oil to lighter distillates such as marine gas oil, provided that an efficient fuel cleaning system is in place and that the temperature and viscosity are within the recommended limits of the engine.

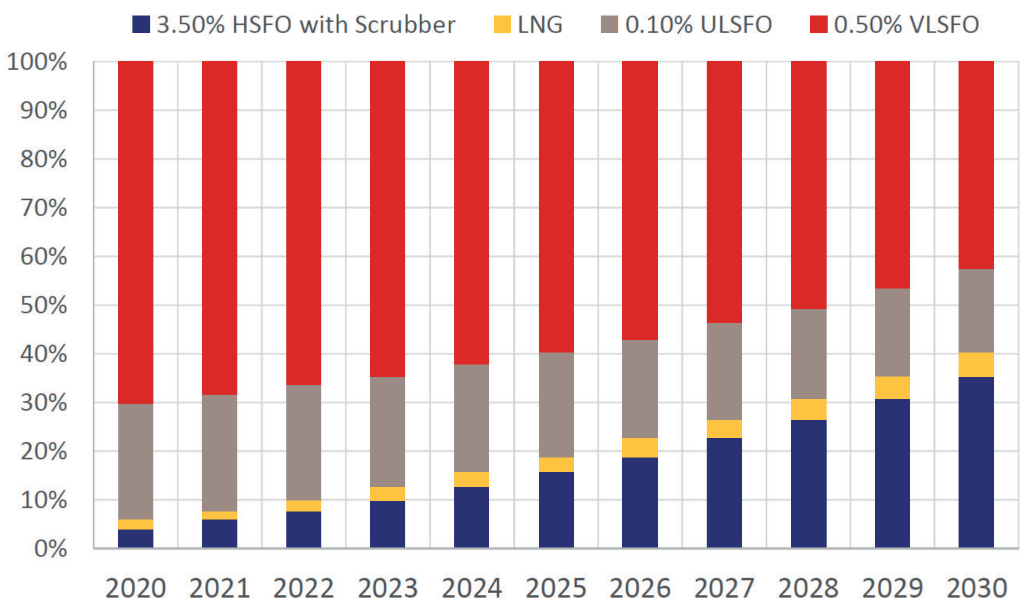


Figure 1. Projected global demand for different fuel types.
This chart shows how the changing international regulations are likely to affect demand for bunker fuels.

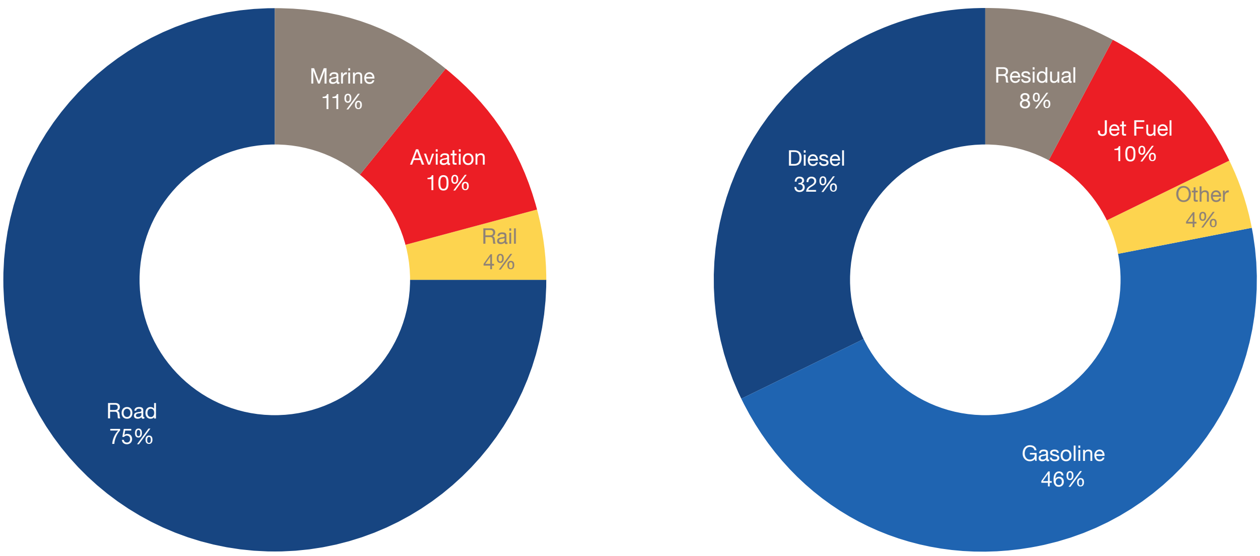


Figure 2. Petroleum consumption by transportation market segment; overall distribution of fuel types.
The marine industry uses 240 million tonnes per year, which corresponds to 11% of the total global demand.

1.1.1 Residual fuel oil

Residual fuel oil, or heavy fuel oil (HFO), is essentially a refinery by-product. It is blended to satisfy market demand for a relatively low-cost source of energy. The main drivers in the refining industry are the production of light and middle distillate grades used to formulate gasoline, jet fuel, automotive diesel fuel, and chemical feedstock.

1.1.2 Distillates and other liquid fuels

The use of distillates has become more common within the shipping industry due to the 0.10% sulphur cap in ECAs that entered into force on January 1, 2015. Typically, ships run on HFO outside ECAs, then switch to distillates as the ships enter ECAs. Low-sulphur fuel oils used in the marine industry are commonly divided into marine gas oil (MGO), which is a pure distillate, and marine diesel oil (MDO), which is a blend containing both distillates and residuals.

1.1.3 Renewable fuels (FAME)

Vegetable oils and fats are sulphur-free and can be converted into fuel suitable for combustion in diesel engines. The oil must be processed to reduce the viscosity and improve the cold-flow properties. The resultant fuels are known as fatty acid methyl ester (FAME) or hydrotreated vegetable oils (HVO). The costs of FAME and HVO are significantly higher than distillates derived from crude oil. Fuel handling is also more challenging since FAME is a nutrient for microorganisms, which can multiply, especially in the presence of free water in or under the fuel. Due to their high costs and limited availability, today's renewable fuels are not commercially attractive alternatives to marine fuels derived from crude oil. However, in the ISO 8217:2017 standard, up to 7% of bio-fuel drop-in is allowed in the fuel blend.

1.2 Refining processes

Crude oils are the typical source of the most common fuels. This section describes some of the basic refining processes that are applicable to the production of residual fuels.

1.2.1 Crude oil

Crude oil is a complex mixture of hydrocarbons recovered from geological pockets through drilling, then processed into various petroleum products. No two crude oils are alike due to significant variations in density, viscosity, sulphur content, vanadium content and other properties, so the end-product can also vary from one refinery to another.

Fractions of crude oil are separated by distillation. In the early days, crude oil was only distilled in an atmospheric distillation process to obtain the required grades at the required quantity. However, vacuum distillation enables further refinement of atmospheric residue. Both atmospheric distillation and vacuum distillation are refinery processes based on the physical separation of crude oil components into fuels.

1.2.2 Atmospheric distillation

The first step in crude oil refinement is the separation of the oil into various fractions by distillation. The process takes advantage of the fact that crude contains a complex mixture of hydrocarbons with different boiling points. The lightest and most volatile hydrocarbons boil off as vapours first, and the heaviest and least volatile last (Figure 3). The non-boiling fraction collects at the base. This crude fraction is known as atmospheric residue and may be used as a blended component of residual fuel oil.

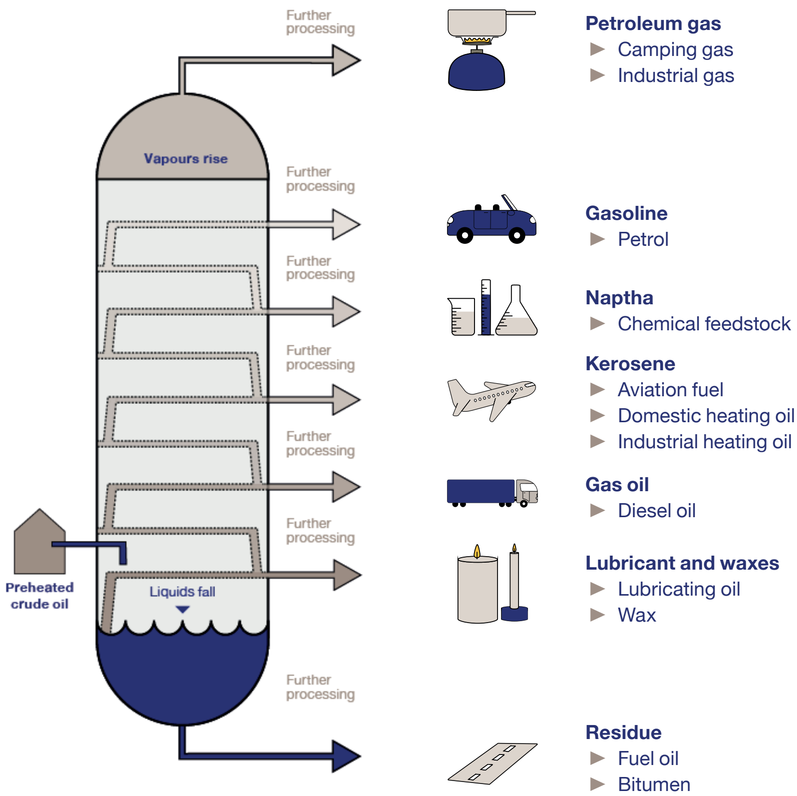


Figure 3. Distilling crude oil into different fractions.
Distillation is carried out as a continuous process in a fractionating tower.

Atmospheric distillation is a relatively simple physical process, where the fuels are separated according to specific boiling ranges. The type of crude determines the percentage of each product that can be obtained. To increase refining margins, many refineries make use of additional refining processes apart from atmospheric distillation. The general aim is to reduce the amount of residue and increase the amount of distillate fuel.

1.2.3 Vacuum distillation

Vacuum distillation is similar to atmospheric distillation but takes place under vacuum conditions. Due to the correlation between pressure and the boiling point of a liquid, a higher portion of light distillate fractions can be drawn off without exceeding temperatures where thermal decomposition takes place.

As in atmospheric distillation, not all the liquid vaporizes. The fraction collected at the bottom of the vacuum distillation tower is referred to as vacuum residue and may be used as a component of marine residual fuels.

These two simple distillation processes alone, however, do not produce sufficient quantities of distillate oil products to meet increasing global demand. Therefore, subsequent and more complex refinery processes, known as secondary conversion processes, are frequently required.

1.2.4 Secondary conversion processes

Secondary conversion processes allow refineries to extract a higher proportion of light distillate fuel from crude oil. As distillation separates fractions of crude oil according to their volatility, these processes alter their chemical structure.

Secondary conversion processes include “cracking” the long hydrocarbon chains of heavy fuel fractions into shorter molecules, which can then be more easily processed into required fuel oil products. There are two basic types of cracking processes: thermal and catalytic.

Thermal cracking

Thermal cracking uses temperature and pressure to provoke a chemical reaction that alters the structure of the oil. Thermal cracking can be carried out on both distillate and residual fuels. Typical thermal cracking processes include: visbreaking, which significantly lowers the viscosity of heavy residue to enable blending with other fuel oils, and coking, which is a severe form of thermal cracking that converts the heaviest low value residue to valuable distillates and coke.

Catalytic cracking

Catalytic cracking also alters the chemical composition of residual fuel oil. Chemical catalysts, rather than high pressure, are used to break down complex hydrocarbons into simpler molecules. Catalysts are substances that stimulate chemical reaction without being changed in the reaction itself; the chemical properties of catalysts remain constant throughout the process.

The most common process is fluid catalytic cracking (FCC), which is used to convert gas oil and residual oil into high-octane gasoline and diesel fuel. Figure 4 shows how the catalysts, in the form of fine particles approximately 20 to 100 µm in diameter, are circulated between a reactor and a regenerator in a fluidized bed process. The catalysts used in this process are generally expensive, and large cracker units typically contain about 500 tonnes of catalyst.

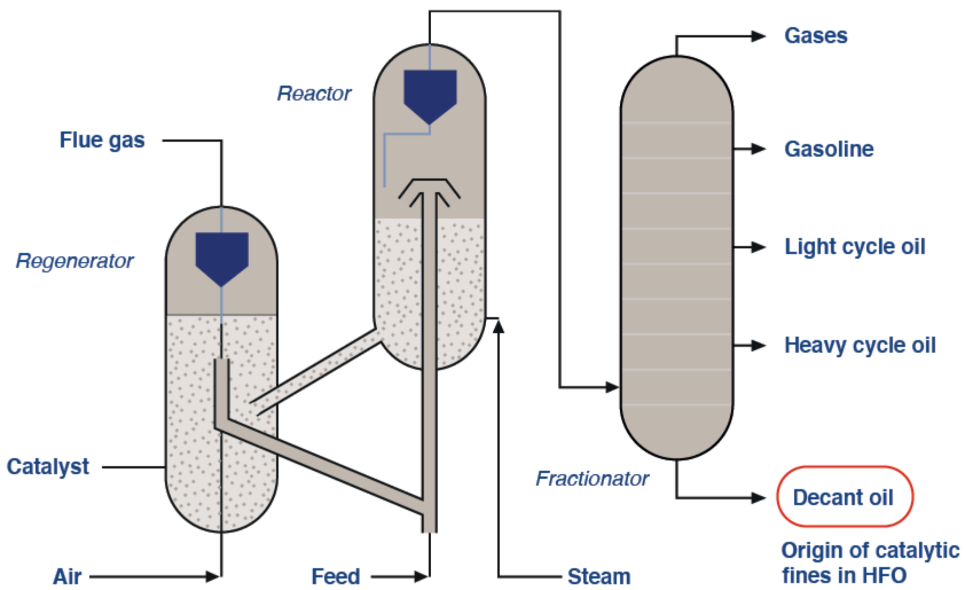


Figure 4. Catalytic cracking process.
Hard chemical catalysts are used to break down complex hydrocarbons.

