Operation on Low-Sulphur Fuels

MAN B&W Two-stroke Engines

Engineering the Future – since 1758.

MAN Diesel & Turbo

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Operation on Low-Sulphur Fuels

Introduction

The average sulphur content of heavy fuel oil (HFO) used for marine diesel engines is 2.7% today. This will undoubtedly change with the coming emission legislation, which will lower the emission limits of SO_x, NO_x, particulate, HC, CO and CO_2. See also list of abbreviations.

So far, the authorities have reduced the SO_x content in the exhaust gas by introducing limits on the content of sulphur in the heavy fuel (HFO) used. This is a much more efficient and straightforward solution, obtained from the refining process, than the installation of separate SO_x cleaning techniques on board each vessel.

However, this solution still requires that it is feasible for the refineries to lower the sulphur level at a reasonable cost and effort. So far, the question is whether there will be sufficient low-sulphur HFO available in the future, and whether marine diesel and gas oils will be used to any wider extent. This is a somewhat political question, which will not be discussed in this paper, but which could result in less HFO produced, more distillate used, and a higher avarage sulphur content in the remaining heavy fuel.

However, we will highlight for the Marine Industry, the technical areas which MAN Diesel & Turbo expects will be affected when changing from higher sulphur fuel oils to lower sulphur fuel oils.

We will inform of the latest experience gained from operation on low-sulphur fuel, and also of the potential operational difficulties if the main engine and auxilliary systems are not prepared.

In cooperation with a number of scrubber suppliers, MAN Diesel & Turbo has completed more than 170 tests on a 1 MW research plant in Denmark. Futhermore, the experience from a full scale test in progress on a 20 MW main engine scrubber will be described in a separate chapter.

Most MAN B&W two-stroke engines of today are operating on fuels with sulphur levels higher than 1.5%. This gives us much experience with high-sulphur fuels. However, on the basis of operation on power stations and special marine vessels designated for operation on low-sulphur fuel, we have created the guidelines described in this paper.

It should also be mentioned that on testbed all two-stroke engines are operated on standard environmentally friendly fuel oil, which is typically a land-based diesel oil with a very low sulphur content and viscosity but, also in this condition, the two-stroke engine operates successfully as long as the necessary precautions are being taken.

Latest Emission Control Regulations

The International Maritime Organisation (IMO)

The IMO Annex VI of MARPOL 73/78, Regulations for the Prevention of Air Pollution from Ships has been in force since May 2005.

Thus, the sulphur oxides (SO_x) limit applies to all vessels in the category of ships with an engine power output of more than 130 kW.

The general international limit on sulphur is reduced from 5% to 4.5% through the ISO 8217 fuel standard.

IMO has specified that, in future, further limitations will be imposed on SO_x as well as on other components in the exhaust gas.

Fig. 2 illustrates the IMO fuel sulphur content limits for both ECAs (Emission Controlled Areas) and for international waters.

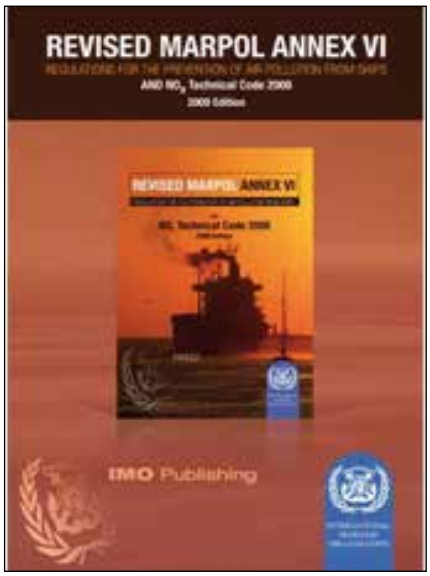


Fig. 1: The revised Annex VI with associated NO_x technical code, entered into force in July 2010