Hot catalyst from the regenerator mixes with the feedstock and then enters the reactor. Upon contact with the catalyst, the feedstock vaporizes. The vapours in turn react, breaking the chemical bonds to achieve the desired product quality. The reaction causes some carbon to be deposited onto the catalyst particles. Catalysts and vapours are then separated in the reactor where vapours rise and flow into a fractionating tower for further processing. The catalyst flows back into the regenerator where heat is applied to burn off the carbon deposits before the catalyst is returned to the reactor to be mixed anew with the feedstock.

Continuous recycling of the catalyst causes it to break up into smaller particles. Some of these particles are carried over into the fractionator and are commonly referred to as catalytic fines (cat fines). Although refiners attempt to minimize the loss of catalyst from the catalytic cracking process by use of cyclones, carryover of the cat fines is inevitable.

The product drawn off at the bottom of the fractionator is called slurry oil, decant oil or FCC bottoms. It has a high density of about 1,000 kg/m³ at 15°C and a low viscosity of approximately 30 to 60 cSt at 50°C. It is an ideal blending component and cutter stock for residual fuels due to its high aromaticity, conferring stability to the end fuel product. It is through this bottom fraction of catalytic refining that cat fines enter residual marine fuel with the potential to cause severe damage to the engines in which the fuel is combusted.

1.3 Cat fines

Cat fines are very hard particles that typically consist of silicon and aluminium compounds. Their presence in marine residual fuel oils is a consequence of catalytic cracking. Cat fines are undesirable, as they can cause severe abrasive engine wear if not removed by the fuel treatment system (Alfa Laval AB, BP Marine Ltd & MAN B&W Diesel A/S, 2016).

1.3.1 Cat fines units

When discussing cat fines, it is central to distinguish between particle concentration and particle size.

- Particle concentration is described in parts per million (ppm). For cat fines, concentration describes the mass ratio between cat fines and oil, for example, 60 mg/kg = 60 ppm.

- Particle size is measured in μm, referred to as microns, where 1 μm = 1 micron = $1 \cdot 10^{-6}$ m.

1.3.2 Cat fines composition

The composition of cat fines varies depending on the type of feedstock and whether the main unit of the cracker is optimized towards gasoline (light) grade or diesel (heavier) grade production. Catalyst composition is not disclosed by refiners today, but all catalysts contain various forms of synthetic crystalline zeolite. Zeolites are aluminosilicate minerals especially suitable as catalysts because of their microporous material structure and potential to hold high amounts of cations. The zeolite used in FCC catalytic cracking is typically composed of alumina and silica tetrahedral molecules with one aluminium or one silicon atom at the centre, and one oxygen atom in each corner (Figure 5).

About 10–60% of the particle volume consists of the pores (Figure 6), and specific rare metals are added to yield catalytic properties. The pores give the particles a large surface area, which enhances the chemical reaction in the cracking process.

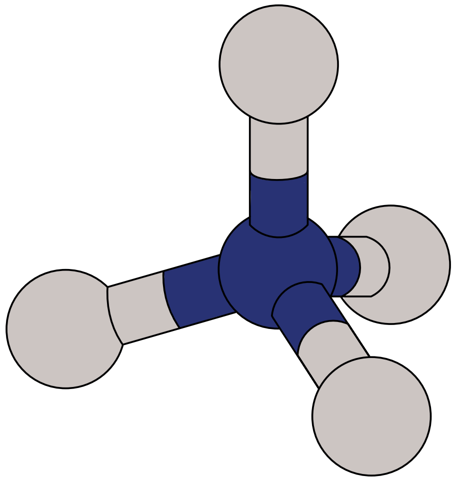


Figure 5. Tetrahedral zeolyte molecular structure.

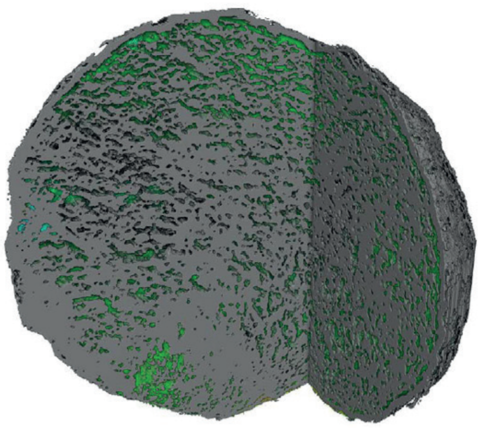


Figure 6. Cross section of a typical cat fine.
Zeolites' microporous structure makes them suitable as catalysts.
(Image © 2016, Springer Nature; Liu, Y., Meirer, F., Krest, C.M., Webb, S., & Weckhuysen, B.M.)

Cat fines are formed through the breakup of the catalyst, mainly due to attrition, as the catalyst is recycled through the cat cracker plant. Cat fines are variable in shape and size, ranging from submicron to approximately 30 μm and occasionally up to 100 μm (Figure 7).

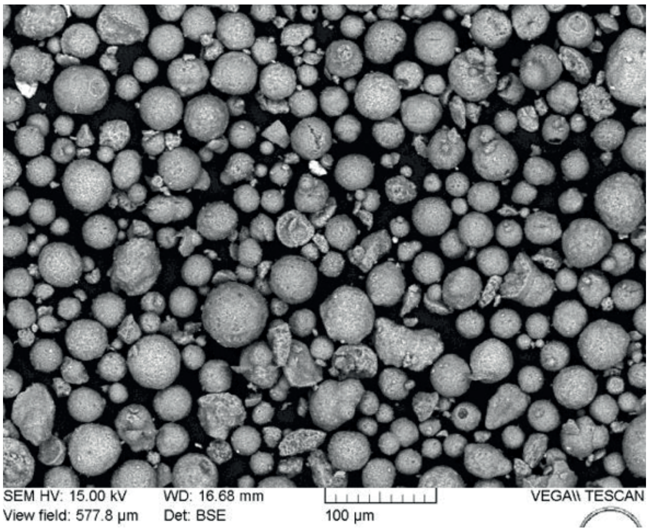


Figure 7. Cat fines magnified.
Cat fine particles vary considerably in size and shape.

Judging from scant literature references, the density of cat fines may vary between 0.9 and 1.3 g/cm³ (compared to a typical HFO density of 0.90–1.01 g/cm³). Similar densities and the fact that zeolite pores are most likely filled with oil after the cracking process implies a reduced margin of success in separation through settling alone.

1.3.3 Cat fines concentration standards

ISO 8217 is the globally accepted standard concerning fuel quality. The most recent version of the standard restricts the concentration of cat fines in fuel oils available on the market to 60 ppm Al+Si (aluminium plus silicon). Marine engine manufacturers currently stipulate 15 ppm as the maximum acceptable levels of cat fines in fuel prior to injection. Therefore, proper onboard fuel cleaning procedures, including separation and filtration, are needed to reduce the level of cat fines present in bunker fuel before entering the engine.

1.3.4 Measuring cat fines content

There are two reasons for determining the cat fines concentration of fuel oil. The first is to check whether the refined oil from a plant fulfils the ISO 8217 fuel standard and thereby has an acceptable level of cat fines upon delivery. The second reason is to provide a continuous update on the quality of fuel used on board and to minimize engine wear.

ISO 10478 is the standardized method of determining the aluminium and silicon content of fuel oils. The method makes use of inductively coupled plasma emission and atomic absorption spectroscopy. It is worth mentioning that this method measures the concentration of cat fines in fuel oil, but it does not give any indication of cat fines size distribution, which is highly relevant in the context of onboard fuel treatment.

Measuring the cat fines content of fuel oil as part of onboard routines is a relatively new concept, but highly relevant considering the recent increase in frequency of cat fines attacks. While the ISO 10478 method is ill-adapted to continuous onboard measurement, one existing method employs the same user-friendly technique used for medical imaging. This method, known as Nuclear Magnetic Resonance (NMR) spectroscopy, exploits the magnetic properties of the cat fines in order to detect them, and is available today.

1.3.5 Cat fines trends in today's heavy fuel oil

Various sources point to a trend of increased concentrations of cat fines in marine heavy fuel oils. Data collected by DNV Petroleum Services (DNVPS) supports this statement. Figure 8 shows cat fines concentrations across different fuel grades. Environmental legislation has led to an increased demand for low-sulphur fuels (Chapter 3). This in turn has motivated refineries to increase blending of heavy fuel oil. As described in the section on Catalytic cracking (page 9), fuel blending is the main source of cat fines.

The first ECAs were introduced in Northern Europe between 2006 and 2007. This primarily had an impact on fuels supplied in the Antwerp-Rotterdam-Amsterdam (ARA) area. Similar trends can be observed when the regulations change and new ECAs come into effect.

Fuels with a high content of cat fines can be found in all residual fuel grades. However, on average, lighter grades have a lower concentration of cat fines compared to higher viscosity grades. Figure 8 presents the average cat fines concentration in different fuel grades. Concentrations of Al+Si of different fuel grades are presented in mg/kg (equivalent to ppm with respect to weight) and are divided into seven residual fuel types. The height of the bars represents how the cat fines concentration varies for different viscosity fuels; the circle represents the average cat fine content. Note that the most common fuel grade, RMG 380 cSt, contains cat fines in the range from 1 to 110 ppm Al+Si, and RMG 700 fuels contained up to 400 ppm Al+Si.

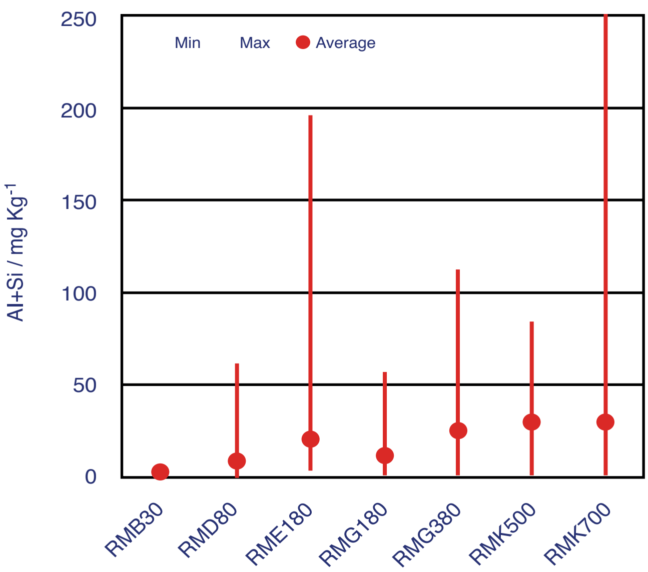


Figure 8. Average cat fines concentration of different fuel grades.
On average, cat fines concentration is higher in higher viscosity fuel grades (VeriFuel, Alfa Laval (2017)).

1.4 Separation basics

Particles are removed from fuel oil in separators as well as in settling tanks based on the principle that particles have a greater density than the oil. In settling tanks, given a sufficient amount of time, all particles will settle to the bottom of the tank. However, if the particles are very small, they will settle very slowly.

The action of a separator increases from 1 g (9.8 m/s^2), as in gravitational settling, to many thousand times this value. Cat fines particles are subject to the same principle when being separated in a disc stack separator as in a tank. The centrifugal force acts upon the particles, moving them to the periphery, whereas the flow of the oil brings the particles towards the centre of the bowl. When the flow reaches a certain rate, the cat fines particles will escape with the oil rather than being separated from it. Here again, the particles do not have time to settle.

1.4.1 Sizing of separators

Correct sizing of the separators is of utmost importance. When specifying the total required flow rate of the fuel cleaning system, the fuel consumption of auxiliary engines and boilers, if any, must be considered. Currently, the appropriate separator is selected using the capacity tables issued by the separator suppliers and engine manufacturers.

Tests for finding specific fuel oil consumption are normally conducted using distillate fuel, and the results may have to be adjusted by a factor for so-called non-ISO conditions.

Calculating settling velocity

The factors determining the settling velocity ($V_{settling}$) of the particles are described by the well-known Stokes equation:

Where:

$$V_{settling} = \frac{d^2 (\rho_p - \rho_l)}{18\mu} \alpha$$

d = Particle diameter
ρp = Particle density
ρl = Liquid density
μ = Liquid viscosity
α = Gravitational or, in a separator, centrifugal acceleration

Oil consumption

To base oil consumption on the maximum continuous rating (MCR) of the engines, the following formula can be used:

Where:

$$Q = \frac{P \cdot b \cdot 24}{\rho \cdot T} \quad (l/h)$$

Q = Fuel oil consumption (l/h)
P = MCR (kW or HP)
b = Specific fuel oil consumption (kg/kWh or kg/HPh), specified by the engine supplier
ρ = Fuel oil density (presumed to be 0.96 kg/l)
T = Daily net operating time (number of operating hours per 24-hour day)

1.4.2 Maximum recommended capacity vs. certified flow rate

There are two models used to compare separators: maximum recommended capacity and certified flow rate.

Maximum recommended capacity

Suppliers of separators determine the maximum recommended capacity (MRC) for each unit according to individual criteria, which are not commonly known and not absolutely comparable.

Certified flow rate

A separator's certified flow rate (CFR) is measured according to the Separation Performance Standard stated in the CE standard CWA15375:2005. Spherical test particles that are five microns in size are added to a fuel-like test oil. The CFR is defined as the flow rate when 85% of the particles are separated from the oil by the separator. Using CFR to specify a separator's capacity ensures the selection of the correct separator size for the performance required and thereby ensures safe engine operation.

1.5 Filtration basics

Filters play an important and complementary role to the separation system. Fuel that has passed through separators goes to the service tank. Then, before being supplied to the engine, the fuel passes through the filters, which are a final protection layer to catch particles that have either passed through the separator or have entered the line further downstream. Filters can also serve as a useful indicator of overall system performance – a pressure drop across the filters can indicate problems such as incorrect separator operation, dirty bunkered fuel, or incompatibility issues (MAN Service Letter SL2017-638/DOJA).

1.5.1 Filtration efficiency

In general, filtration systems fall into two categories – depth filtration and surface filtration. Depth filtration traps pollution permanently within the filter medium, which needs to be replaced frequently. The more commonly used surface filtration traps pollution on the surface of a woven mesh, which is able to be automatically cleaned. The mesh aperture size is expressed microns (µm). Standards for filtration assume spherical particles. However, because real-life particles vary in shape, surface media will remove approximately 100% of particles larger than the given absolute mesh size as well as some particles below this size.

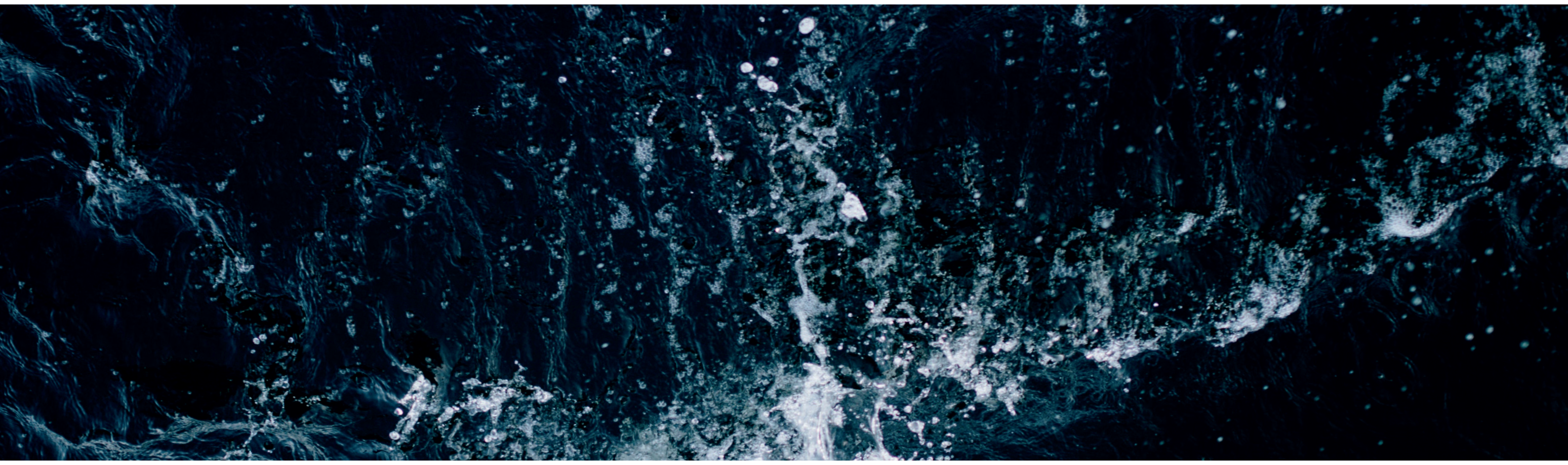
1.5.2 Self-cleaning solutions

Filtration media can be automatically cleaned by either sequential or continuous backflushing. Sequential backflushing filters wait for the filtering medium to reach a pressure drop threshold before backflushing. Many sequential backflushing systems use air to push the fluid backward to clean the filtering mesh.

Continuous backflushing filters, on the other hand, use a small portion of the cleaned oil to continuously remove the pollution before it can accumulate on the filtering screen, ensuring a minimal pressure drop.

1.5.3 Industry recommendations

Industry recommendations have recently evolved in response to dirtier fuels and tighter specifications. It is now recommended to place fine 10 µm filters on the recirculation side of the system where working temperature is high (MAN D&T Service letter SL2017-640/LNW, SL2016-615/JFH, Wärtsilä Technical Bulletin RT-140 29/11/2012, or CIMAC WG7 recommendations for filtering residual oil).



2 Fuel treatment – Engine performance

Marine fuel oil can be categorized into several grades with varying characteristics. Some of the characteristics can be affected by onboard fuel treatment systems, while others cannot. The quality of the fuel specified by international standards is explained in this chapter.

2.1 Fuel treatment today

Marine diesel engines are designed to accept all commercially available fuel oils, provided they are adequately treated on board. For this purpose, a well-designed fuel treatment system is required. Separators, in combination with filters and a settling tank, are generally accepted as the fuel cleaning system within the industry.

2.1.1 Standards and recommendations

Statements from these independent associations, CIMAC (International Council on Combustion Engines) and ISO (International Organization of Standardization), are highly relevant for all stakeholders within the maritime industry. CIMAC is a non-profit collaboration with the aim of promoting the exchange of insights, technology, and advancements among its members. Members include engine manufacturers, research organizations, suppliers, classification societies, and universities.

Concerning onboard fuel cleaning in general (ISO 8217 bunker fuel standard), CIMAC fuel recommendations and Alfa Laval product guidelines converge at three basic, but essential, precautions for the safe and efficient operation of separators:

- Fuel requires preheating to the correct temperature before entering the engine.
- The correct separator capacity/layout must be ensured, that is, that fuel throughput must correspond to the specified flow capacity.
- Proper separator operation and maintenance.

In response to the growing issue of cat fines attacks, both ISO 8217 and CIMAC have specified that the content of cat fines in fuel oil delivered to the ship must not exceed 60 ppm. Engine manufacturers generally require that the maximum cat fines level is further reduced by the fuel treatment system on board to a maximum of 10 ppm prior to fuel injection into the engine. As the level of cat fines in the bunkered fuel is lowered, the engine builders expect a related reduction in the amount of cat fines in the fuel entering the engine.

CIMAC
INTERNATIONAL COUNCIL ON COMBUSTION ENGINES

The International Council on Combustion Engines (CIMAC) is a worldwide non-profit association of national member associations, national member groups, and corporate members in 26 countries in America, Asia, and Europe. It brings together manufacturers of diesel and gas engines and gas turbines, users such as shipowners, utilities, and rail operators and also suppliers, oil companies, classification societies and scientists.

CIMAC Working Groups develop solutions and guidelines for technical, commercial, and regulatory challenges in the large engine industry.

2.1.2 Fuel oil quality and onboard treatment

Fuel oil quality varies, even among fuels nominally classified as the same type. Changing bunker demands bring new fuels to the market. Hence, it is essential to have accurate specifications of the fuel bunkered. It is equally important to interpret the parameters accurately and to know which ones may be affected by onboard treatment. Table 1 lists significant fuel oil parameters together with their main implications on ship operation. The right column indicates to what degree each property may be affected by separation. All parameters in Table 1 are included in the ISO 8217 fuel oil standard.

Water content, sediments, sodium, and cat fines can effectively be reduced by the separation systems on board. Some ash content can also be reduced. It is also important to evaluate the levels of zinc, phosphorus, and calcium in the fuel since this may indicate the presence of lube oil in the fuel.

2.1.3 Fuel cleaning equipment

Figure 9 illustrates a typical fuel treatment system. The main units are the settling tank, separator, service tank, and fuel conditioning module or FCM (also known as a booster system). The fuel treatment system includes equipment that cleans the fuel, including the settling tank, centrifugal separators, and filters.

Settling tank

Heavy and large particle components in fuel oil, such as large cat fines, will accumulate on the bottom of the settling tank due to gravity. However, high seas and rough weather may cause these components to be stirred up and fed to the separators. Since the capacity of the separators is limited, this may influence the purity of the cleaned fuel. Regular draining of the settling and service tanks is, therefore, necessary to reduce this risk.

Fuel property	Implication	Affected by separation
Density	Bunker price and separator adjustment	Not affected
Viscosity	Injection temperature and required heating/cooling	Not affected
Water	Corrosion and deposits in tank	Strongly
Micro carbon residue	Deposits in engine	Not affected
Sulphur	Emissions, lubrication and base number (BN)	Not affected
Sediments	Separator (and filter) load	Strongly
Ash content	Engine wear	Moderately
Vanadium	High temperature corrosion in engine	Not affected
Sodium	Deposits and corrosion in engine from NaCl	Strongly
Aluminium + Silicon	Abrasive wear from cat fines	Strong to moderate
CCAI	Engine ignition quality	Not affected
Pour point	Filter clogging	Not affected
Flash point	SOLAS and classification societies rules generally require temperatures at a minimum of 60°C	Not affected

Table 1. Important fuel oil parameters.

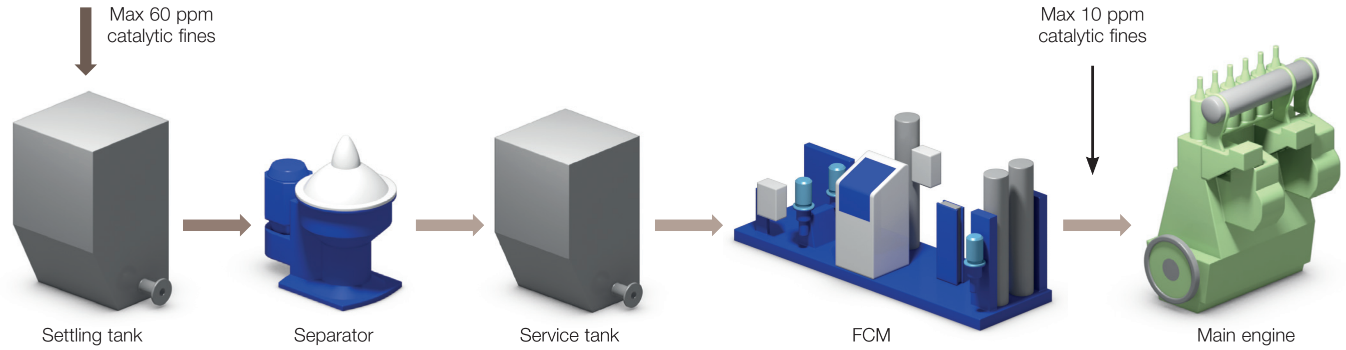


Figure 9. Typical fuel treatment system.
The maximum cat fines content of bunkered fuel must not exceed 60 ppm, according to ISO 8217/2012. Engine manufacturers recommend a maximum level of 10 ppm cat fines in fuel prior to injection into the engine.

Separators
If properly operated, most separators are capable of removing nearly 100% of cat fines larger than 10 µm in size. Most cat fines smaller than 3 µm, however, will not be removed by separators when operating at the maximum recommended flow rate. To check the efficiency of the separators, it is recommended that samples are taken from the separator feed and outlet at least every four months and sent to an established third-party institution for analysis.

Filters
Filters are installed as a final protective measure to prevent remaining particles from entering the fuel system. Formerly, fuel systems included coarse filters on the supply line (cold side). While that is a cheaper option initially, it is now recommended to use fine – minimum 10µm – automatic backflushing filters on the recirculation (hot) side. Particles with low densities may pass through the separator yet still be trapped by the filters. Monitoring the pressure drop across the filter also provides information about the total system performance.

2.2 Cat fines and engine performance

Cat fines particles vary in size from submicron to tenths of µm – from the size of a speck of dust or pollen to the width of coarse human hair. Though virtually invisible to the human eye, cat fines are very hard and capable of severely scratching metal (Alfa Laval, BP Marine, MAN B&W Diesel, 2007).

Rust, sand and dust are sometimes found in fuel but most often are removed from the fuel by the separators before entering the engine. Such components are also normally less harmful than cat fines and found in much smaller quantities.

All cat fines that remain in fuel oil after centrifugal separation have the potential to cause abrasive wear and damage to the engine, which in turn can lead to inefficient and potentially unsafe operating conditions (Figure 10). That is why cat fines levels must be reduced as much as feasibly possible by the fuel treatment system.

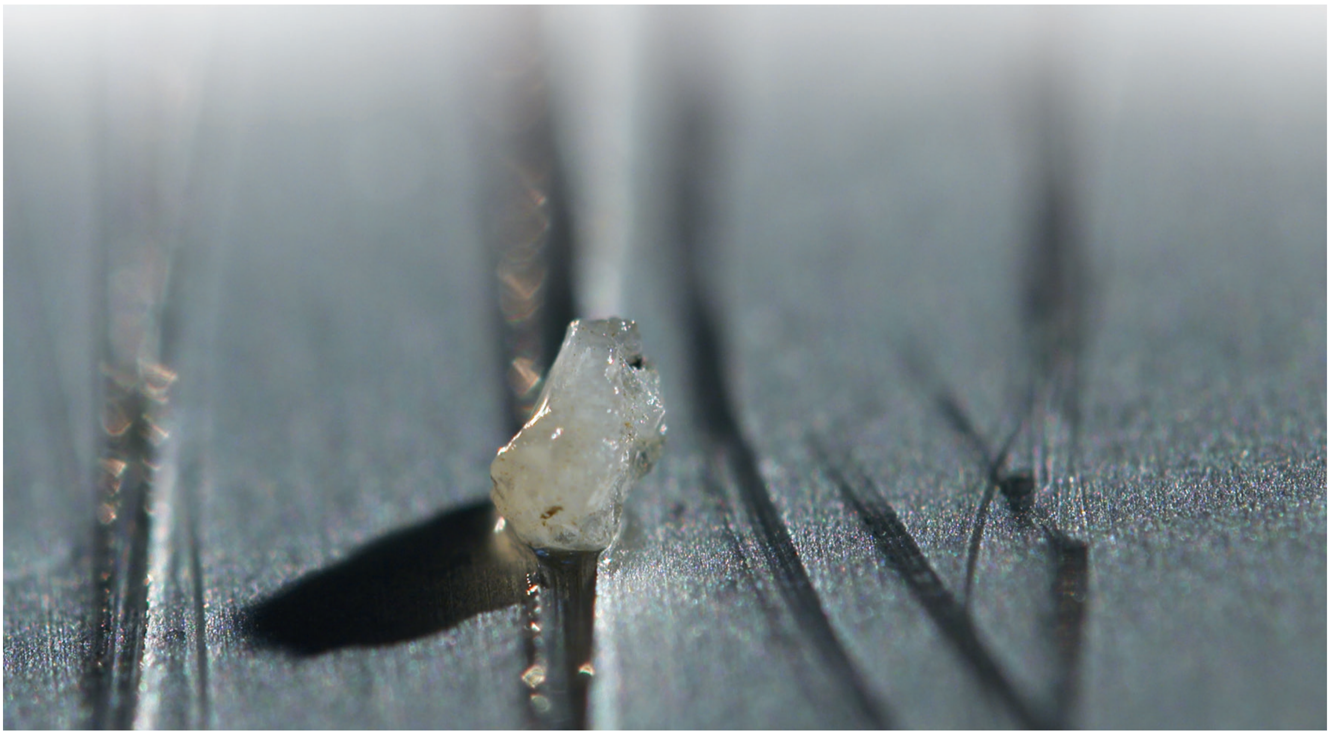


Figure 10. Magnified view of cat fine damage.
Cat fines are very hard particles, capable of scratching and cutting metal.