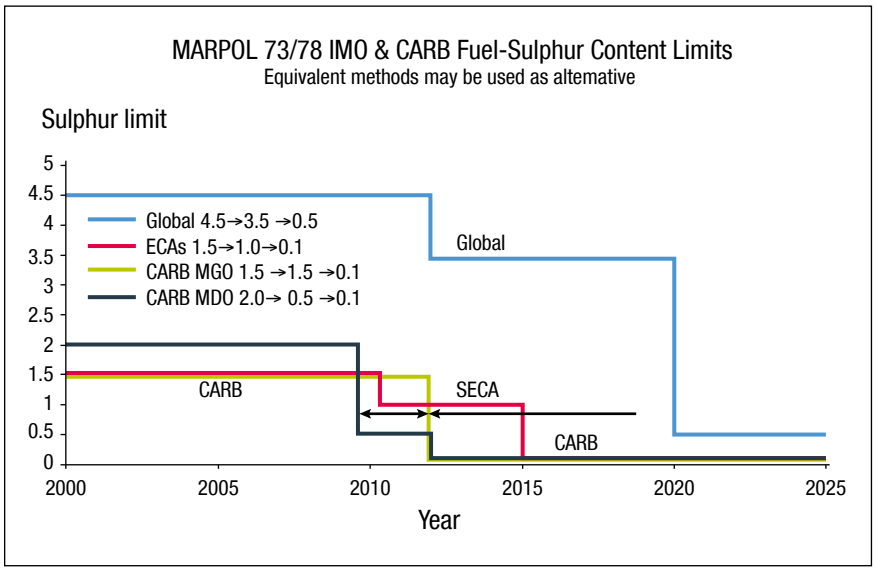


Fig. 2: Limits on the sulphur content in fuel ECA. Today, Baltic Sea, North Sea and English Channel. Coming ECA: possibly Mediterranean in August 2012, 200 nautical mile zone at the US coast. CARB: Californian Air Resources Board: 24 nautical miles of the Californian baseline.

Today, ECAs comprise the Baltic Sea, the English Channel and the North Sea, however, more areas will be added to these in the future.

The coasts of the USA, Hawaii and Canada are considered to become ECA areas by 2012, and many more are under consideration to be designated as ECA areas between 2010 and 2015.

California Air Resources Board

California Air Resources Board (CARB) has introduced limits on the use of sulphur for distillates.

The EU

The EU has introduced separate regulations to cut SO emissions from ships.

Currently, marine heavy fuel has a maximum sulphur content of 4.5% or 45,000 parts per million (ppm), compared with petrol for cars, which have 10 ppm from 2007.

A 0.1% sulphur limit has be introduced on fuels used by inland vessels and seagoing ships at berth in EU ports from 1 January 2010.

The alternative to reducing the amount of SO_x in the exhaust gas is to clean the exhaust gas using the scrubber technique. So far, only a few plants are operating with such a solution, and it is still considered primarily for larger engines. See also a later chapter.

Incompatibility of Fuels

Due to the current considerable price difference, we do not expect total change-overs from heavy fuel to distillates, see Table I. However, an operator could be forced to change over for reasons of fuel availability.

Low-sulphur heavy fuel has a somewhat higher price than the high sulphur heavy fuel, due to increasing demand and the cost of the desulphurisation process.

When switching from heavy fuel to a distillate fuel with a low aromatic hydrocarbon content, there is a risk of incompatibility between the two products. The change-over procedure takes quite some time, during which there will be a mix of the two very different fuels for an extended period of time. The asphaltenes of the heavy fuel is likely to precipitate as heavy sludge, with filter clogging as a possible result.

Even though incompatibility seldom occurs, the most obvious way to avoid this is to check the compatibility between the fuels before bunkering. This can be done manually with a kit on board, or via an independent laboratory. The latter often being too slow a process, as the ship will already have left the harbour before the laboratory returns with the test result. Therefore, in practice, and in the event that the fuel supplier is not supplying both low and high sulphur fuels, the incompatibilities will not be discovered until both fuels are on board.

BP Marine has found that even though the TSP (Total Sediment Potential) and TSE (Total Sediment Existing) values of the fuel are completely satisfactory, still or small number of fuel deliveries give rise to complaints of filter blocking, excessive sludge, etc. It is suspected that most at these incidents are due to fuel incompatibility.