Engine builders claim that cat fines smaller than 4 µm are considered to be less harmful than larger cat fines (CIMAC, Paper No. 51, 2013). However, the higher the concentration of cat fines, the greater the risk of unsafe operating conditions. Engines affected by high cat fines levels will likely require more frequent maintenance and face an increased risk of breakdown.

The fuel injection system and the combustion chamber are two units of the fuel treatment system that are most susceptible to wear from cat fines. The fuel injection pumps increase the pressure of the fuel before it enters the engine. The small tolerances between the plunger and barrel can lead to particles getting trapped between the surfaces and embedded in the material. The same problem occurs in the combustion chamber, where the cat fines may become embedded between the piston ring and cylinder liner.

The relative movement between the surfaces leads to abrasive and accelerated wear of the components.

If the pumps are damaged, they will deliver subpar performance and lower fuel pressure to the engine. This, in turn, will reduce the engine efficiency and increase the operational costs. Engine wear and subsequent damage is expensive and should be avoided.

2.3 Distillate-specific concerns

The ISO 8217 standard regarding maximum sulphur content in fuels used on board ships has focused on the use of low-sulphur distillates in engines designed for use with residual fuel oil. The low viscosity of these distillates has led engine manufacturers to restate their criteria regarding minimum viscosity and lubricity. The use of low viscosity distillates will increase when the global 0.50% sulphur cap takes effect in 2020.

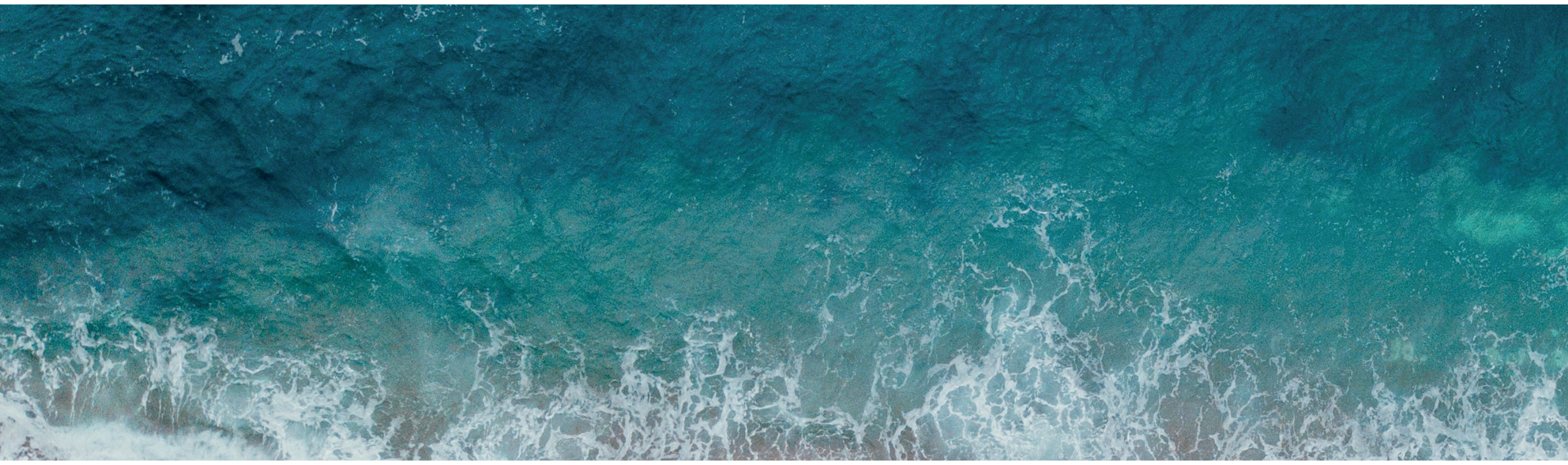
Influence on diesel engines
The burning of distillates in diesel engines has some critical aspects that can affect engine injection systems, pumps, and other equipment. Fuel viscosity at injection, which affects the lubrication capacity of fuel injection components, is the first issue with which to deal. Since the injection temperature of light fuel is much lower than that of HFO, a second issue arises from the temperature gradient: a sudden temperature change can cause thermal shocks within the injection system.

To address these issues and to maintain the correct fuel parameters at the injection point, it is essential that the fuel conditioning unit is suitable both for managing fuel changeovers in a simple and safe way by controlling temperature ramp inside the system and for maintaining the correct temperature of light fuel at the time of injection.

Demands on the fuel conditioning system
To meet engine manufacturer's requirements, the fuel conditioning system must be able to:

- Control the transition from the high injection temperature of HFO to the low injection temperature of distillate fuels so that the temperature gradient remains within the engine manufacturer's recommended limit. A typical rate of temperature change at the fuel inlet to the fuel pumps is 2°C per minute.

- Keep the distillate fuel oil temperature and its viscosity within the engine manufacturer's recommended limits.



3 Legislative impact on ship operation

The establishment of Emission Control Areas (ECAs) together with increasingly stringent global emission regulations has led to new operational requirements for fuel use. Here we examine the main sources of regulatory change and the operational implications of those changes for owners and operators.

3.1 The importance of sulphur restrictions

The main driver for reducing sulphur content in exhaust gas is the negative impact that sulphur oxides have on human health. Sulphur in the exhaust reacts with the air and forms small particles known as sulphate aerosols. When breathed in, these particles can pass through the lungs and enter the bloodstream, where they can trigger lung inflammation and cause cardiovascular disease as well as lung and heart failure (Platts, 2016). Atmospheric sulphur also contributes to water and soil acidification.

3.2 IMO MARPOL Annex VI

The MARPOL Annex VI legislation regarding sulphur emissions can be summarized into two regulations.

• Regulation 14 covers sulphur oxides and particulate matter. It should be noted that this regulation applies to the fuel used not only by new vessels but also by all vessels in operation after the introduction date. The regulation defines the sulphur content of the fuel, where compliance is to be achieved based on the fuel as loaded. There are different sulphur limits applicable inside and outside of ECAs, which are areas where the IMO has agreed that a higher level of protection is required.

• Regulation 4 covers equivalents, by which a vessel is fitted with an apparatus (i.e., an exhaust gas cleaning system) or the ship owner uses other strategies to ensure that the compliance method is at least as effective in terms of emissions reductions as those defined in Regulation 14.

Figure 11 shows current ECAs (2016), where there is more stringent control of emissions of sulphur oxides and nitrogen oxides, as well as areas that may be considered as ECAs in the future. The emissions limits have gradually been reduced, both inside and outside the ECAs (Figure 12). In 2020, a global sulphur cap of 0.50% will take effect.

3.3 European Union regulations

To implement the IMO MARPOL Annex VI regulations in EU legislation, the European Union originally developed Directive 1999/32/EC, which was subsequently amended by Directive 2005/33/EU. However, this legislation also contained certain additional requirements. Notable additions are (with all limits expressed in mass percentage):

• In EU territorial seas, exclusive economic zones and pollution control zones (excluding ECAs), the content of sulphur in fuel is limited to a maximum of 1.50% for passenger ships, including ferries and cruise vessels on scheduled services, arriving at or departing from any EU port.

• From January 1, 2010, ships at berth in an EU port must use fuel with a maximum sulphur content of 0.10%, except for ships that, according to published timetables, are due to be at berth for less than two hours.

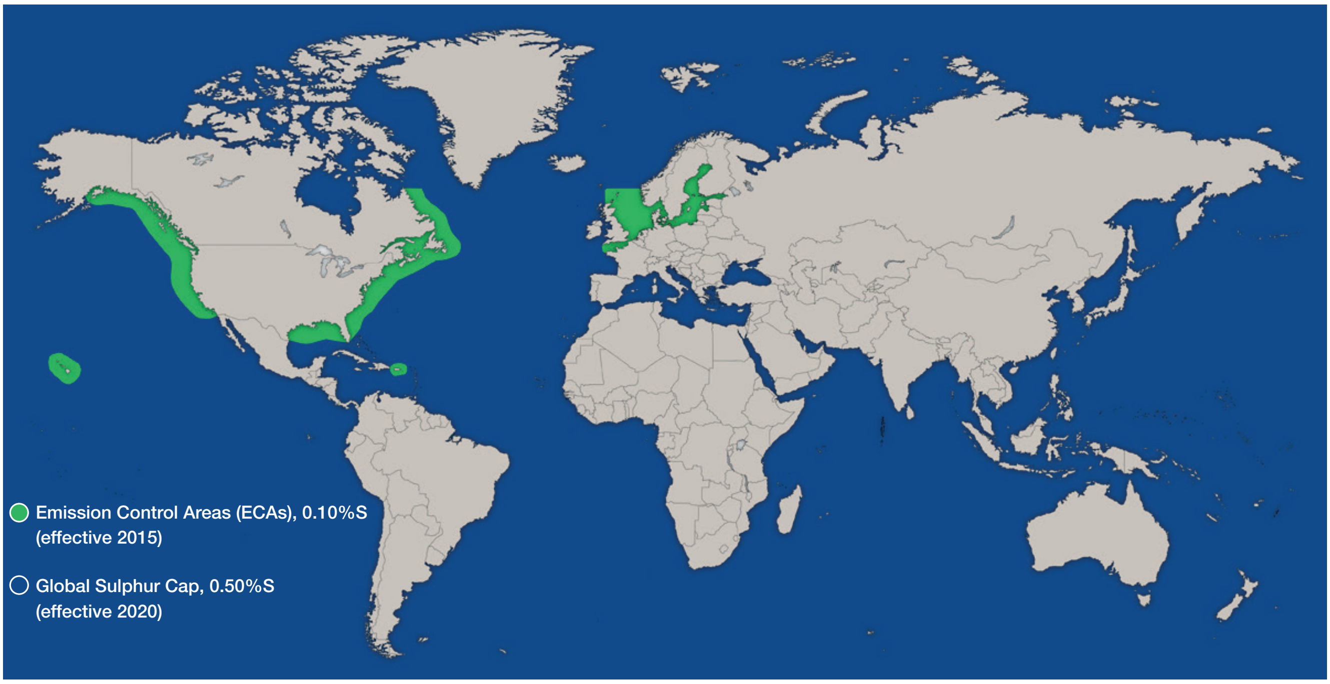


Figure 11. 2016 Emission Control Areas (ECAs).
Source: DNV.

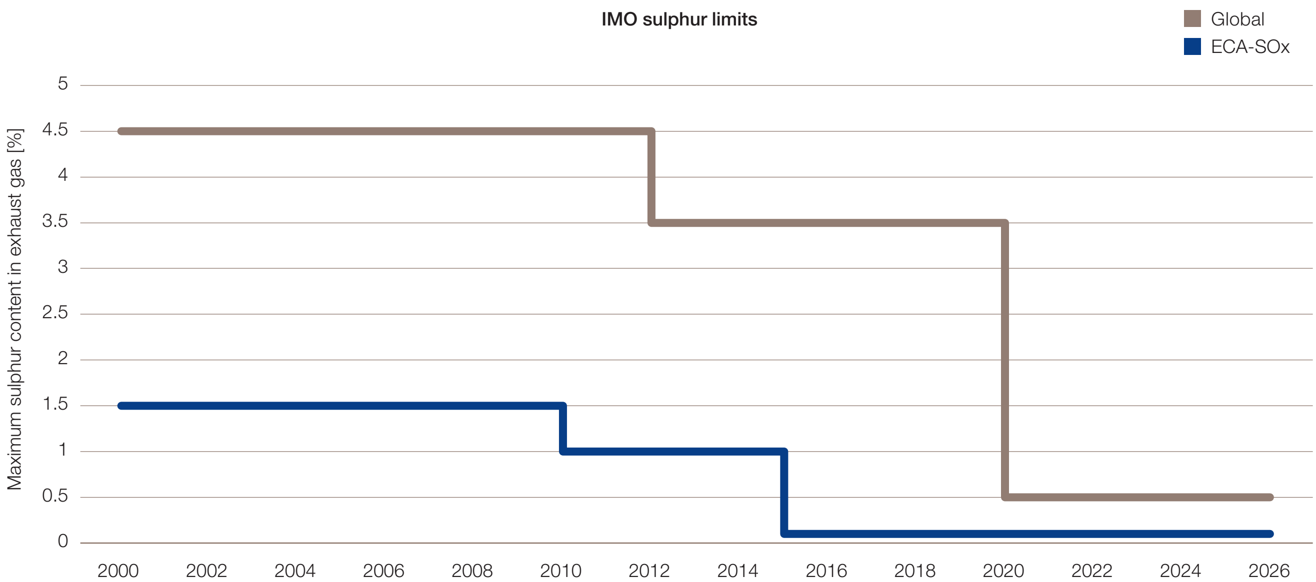


Figure 12. The reduction timetable for sulphur emissions.
Since 2015, the sulphur limit in ECA zones has been 0.10%. In 2020, the global limit will be lowered to 0.50%.

The European Parliament Directive 2009/30/EC limited the sulphur content of fuels used by inland waterway vessels to a maximum of 0.0010% (10 mg/kg) from January 1, 2011. The 2012/33/EU review of the EU legislation incorporates the latest MARPOL Annex VI regulations and contains the following additional stipulation:

- Fuel with more than 3.50% sulphur content will only be allowed for sale and use by ships equipped with an approved closed-loop exhaust gas cleaning system (i.e., one with no discharge of wash water overboard).

3.4 California sulphur regulations

The California Air Resources Board (ARB) has defined a region, extending up to 24 nautical miles from the California shoreline or from the shoreline of the Channel Islands off the southern California coastline, in which only the use of distillate fuels of grade-specific maximum sulphur contents is permitted. As of January 1, 2014, the maximum sulphur content limit is 0.10%.

There is an ongoing sunset review by ARB, which will lead to a decision on whether to allow the use of ULSFO) blends and the use of scrubbers. These sulphur-reducing fuels and techniques are allowed in the other ECA areas, and the review will evaluate if they achieve the same results on emissions as the current California ocean-going vessel fuel regulations. The evaluation is planned to be continue until 2018 (still pending at time of this publication).

3.5 Changeover between residual and distillate fuels

Since most ships are still running on HFO (a high sulphur fuel), many vessels will switch fuel when entering or leaving an ECA, unless an approved equivalent (e.g., abatement technology) is employed to achieve compliance. From 2015 onwards, before entering an ECA, a vessel must change over from residual fuel with a maximum sulphur content of 3.50% to distillate fuel with a maximum sulphur content of 0.10%. Conversely, after exiting an ECA, it generally is desirable to change back to residual fuel from distillate to reduce fuel costs, unless a return into the ECA is imminent. The requirements dictate that changeover must take place during sailing, while approaching or leaving the ECA boundary.

Most operators have experience of changing over between residual and distillate fuels and vice versa. Automatic fuel changeover systems are available; however, the process can be carried out manually. It is mandatory for detailed procedures to be put in place and duly documented on board, and for the crew to be familiar with the operation. Insufficient knowledge of the required actions may result in component damageor engine shutdown. For detailed advice on changeover procedures, the specific equipment manufacturer's recommendations should always be consulted.

3.5.1 General considerations

To avoid compounding compatibility problems (such as asphaltenes precipitating in the tanks, reduced viscosity of HFO when diluted by MGO, or high sulphur fuel contamination of the MGO), it is recommended not to return residue and distillate mixtures back to the distillate or MDO service tank.

To control the MGO temperature, installing dedicated coolers is strongly recommended. This will also limit the use of MGO and the associated costs.

When a two-stroke engine is to be operated with low-sulphur fuel for a prolonged period, many engine manufacturers recommend that the cylinder oil be switched from a high-BN type to one with 40BN or a lower value. Cylinder oil feed rates should also be taken into consideration, and engine manufacturer recommendations must be followed. The operation of two-stroke engines on high-BN cylinder oil at high feed rates while using low-sulphur distillate fuel can lead to rapid accumulation of piston crown deposits, which result in severe scuffing.

There are also several technical considerations and challenges associated with fuel changeover. These include:

- Temperature gradient
- Changes in viscosity
- Incompatibility
- Lubricity
- Cold flow properties
- Filtration
- Consumption monitoring

3.5.2 Temperature gradient

To ensure fuel injection equipment keeps functioning properly, it is recommended that a maximum fuel changeover temperature gradient should not be exceeded. Generally, engine manufacturers recommend a gradient of no more than 2°C per minute. Rapid changes in fuel temperature will increase the likelihood of pump malfunction and seizures. For the reasons stated above, it is preferable to use an automatic fuel changeover system capable of maintaining a correct temperature gradient across the complete changeover process. Automating this process also helps minimize the crew's workload and the risk of operational mistakes that can lead to contamination of the MGO fuel tank with HFO.

3.5.3 Changes in viscosity

Typically, the optimum operational viscosity of a fuel at the engine fuel pump is within the range of 10–20 mm^2/s (cSt), though it is vital to ensure that the requirements for each engine are met.

To achieve optimum viscosity with residual fuels, it may be necessary to heat them to more than 100°C. However, distillate fuels have significantly lower viscosities than residual fuels, typically in the range of 2.0 to 11.0 mm^2/s (cSt) at 40°C and, as such, must not be heated and may instead have to be cooled or chilled.

Engine makers recommend a minimum fuel viscosity at the engine fuel pump inlet of 2.0 to 3.0 mm^2/s (cSt). Fuel with a viscosity that is too low may lead to excessive leakage within the engine fuel pumps and consequent reduction of the fuel pressure. This, in turn, can lead to startup difficulties and problems when operating at high load. Insufficient viscosity may also lead to fuel pump seizure and premature wear due to a reduced hydrodynamic lubricating oil film. In addition to engine-mounted pumps, the operation of pumps in the fuel handling system should also be taken into consideration. The minimum viscosity for them is also close to 2 cSt, with lower viscosity carrying the risk of excessive wear or seizure.

To achieve the equipment manufacturer's minimum requirements, distillate fuels should be sourced with sufficient viscosity. Fuel coolers or chillers can be used, if necessary, to help prevent the viscosity of the fuel from becoming too low. Additionally, switching off the pipework steam and trace heating systems early will assist in reducing the fuel temperature when the changeover is made.

Conversely, when changing back to residual fuel from distillate, it is critical to ensure that the temperature of the fuel is sufficiently high to achieve the required viscosity at the fuel pump inlet. Trace and steam heating in the pipework can be switched on to assist this process, but heating of the distillate must be avoided.

3.5.4 Incompatibility

As described above, the changeover procedure requires sufficient time, during which there will be a mixture of the two very different types of fuels. The risk of incompatibility between residual fuel and low-sulphur distillates is considered higher than what is typically associated with mixing different types of residual fuel. Introducing distillate may cause the asphaltenes in the residual fuel to precipitate as heavy sludge (Figure 13). This may result in filter clogging and, in extreme cases, may cause fuel starvation in the engine and subsequent engine shutdown. Another associated issue may be sticking of the injection pump due to deposits between the plunger and the barrel.

Figure 13. A separator subjected to instable fuel.

Incompatibility of fuels can't be reliably predicted, nor is it influenced by the conditioning process, therefore compatibility testing is essential. The tests may be carried out either on board during bunkering or via an independent laboratory.

3.5.5 Lubricity

Lubricity is the ability of the distillate to lubricate between surfaces, which are not in motion relative each other, or so-called boundary lubrication. Distillates with sulphur content less than 0.05% can exhibit lubricity that is too low. The result may be seizure of the fuel pump. To keep the MGO viscosity and lubricity at acceptable levels in all conditions, coolers must be installed. The coolers should be automatically controlled to maintain proper temperature set points.

3.5.6 Cold flow properties

Distillates are indeed characterized by their low viscosity. However, they can differ in chemical nature and have large variations in cold flow properties, for example, viscosity at low temperatures can impact their abilities to be pumped.

Cold flow properties are measured as:

- Pour point: The lowest temperature at which the fuel will flow.

- Cloud point: The temperature at which dissolved particles precipitate and give the fuel a cloudy appearance.

- Cold filter plugging point: The lowest temperature at which the fuel will pass through a filter under specified conditions.

The cold filter properties of a distillate are mainly dependent upon the wax content and the ability of long paraffinic hydrocarbon chains to precipitate as wax crystals.

Ships operating in cold areas should demand distillates with winter quality specifications to avoid wax precipitation in fuel storage tanks. Heating the distillate before separation to avoid the precipitation of any waxes in the treatment system is also recommended.

3.5.7 Filtration

Filters are also affected by the flushing effect of diesel oil at changeover, as accumulated pollution inside the piping is forced to the filter.

3.5.8 Consumption monitoring

Frequent fuel changeovers make measuring the consumptions of HFO and MGO more critical. Installing dedicated flow meters for the alternative fuels improves measurement accuracy. Mass flowmeters are preferable to the volumetric type, since they allow the direct measurement in weight units, unaffected by density changes.

3.6 Using scrubbers instead of changing fuels

A scrubber is an exhaust gas cleaning system that reduces sulphur oxide emissions. Using a scrubber (Figure 14) enables the ship owner to use high-sulphur HFO within ECAs instead of low-sulphur MGO, while still complying with IMO sulphur emissions regulations. This method is approved by IMO legislation

Figure 14. The Alfa Laval PureSOx system.
Scrubbers installed in the exhaust line reduce the levels of sulphur oxides emitted.

By the time the global 0.50% sulphur cap takes effect in 2020, the use of scrubbers may be an attractive alternative for ship owners who want to continue to use less expensive HFO yet still comply with the legislation. According to DNV GL (2016), an initial investment in scrubbers will pay for itself within one to six years, depending on the ship type and trade.

4 Fuel oil treatment – The modern approach

The requirements for handling fuel on board are completely different today than a decade ago. Single-fuel operation has been replaced by multi-fuel operation and stricter regulations have been implemented to govern sulphur emissions. As we discuss in this chapter, many aspects of today's fuel treatment systems must be adapted and optimized to current and future conditions.

4.1 The Alfa Laval Adaptive Fuel Line

The modern approach to fuel treatment systems is especially focused on:

- Energy efficiency
- Fuel quality
- Environmental compliance
- Engine protection

Five different areas have been identified where it is possible to optimize fuel treatment:

- Optimization of the fuel system layout
- Equipment and feed optimization
- System monitoring and automation
- Multi-fuel management
- Waste fuel recovery

The Alfa Laval Adaptive Fuel Line is a complete solution for minimizing energy consumption and maximizing protection against cat fines. It is not a single product, but rather a comprehensive and systematic approach based on several key products and Alfa Laval knowledge. It uses slow steaming synergies and ground-breaking technologies to increase both the total energy efficiency and total separation efficiency.

The following is a brief overview of the Adaptive Fuel Line. The different targets, solutions, and outcomes are summarized for each part of the fuel treatment process.

4.1.1 Optimization of fuel system layout

When uni-fuel fuel treatment systems are replaced by multi-fuel systems, special considerations are needed to ensure safe and compliant operation. In particular, multi-fuel systems must be designed and operated to mimimize the risks of fuel incompatibility. See Table 2.

Solution	Outcome	Reference
Modern multi-fuel system layout	• Fuel oils of different types kept and handled separately • Reduced risks	page 26-27

Table 2. Optimization of fuel system layout.

4.1.2 Equipment and feed optimization

Using equipment with the latest technology is essential in meeting requirements. Equipment with outdated technology often consumes more energy while delivering the same performance; furthermore, the separation efficiency of older technology is generally poorer, and the process control is not sufficiently accurate. One aspect, in particular, relates to optimizing the fuel feed to align with the actual engine load. This, in turn, increases separation efficiency and decreases energy consumption. See Table 3.

Solution	Outcome	Reference
Alcap™ technology in high-speed separators	• Measures the water content at the oil outlet • Provides flexibility • Cleans fuel with varying density	page 28
FCM One	• Conditions fuels to match engine specifications exactly • Can produce fuel blends • Manages the changeover between different fuels	page 32
FlowSync™ using VFD control to adjust pump flow to actual engine load	• Reduces energy consumption by the pump, heater and separator • Provides more efficient separation and better particle removal due to the fact that the fuel remains in the separator for a longer period of time	page 29
High-temperature separation	• Reduces thermal losses • Effectively uses thermal energy • Maintains cleaning efficiency • Retains throughput capacity	page 30

Table 3. Equipment and feed optimization.

4.1.3 System monitoring and automation

A properly designed system for monitoring the fuel treatment plant can prevent unwanted effects and provide valuable information for reliable operation. See Table 4.

Solution	Outcome	Reference
FCM One fuel consumption monitoring	• Accurately measures fuel use • Provides data for optimization of fuel treatment system • Detects fuel losses at an early stage	page 32-33
10 µm filter on hot side	• Reduce wear • Maintain condition of flow supplied to engine • Monitor system performance	page 34

Table 4. System monitoring and automation.

4.1.4 Multi-fuel management

Multi-fuel management enables precise control of fuel blending and changeover as well as recording data related to fuel blending and changeover. This ensures safe engine operation and prevents non-compliance. See Table 5.

Solution	Outcome	Reference
ACS: Changeover	• Lowers consumption of distillate • Optimizes fuel composition • Ensures safe changeover • Exactly matches sulphur targets	page 30
FCM One: Electronic fuel record book	• Records changeovers • Automatically provides time stamp and GPS data • Documents activity via printout or secure digital export	page 32-33

Table 5. Multi-fuel management

4.1.5 Waste fuel recovery

Recovery of fuel oil from waste fuel oil contributes to substantial savings in the total cost of fuel as well as waste oil and solids handling. Up to 1% of a vessel's bunker consumption, normally lost, is recovered for use as reusable fuel. See Table 6.

Solution	Outcome	Reference
PureDry	• Recovers lost fuel as reusable fuel • Reduces amount of waste to handle, store and deposit by 98%	page 30

Table 6. Waste fuel recovery

4.2 Operating parameters

Various operating parameters affect separation efficiency. These include flow rate and temperature, which control both fuel viscosity and density.

Continuous flow control is a simple and effective way of ensuring optimized separation performance. Because ships do not always operate at their MCR and design speed, there is an opportunity to reduce flow rates and improve separation efficiency. It is recommended that operators use the entire installed separator capacity and run standby separators in parallel. Manual flow control is sometimes installed and should be used.

4.2.1 Slow steaming contributes to better separation

Slow steaming refers to the practice of operating transoceanic cargo ships, especially container ships, significantly below their maximum speed. Normally, a fuel oil separator has a layout for 100% engine fuel consumption plus constant values for different margins. However, ships today rarely operate their engines at 100% load. Decreasing the flow through the separator in relation to the engine fuel consumption will result in higher separator efficiency, because the fuel will remain in the separator longer. Therefore, there is a great potential to increase separation efficiency by applying automatic flow control in response to the actual fuel consumption.

4.2.2 Separator flow control

Controlling the flow through the separator is essential for the separation result. To maintain the highest possible separation efficiency, the flow through the separator should be kept low and as stable as possible. The flow speed can be controlled in two ways:

• *Fixed flow control*

In fixed flow control, a flow-regulating valve is installed before the separator. When it is throttled and the pressure exceeds a value determined by a spring-loaded valve, the valve opens and oil is sent back to the settling tank. This solution is simple, but not the most energy efficient since some of the oil is pumped back to the settling tank.

• *Variable flow*

A variable frequency drive (VFD) can be used to control the speed of the feed pump motor, enabling the feed rate to be adjusted to match the actual engine load. Unlike a fixed flow control that throttles the flow, the use of variable flow reduces energy use of both the feed pump and the separator. Using variable flow for an engine operating at 75% MCR reduces the flow, thereby increasing separation efficiency (Figure 15).