When blending for low-sulphur fuel more cases of incompatibility might be seen

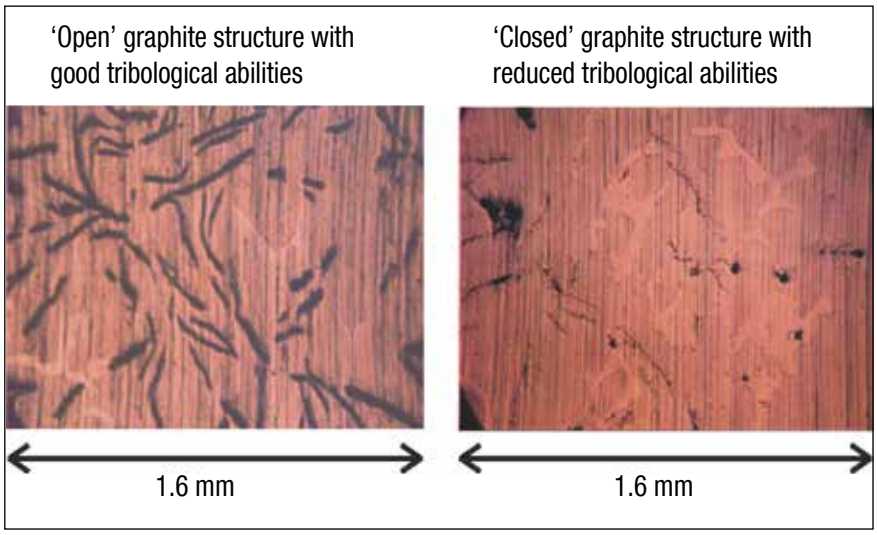


Fig. 3: Cylinder liner surface

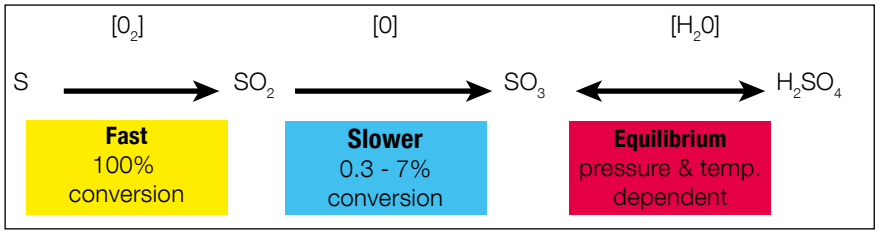


Fig. 4: Chemical conversion of sulphur (S) to sulphuric acid (H_2SO_4)

Operational Considerations Related to Operating MAN B&W Two-stroke Engines on Low-sulphur Fuels

Due to the environmental legislation on fuel sulphur contents, MAN B&W two-stroke engines operate on distillate fuels already (marine gas oil (MGO), and marine diesel oil (MDO)). As engine designer, we get many questions related to this, and we are in contact with the authorities regarding safety and reliabilty issues.

It must be emphasised that MAN B&W two-stroke engines can operate on fuels fulfilling the ISO 8217:2010 specification, including distillate fuels, without making modifications to the engine itself

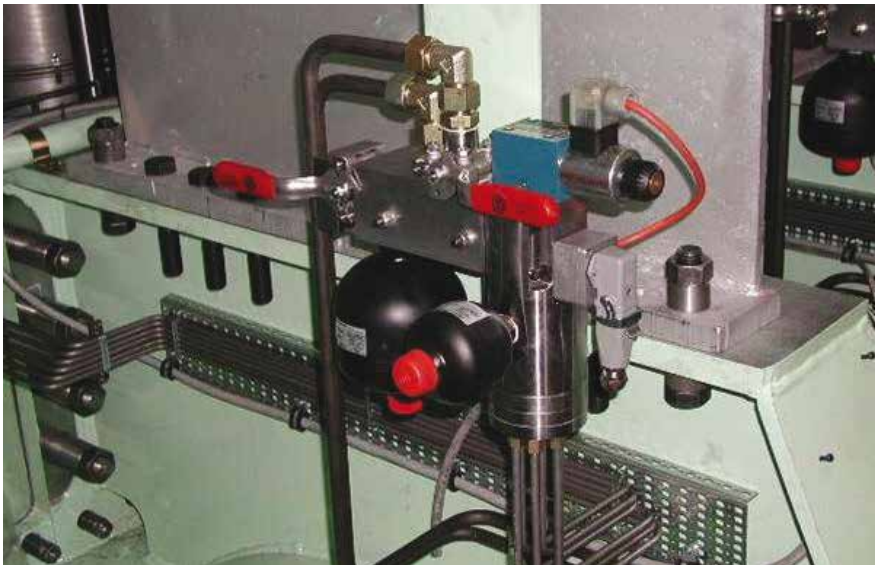


Fig. 5: Alpha Lubricator

Correlation between fuel sulphur level and cylinder condition

Our experience with continuous low-sulphur fuel operation and cylinder lubrication with low-BN cylinder lube oil is primarily obtained from stationary engines, operating at 100% load and 100% rpm in high ambient conditions. Whether the same necessity for low-BN cylinder lube oil applies for marine engines as well will, as such, depend on the operational profile, engine size and overall engine condition.

It is therefore important to acknowledge the corrosion mechanisms prevailing on the cylinder liner, and know about the low-BN cylinder oil.

Acid corrosion, which is by far the most influencing cause of wear seen in cylinder liners, is basically the result of a condensation of the heavy fuel sulphur compound. The corrosion is caused by the combination of water being present during the combustion process, and a thermodynamic condition where the temperature and pressure are below the dew point curve of the sulphur trioxide, see Fig. 4. Even though the water mist catcher of the scavenge air cooler removes water droplets, the scavenge air is saturated with water vapour when entering the cylinder.

It has not been clearly mapped, as such, how much sulphur trioxide is formed, and what is the necessary time frame before the acid corrodes the surface of the liner wall, and when new cylinder oil must be fed to the liner surface in order to neutralise the sulphuric acid.