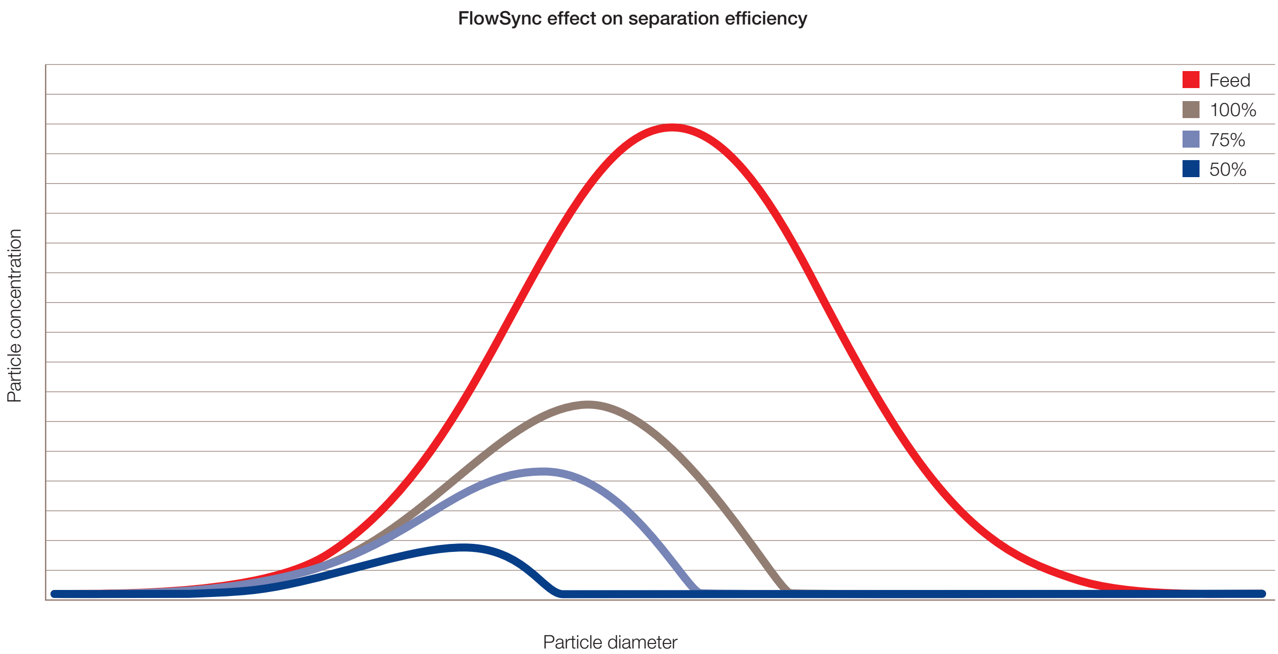


Figure 15. Effect of flow rate on separation efficiency.
Separation efficiency, illustrated by particle concentration after separation, when flow is reduced from 100% to 75% and 50% of maximum recommended capacity. The red curve represents the particle concentration at the separator inlet.

4.2.3 Temperature

Another parameter that can be altered to improve separation efficiency is oil viscosity. As the temperature of the oil increases, the viscosity of the oil decreases. If the temperature drops to 90°C, then the flow must be reduced to 72% of the nominal flow to maintain separation efficiency at the same level that can be achieved at 98˚C. At 85°C, the flow needs to be cut to 50%. Figure 16 illustrates what happens to the separation efficiency if the temperature is reduced while the flow rate is kept intact. It may seem natural to consider the separation efficiency of fuels at temperatures higher than 98°C due to the potential to improve efficiency by increasing separation temperatures. However, the present limit of 98°C is in place because of important safety reasons. It should also be mentioned that today's onboard separators are designed as open atmospheric systems. Provided that safety issues can be managed, however, a separation temperature of 115°C would translate into a flow improvement of 80% over current levels while maintaining performance. In other words, maintaining the flow at an increased temperature will improve separation efficiency.

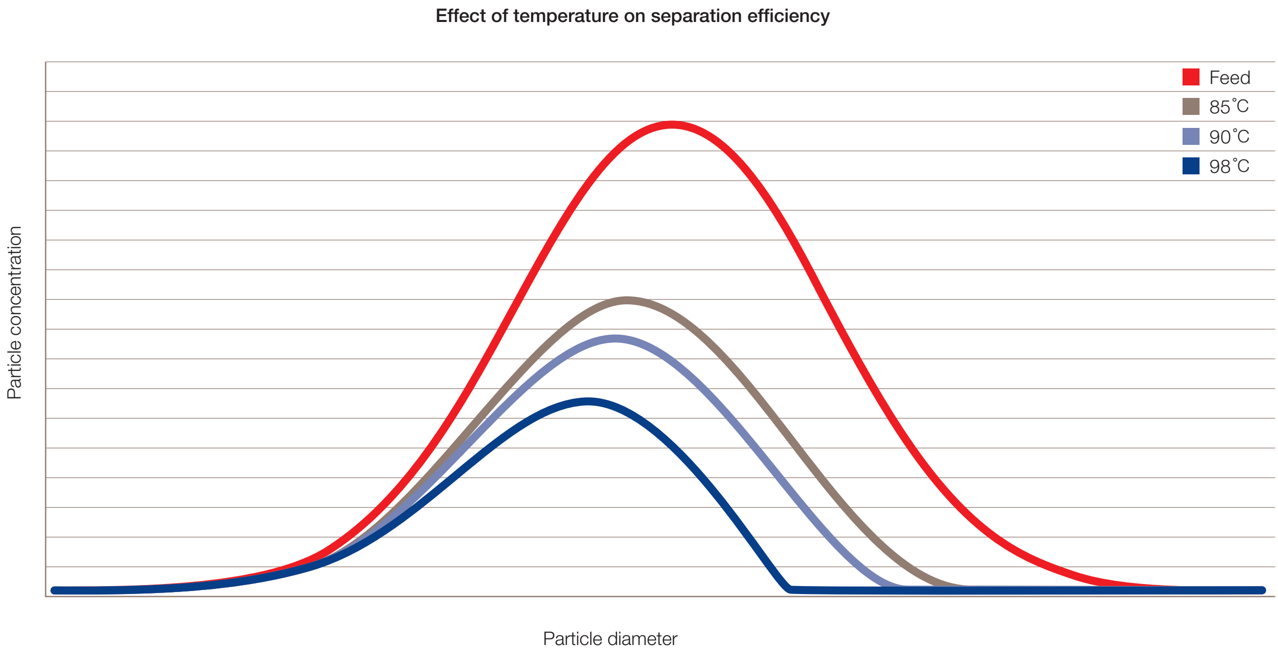


Figure 16. Effect of temperature on separation efficiency.
The red curve shows the particle concentration in the feed, while the other curves indicate the particle concentration at the separator outlet at separation temperatures of 85 ˚C, 90 ˚C and 98 ˚C.

4.3 Fuel system design

For more than 25 years, the shipping industry adapted onboard systems to run on heavy fuel oil. Extra effort has been put into enabling auxiliary engines to run on HFO. This reduced costs as well as simplified the fuel system set-up. Environmental regulation puts extra demand on fuel system design and set-up when ships are no longer able to run on HFO in ECAs. With the introduction of the global 0.50% sulphur cap in 2020, the use of MDO and other blends of distillates and residuals is expected to increase. However, pure distillates, such as MGO, will still be used in the ECA areas.

4.3.1 Uni-fuel system

The use of two separators is recommended for a fuel treatment system of a ship running on a single fuel type (Figure 17). One of the separators is usually sufficient to supply the service tank when running at full steam; the other separator usually remains in stand-by mode. This simple, straightforward system is suitable for ships using only one fuel for very long periods, thus seldom needing to operate a fuel changeover.

4.3.2 Multi-fuel systems

The systems for HFO, ULSFO, and distillates should remain separate and distinct to reduce any risk of contamination among the fuels that could lead to compatibility problems and affect the fuels' compliance with ECA rules. In fact, if the sulphur content in the fuel used in the ECA is very close to the sulphur content limit, even small amounts of HFO can result in non-compliance. Segregating the fuels throughout the entire fuel line is necessary to avoid both these problems.

Moreover, a complete duplication of the fuel line (Figure 18) provides further advantages to the ship operator in terms of reduced operational costs and increased flexibility. Separate service tanks allow the fuel changeover to be operated further downstream, resulting in a much faster procedure and reduced use of costly light fuel. Furthermore, separate booster systems for the main and auxiliary engines allow the crew to operate the engines independently with the required fuel. Additional piping also provides more flexibility to the crew, making it possible to operate the auxiliary engines with different fuels.

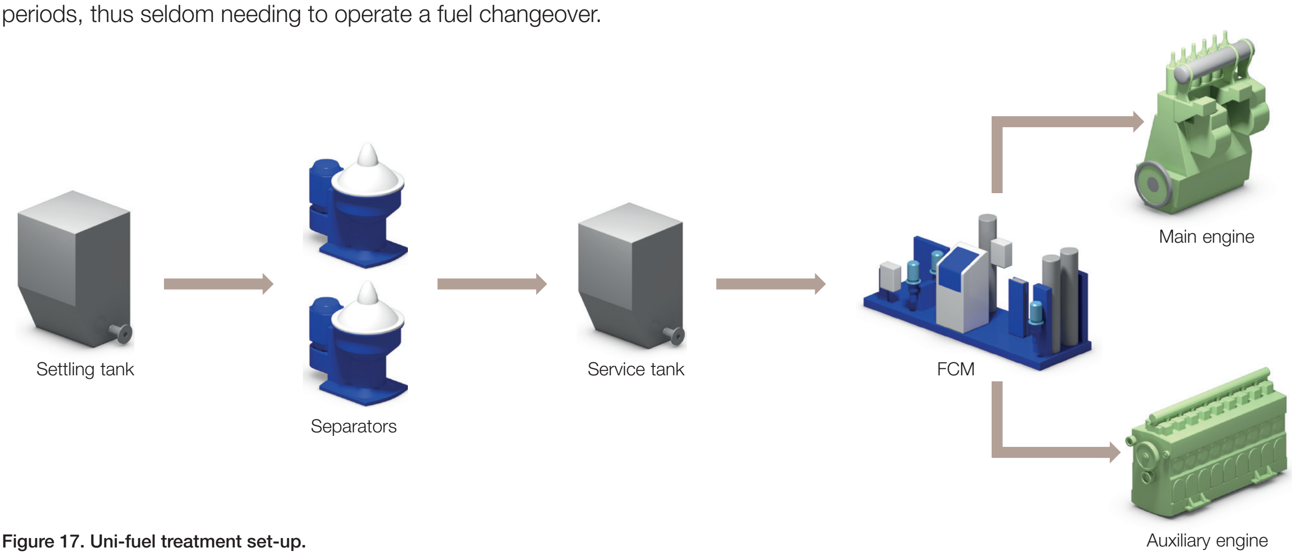


Figure 17. Uni-fuel treatment set-up.

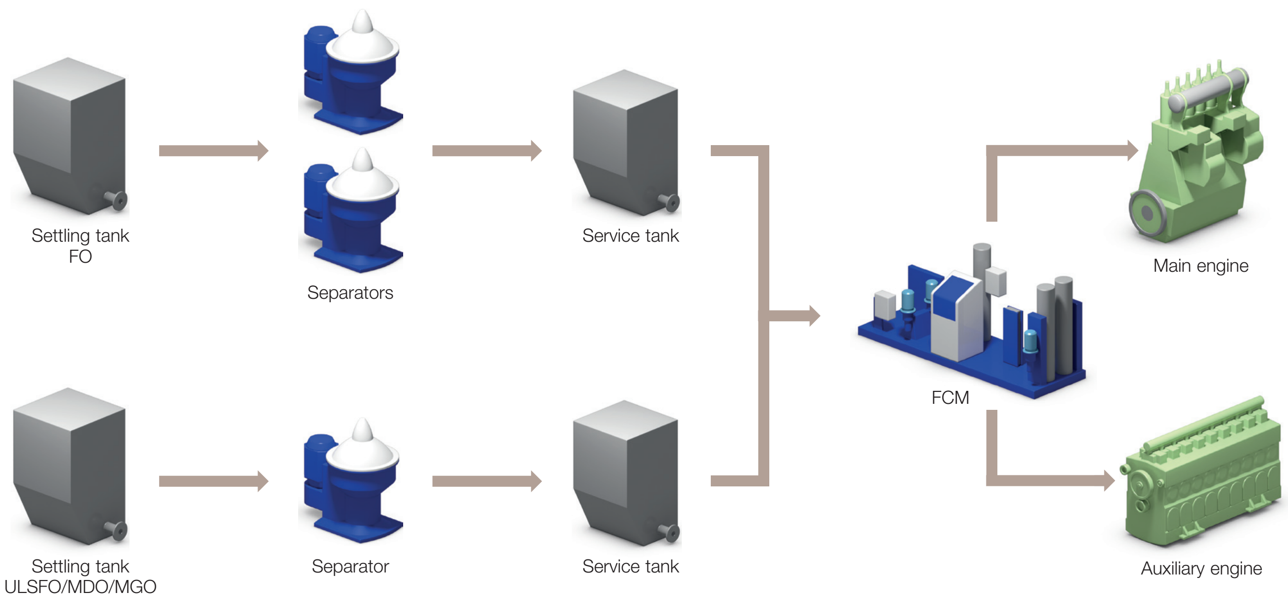


Figure 18. Fuel system layout for ships operating on multiple fuels.

4.3.3 Importance of cleaning HFO and MDO/MGO in different separators

The use of existing HFO separators for cleaning MDO creates some handling issues. When changing from HFO to MDO, even the piping, pumps and heaters are filled with fuel that has a higher sulphur content.

Inadvertently mixing fuel with a higher sulphur content with MDO, even in small quantities, can result in off-spec fuel and cause a great deal of problems. To prevent these problems, the system must be cleaned by running MDO through the pipes until the system is cleaned of high sulphur levels. This again creates some handling issues:

- Incompatibility: Mixing MDO/MGO into HFO is not recommended. This may result in severe handling issues if the HFO becomes unstable and produces large amounts of sludge, which is very difficult to handle and, in severe cases, may clog the entire fuel system.

- Inability to determine compliance with MARPOL sulphur limitations: Without taking and sending samples to a laboratory for analysis, it is impossible to determine when MDO treated in HFO separators is in compliance with MARPOL sulphur limits and can be sent to the storage tank. Such analysis takes time and, in practice, is not an option for most operators.

4.3.4 Tank design

Slanted tank bottoms facilitate the collection and removal of cat fines, solids, and water and prevent them from being stirred up in rough weather. Overflow piping between the service tank and settling tank routes the oil back to the settling tank at reduced engine load. Overflow piping at the service tank bottom directs oil with the highest concentrations of cat fines away from the engine.

4.3.5 Fuel changeover

The ECA fuel switch is an essential part of the multi-fuel management concept for changeover and blending control (Figure 19). Positioning the switch close to the engine helps ensure safety and minimizes the amount of the high-sulphur fuel in the piping when switching over from HFO to distillate. Using GPS data from a monitoring system further contributes to compliance with sulphur emissions regulations by making sure that the changeover is complete well before entering the ECA.

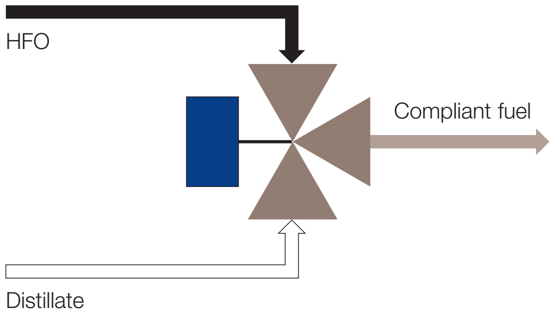


Figure 19. An ECA Fuel Switch.

4.4 Technical solutions

The Alfa Laval portfolio includes highly efficient fuel treatment products for use throughout the entire fuel processing chain. The problem with today's operations is that the fuel handling often runs at full capacity, even if the ship is slow steaming. By interconnecting the individual equipment in the fuel processing line and enabling them to adapt to the actual engine load, the fuel treatment process can be run in a much more efficient way. Reducing the flow of fuel through the separators at moderate ship speed not only saves energy, but also reduces the risk of cat fines entering the engine. This section describes some Alfa Laval technologies and how to connect these technologies to enhance operations with smarter operations.

4.4.1 Alcap™ technology

During the oil crisis in the early 1970s, refineries were forced to remove increasingly more light fractions from the crude oil to improve profitability. To achieve this, different distillation methods were developed, which resulted in reduced HFO quality and densities too high to be handled by conventional purifiers. Both the density and viscosity of the oil became too high and, as a result, separator manufacturers were forced to develop better separation techniques. The density limit for the older, conventional Alfa Laval separators was 991 kg/m³ and 600 cSt; however, the new densities were 1,000 kg/m³ or higher. In response, Alfa Laval set about redesigning the separators to handle the higher densities. In the resulting solution, Alcap (Figure 20), the density limit for the new separators was increased to 1,010 kg/m³ and the viscosity limit was set at 700 cSt.

Figure 20. A separation system with Alcap™ technology.

Separator design

Separators perform two main functions:

- purifying – separating two liquids of different densities (fuel and water)
- clarifying – separating solids from a liquid (in marine separation, primarily cat fines)

Inside the separator, a bowl spins rapidly, using centrifugal force to perform its function. With conventional technologies, to operate as a purifier, a gravity disc is placed into the bowl, setting the interface between the oil and the water. As the bowl spins, the separator continuously discharges water. The gravity disc needs to be matched to the density and viscosity of the fuel, but heavier fuels are a problem and, as noted above, conventional separators are limited to 991 kg/m³ at 15ºC. Therefore, in a conventional arrangement, a purifier would typically be followed by a second separator operating as a clarifier.

Alcap does away with the gravity disc, enabling the separator to handle denser fuels (up to 1010 kg/m³ at 15ºC) and higher viscosities. The discs are designed to accept a wider range of fuels without adjustment. In operation, separators of this type act as clarifier, but automatically monitor water content and drain it through an outlet valve when required. Alcap separators are also more energy efficient than conventional designs.

Controlling the water drain valve

The water drain valve needs to open and drain water when required. Knowing when to open the valve requires monitoring the full flow in the clean oil outlet. As soon as an increase in the water level is detected, the control unit initiates either draining or discharge, depending on the application. A water transducer monitors the water content in the oil by measuring the oil's conductivity at the outlet. Technically, the transducer acts as a capacitor. The capacitance varies with the dielectric constant of the liquid, and there is a significant difference between the dielectric constant of water and that of oil. Therefore, fluctuations in conductivity are very sensitive measures of the changes in the water content. Both free and emulsified water contamination is measured. The higher the value, the more water the oil contains. Oil has a dielectric constant of approximately 4 to 6, and water has one of approximately 90 to 95. This means that even a small amount of water will drastically increase the conductivity reading and thereby indicate the presence of water in the oil.

Process

Alcap is the only separation technology on the market that continuously measures the water in the clean oil outlet. The oil/water interface in the separator bowl automatically adjusts based on this measurement. This allows fuels with varying densities of up to 1,010 kg/m³ to be separated without changing the gravity discs as is required for conventional separators.

The oil losses in Alcap are negligible. Technically, this is because the oil inlet is closed and the oil is pushed towards the disc stack by adding displacement water to the bowl before the separator discharges.

4.4.2 FlowSync™ — Energy efficiency and flow optimization

Today the feed rate to the separators is at maximum capacity at all times. During slow steaming, this implies that the amount of fuel to be processed through the separator is greater than the fuel required from the service tank to the engine. Recirculation of fuel is, therefore, quite significant.

Introducing FlowSync to the fuel line (Figure 21) enables the fuel feed rate to the separators to be matched to the actual engine load.

When the feed rate to the separators is reduced, separation becomes more efficient, and less energy is consumed by the feed pumps and separators.

Separation efficiency increases because the fuel is in the separator bowl longer, enabling particles with a lower settling velocity to be removed from the oil.

An online Flow Sync performance simulator is also available (Figure 22), which allows operators to adjust multiple variables for an indicative measure of the potential energy savings that can be achieved by optimizing the feed rate.

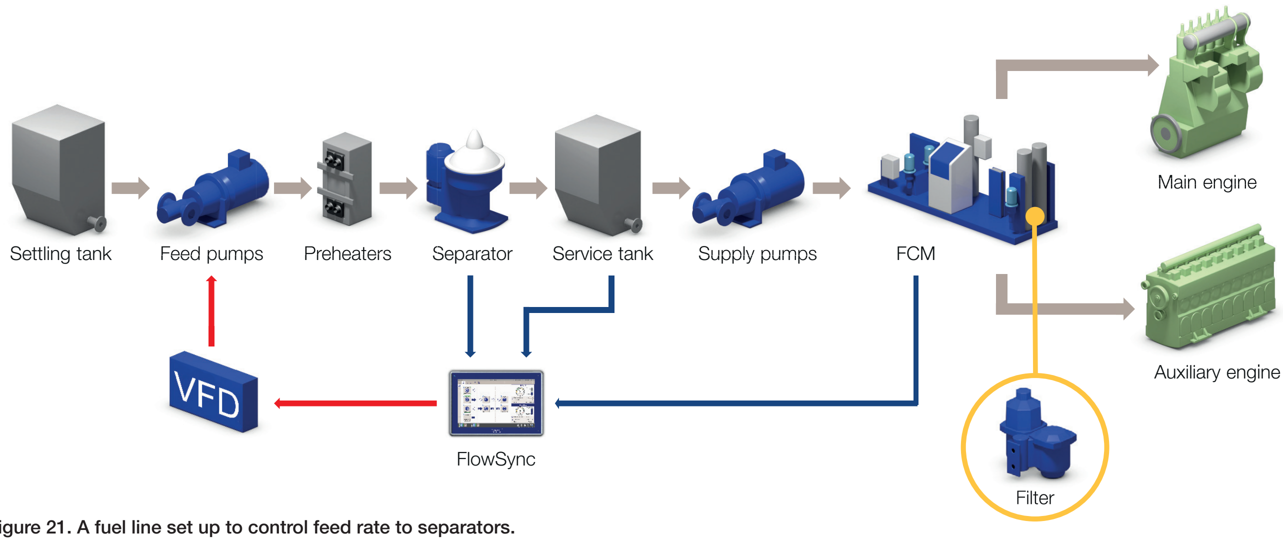


Figure 21. A fuel line set up to control feed rate to separators.
FlowSync controls the flow rate by matching the feed pump speed to the actual engine load.

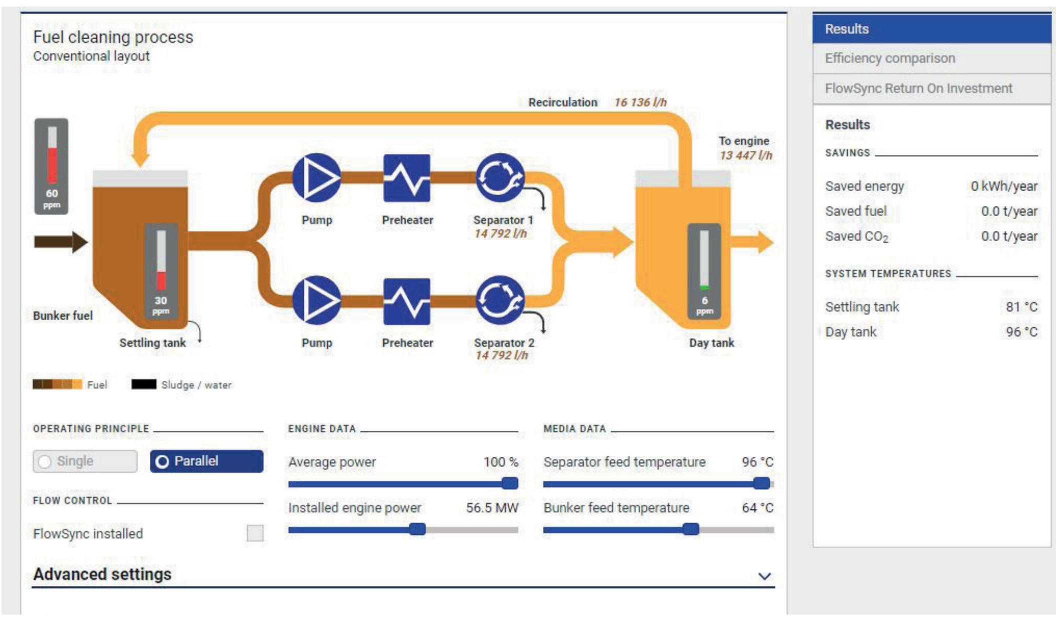


Figure 22. The FlowSync performance simulator interface.
The simulator allows operators to model the energy savings possible by controlling fuel feed rate.

4.4.3 High temperature separation

The viscosity of the fuel is strongly dependent on the temperature. The higher temperature, the lower viscosity; and the lower viscosity, the higher the separation efficiency.

As noted earlier, raising the temperature to 115°C can increase separation efficiency by up to 80% for the same bowl.

However, this becomes a problem for any water contained in the oil. Inside the bowl, the pressure prevents the water from evaporating, but it can have serious consequences during a discharge, when the +100°C water will then be released into atmospheric pressure and boil off instantaneously, leading to a large pressure increase inside the separator stand.

Therefore, it is common practice to heat the HFO to 98°C to prevent the water from boiling.

It is also important to note that distillates have a lower flash point than HFO. Therefore, increasing the temperature too much may create an explosive atmospheric environment. Distillates in general, however, already have much lower viscosities than HFO, therefore high temperature separation is not required.

4.4.4 PureDry — Energy efficiency and fuel recovery

During fuel handling and fuel treatment, some fuel is lost as sludge. Based on experience, the fuel oil loss is estimated at up to 1% of the vessel's bunker fuel oil consumption. Sources of recoverable fuel include:

- Drains from continuous backflushing filters with diversion chamber
- Backflushing from sequential backflushing fuel oil filters
- Fuel settling and service tank drains, tank coamings and cofferdam
- Fuel injection pumps
- Boiler burner leakages
- Drip trays under fuel transfer pumps, etc.
- Pipe leakages
- Fuel spill incidents
- Fuel oil purifiers

To recover fuel oil effectively, waste fuel oil from these sources must be collected in a separate tank and not be mixed with spillage from lube oils, hydraulic oils, and other oils that cannot be used as part of recovered fuel oil. The Alfa Laval PureDry system (Figure 23) treats the waste oil in this tank, continuously separating out the water and solids and recovering reusable fuel. The resulting streams are typically:

- Water with <1,000 ppm oil
- Fuel with <5% water
- Super-dry solids (typically 15-25 kg super-dry solids per 24 hours)

The recovered reusable fuel is led back to the settling tank (Figure 24). Separated water is led to the primary bilge water tank for further treatment. The solids can be landed as dry waste and disposed of in the same way as oily rags and used filter cartridges. PureDry handles fuel with densities up to 991 kg/m^3 (at 15°C).

4.4.5 ACS – Automated Fuel Changeover System

The burning of distillate fuels in diesel engines has some critical aspects that can affect engine injection systems, pumps, and other equipment. Fuel viscosity at injection, which affects the lubrication capacity of fuel injection components, is the first issue to deal with. Then, since the injection temperature of distillate fuel is much lower than that of HFO, a second issue arises from the temperature gradient: a sudden temperature change can cause thermal shocks within the injection system.

To address these issues while maintaining the right fuel parameters at the injection point, it is essential that the fuel forwarding unit is suitable both for managing fuel changeovers in a simple yet safe way by controlling temperature ramp inside the system and for maintaining the correct temperature of light fuel at the injection point.

Figure 23. The Alfa Laval PureDry system.

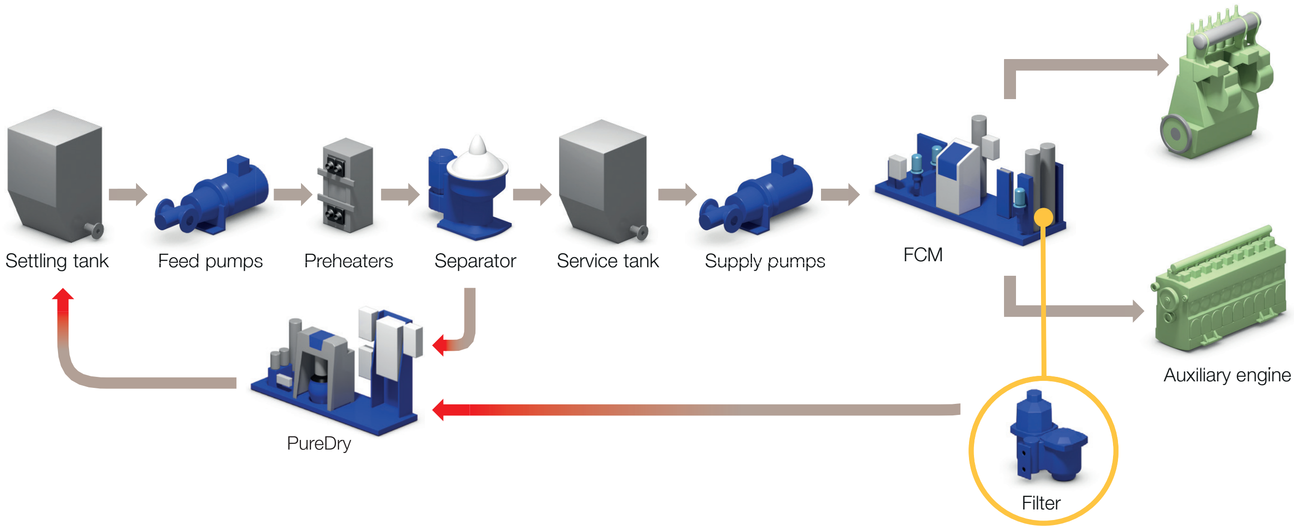


Figure 24. A fuel line with a PureDry system in place.
PureDry recovers waste oil and separates it into reusable fuel, water and super-dry solids. The reusable fuel is pumped back to the settling tank.

Figure 25. The Alfa Laval Automated Fuel Changeover System.

The Alfa Laval Automated Fuel Changeover System (ACS) is a reliable, fully automatic system that facilitates the changeover of fuel, regardless of quality, while keeping fuel viscosity within the limits set by engine manufacturers (Figure 25). As a part of the high-pressure stage of a fuel oil booster, the ACS integrates the heaters with a parallel cooling system.

The ACS makes it possible to:

- Control the transition from the high injection temperature of HFO to the lower temperature of distillate fuels so that the temperature gradient is within the limits set by engine manufacturers.

- Maintain the distillate fuel oil temperature and its viscosity within the limits set by engine manufacturers.

The ACS is configured to work with any fuel oil booster system and can be easily installed as a retrofit system.

4.4.6 FCM One – Fuel Conditioning Module

Fuel conditioning is the treatment of fuel oil by a booster system to meet the pressure, temperature, viscosity, and flow rate specified by diesel engine manufacturers. These parameters are vital for the engine's combustion performance. This makes securing these parameters an important part of both energy efficiency and emissions reduction.

Fuel conditioning today encompasses much more than HFO, especially in marine installations. Emissions legislation is forcing ship owners to use lighter and more expensive fuel oils and distillates, while fuel prices encourage reliance on residual fuels. Most vessels now operate on two or more fuels, which poses operational and safety concerns when switching between them.

Different vessels address the challenges in different ways, so, although some vessels may have the same engine specifications, different requirements may be placed on their boosters.

The Alfa Laval FCM One (Figure 26) is an evolution of the original Alfa Laval Fuel Conditioning Module, providing a new level of functionality. In addition to conditioning fuel to exactly match engine specifications, the FCM One features embedded automation that enables it to be set up and configured to handle multiple fuels (up to four different fuels on the same vessel), produce mass/mass blends, and manage the automatic changeover, preventing the mixing of incompatible fuels.

4.4.7 Electronic fuel records to support compliance

Compliance with environmental regulations according to IMO, California ARB, and EU sulphur directives can be supported through a designated system design along with automatic monitoring and log functions. But in addition to technical solutions, knowledge of the legislation and how to operate in certain situations is also important. It is essential, for example, to know the inspection criteria and the consequences of non-compliance as well as how a technology malfunction may affect non-compliance. Technical solutions like those outlined in Table 7 can help ship owners and operators avoid penalties for non-compliance.

The FCM One provides a secure digital record that can help owners document and show their compliance with the legislation.

Figure 26. The Alfa Laval FCM One.

Blending	Changeover	Bunker information	GPS signal
% Fuel 1	Position CV1	Bunker Delivery Note reference	Latitude
% Fuel 2	Position CV2	Fuel oil grade	Longitude
Sulphur content	Sulphur content	Sulphur content	UTC/GMT time
Fuel consumption	Viscosity	Analysis report ref.	
Viscosity	Temperature	MARPOL sample seal no.	
Temperature		Bunkered quantity	

Table 7. Input data for the electronic fuel record book.

4.4.8 Moatti fuel filters – Engine protection

The Alfa Laval Moatti fuel filter (Figure 27) is positioned at the end of the system to capture and remove many remaining particles and impurities before they can enter the engine.

Figure 27. The Alfa Laval Moatti fuel oil filter.

In line with current recommendations, the Moatti system uses a 10 µm filter screen, installed after the fuel conditioning module in the fuel recirculation system, known as the hot side. For the best protection, the filter should be placed as close to the engine as possible.

The Moatti oil filter features continuous automatic backflushing and a diversion chamber, using the filtered oil to drive the backflushing process. Unlike sequential backflushing systems that use air to clean the filter element, the Moatti system is not susceptible to thermal-induced sludge formation.

Furthermore, the Moatti filter uses a diversion chamber as a post-treatment stage, allowing contaminants to be continuously cleaned away from the backflush oil. Unlike some other systems which use disposable cartridges at this stage, the Moatti filter eliminates the need for additional consumables.

The backflush oil is then refiltered before being recirculated in the system without the need for additional treatment.

4.4.9 2Touch – Monitoring fuel cleaning

To optimize fuel cleaning equipment, it is essential to use the latest fuel-cleaning technology and fuel-cleaning knowledge. Information technology today provides vast opportunities to optimize plant performance in terms of energy efficiency and oil quality. When combined with the control system, the Alfa Laval 2Touch HMI helps operators monitor the separation process.

The Alfa Laval 2Touch HMI employs a colour touchscreen panel (Figure 28). It is used to enter system configuration data, tune and calibrate system components, register alarms, provide means to handle the parameter values required for system-technology diagnosis and process optimization, store trends and recipes, and provide numerous other functions.

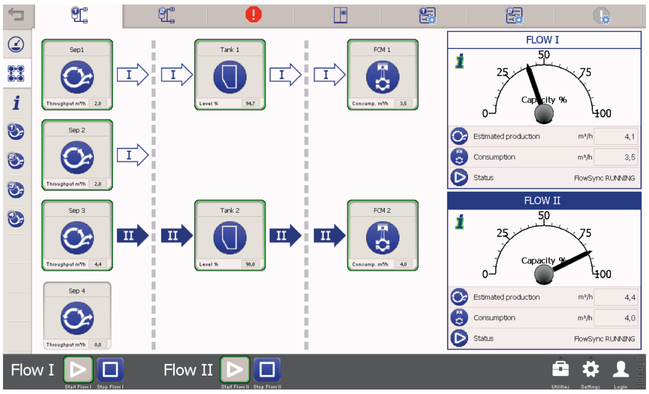


Figure 28. The Alfa Laval 2Touch HMI.

4.5 The Adaptive Fuel Line

The Adaptive Fuel Line concept brings together all of the individual components of the fuel treatment chain, optimized to reduce energy consumption, increase efficiency, and enhance operational safety.

The core of the fuel treatment system is the Alcap™ separators, thanks to their flexibility in handling different fuel densities. Because the density of heavy fuel oil varies significantly, in combination with different low sulphur blends, it is important to maintain good separation efficiency for different fuels.

If the engines are not operating at full capacity, which is often the case, FlowSync reduces and matches the flow of fuel through the separators to the actual engine load. By doing so, energy consumption is reduced and separator efficiency increased because the fuel has a longer time in the separator bowl. FlowSync ensures that the service tank is always filled with a small overflow for recirculation.

The booster unit, FCM One, makes sure that the fuel is within limits for optimal engine efficiency in terms of temperature, viscosity, pressure, flow, and particle protection. The module also handles the transition between different fuel types in a multi-fuel operation, for example, when entering or leaving an ECA.

Before the fuel enters the engine, it passes an oil filter. The Moatti filter is an automatic self-backflushing system that protects the engine against ash and other large solids. The particles are concentrated into sludge at the bottom of the filter.

Sludge from the separators, filters, service tank drains, and other sources is then treated in the PureDry system. This three-phase system separates oil from water and leaves a super-dry solid at the bottom of the unit. The recovered oil phase is then recirculated back to the settling tank and goes through the fuel treatment process once more.

As an extra level of security, the cat fines monitoring module observes the cat fines levels at different points of interest along the fuel treatment chain. If stormy weather occurs, turbulence may stir up large concentrations of settled particles from the service tank, which may then enter the engine. In such an event, the system may switch over to another cleaner fuel.

One possible configuration of the entire Adaptive Fuel Line, bringing together the major elements discussed in this BlueBook, is illustrated in Figure 29.

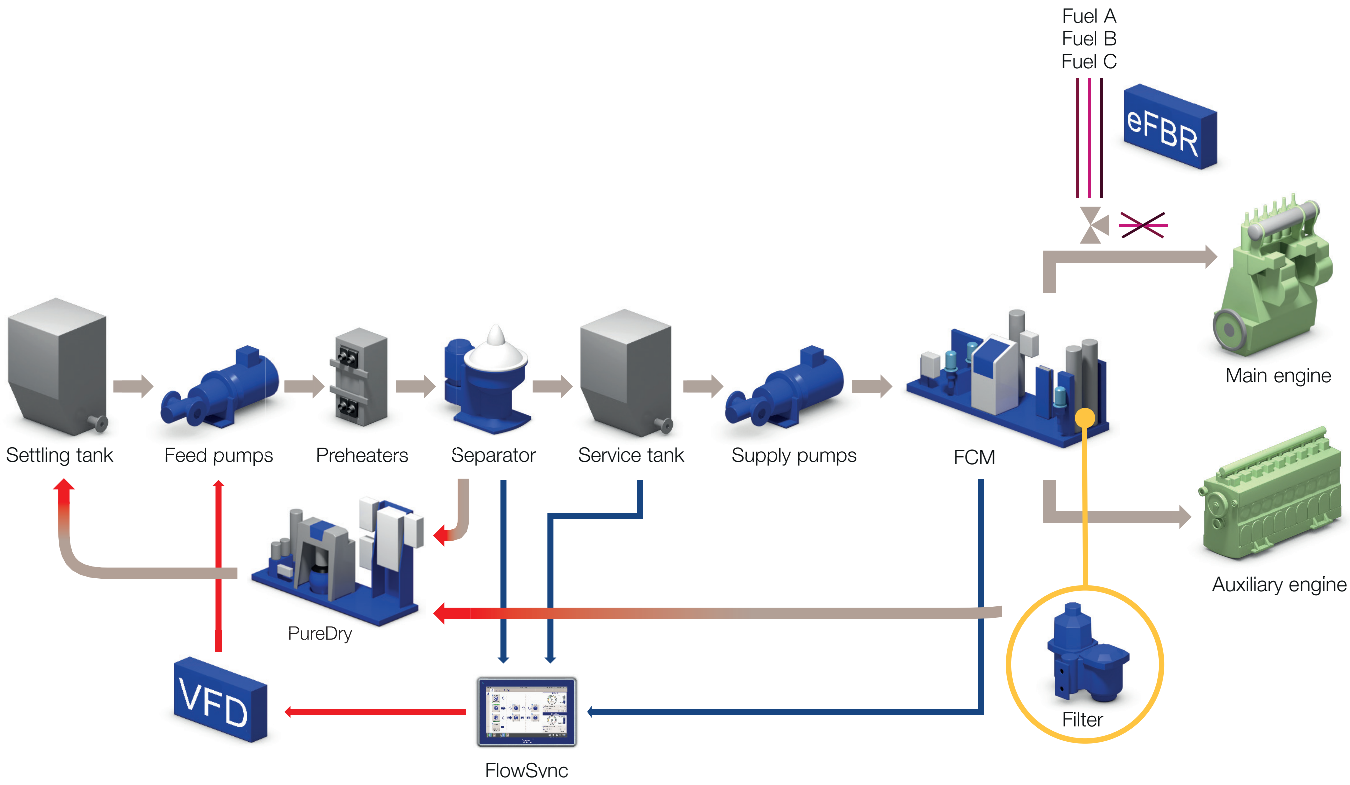


Figure 29. Typical configuration of the Alfa Laval Adaptive Fuel Line.

5 Acronyms

Acronym	Description
ACS	Automated Fuel Changeover System
ARA	Antwerp-Rotterdam-Amsterdam
(C)ARB	(California) Air Resources Board
CFR	Certified Flow Rate
CIMAC	The International Council on Combustion Engines
ECA	Emission Control Area
eFRB	Electronic Fuel Record Book
FAME	Fatty-Acid Methyl Ester (Biodiesel)
FCM	Fuel Conditioning Module
HDME	Heavy Distillate Marine ECA
HFO	Heavy Fuel Oil
HMI	Human Machine Interface
HVO	Hydrotreated Vegetable Oils
IMO	International Maritime Organization
ISO	International Organization for Standardization
LNG	Liquid natural gas
LPG	Liquid petroleum gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil – Blend of distillates and residual oil
MEP	Mean Effective Pressure
MPEC	Marine Environment Protection Committee
MGO	Marine Gas Oil – Distillate, practically sulphur free
MRC	Maximum Recommended Capacity
ULSFO	Ultra-low sulphur fuel oil
VFD	Variable Frequency Drive
VLSFO	Very-low sulphur fuel oil

FUEL LINE

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Alfa Laval in brief

Alfa Laval is a leading global provider of specialized products and engineering solutions.

Our equipment, systems and services are dedicated to helping customers to optimize the performance of their processes. Time and time again.

We help our customers to heat, cool, separate and transport products such as oil, water, chemicals, beverages, foodstuffs, starch and pharmaceuticals.

Our worldwide organization works closely with customers in almost 100 countries to help them stay ahead.

How to contact Alfa Laval

Contact details for all countries are continually updated on our web site. Please visit **www.alfalaval.com** to access the information.

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