In order to neutralise the acid, the cylinder lube oil contains alkaline components – usually calcium salts. Normally, the Base Number (BN or TBN) is a measure of the cylinder lube oil's ability to neutralise acid. The higher the BN, the more acid can be neutralised.

The BN is therefore an important parameter in controlling the corrosion on the cylinder liner surface. Controlled corrosion – not avoiding corrosion – is important to ensure the proper tribology needed for creation of the lubricating oil film. If the neutralisation of the acid is too efficient, the cylinder liner surface has a risk of being polished, i.e. the lube oil film is damaged and the risk of scuffing increases.

In other words, operating the engine with an unmatched BN/fuel sulphur content could increase the risk of either scuffing or excessive corrosive wear.

Fig. 3 shows the same cylinder liner, first where a BN70 lube oil has been used, and then where a BN40 lube oil has been used for the same type of low-sulphur fuel.

Based on experience, MAN Diesel & Turbo finds it essential for a good cylinder condition and overall engine performance that an "open" graphite structure is kept on the cylinder surface, so that a hydro-dynamic oil film is kept

between the piston rings and cylinder walls at all times.

Therefore, running on low-sulphur fuel is considered more complex due to the relationship between liner corrosion and scuffing resistance, dry lubrication properties from elements in the fuel (or lack of same), the interaction between the BN in the cylinder oil and the detergency level, possible surplus of alkaline additives, the piston ring pack, etc.

The total alkaline content of the cylinder oil has to match the sulphur content in the fuel oil in accordance with the equation: Dosage F x S%, where F = 0.20 g/kWh for the new large bore engines, based on a BN70 cylinder oil. Some of the newer types of cylinder oils are developed to handle a broader line of sulphur content in fuels. The minimum feed rate for proper oil distribution and oil film thickness has so far been set at down to 0.6 g/kWh, which at the above-mentioned equation will be reached at 3% sulphur, Ref. [2]. This means that the theoretical limit, using an ordinary BN70 oil, is 3%.

As an example, an engine using 1% sulphur fuel at a dosage of 0.6 g/kWh would therefore be overadditivated.

A fuel with a sulphur content as low as 0.5% could call for a combination of a low cylinder oil dosage and a low-BN oil (BN40 or even lower).

When this is said, it is essential that the actual cylinder and piston ring condition is inspected. With its unique distribution of oil film, the Alpha Lubricator, see Fig. 5, which is used for cylinder lubrication on MAN B&W two-stroke engines, has

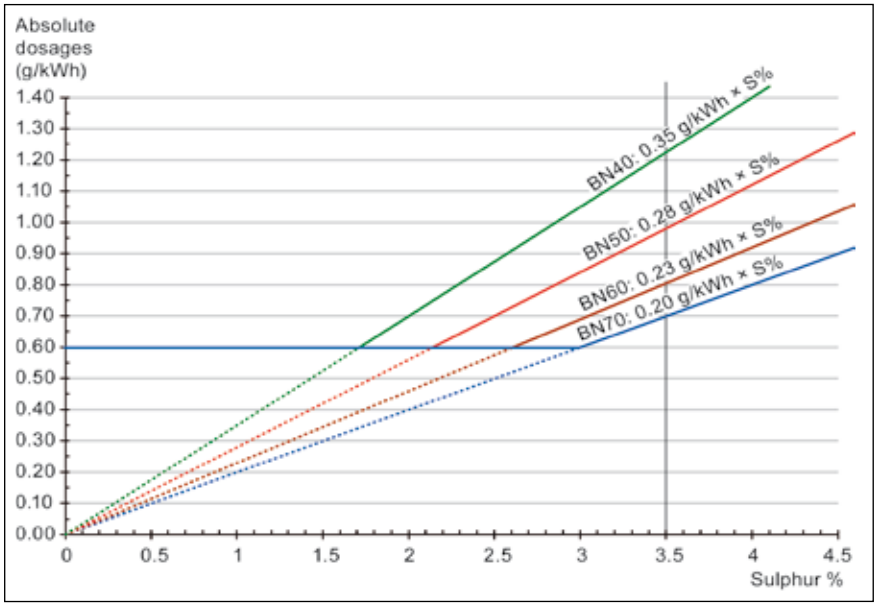


Fig. 6: Use of BN40, BN50, BN60 and BN70 cylinder oils

shown that a lube oil feed rate down to 0.6 g/kWh can be reached.

It has also been shown that thanks to the low cylinder lube oil feed rate, many engines can use low-sulphur fuel and still use BN70 cylinder oil, going in and out of ECA areas.

It is therefore important to acknowledge that before changing from BN70 to BN40-50, it is important to evaluate the engine's actual condition after the first operating period on low-sulphur fuel.

The complexity of designing a low-BN cylinder oil consists in achieving the proper detergency level, which is seldom at the same high level as for BN70 oils.

Therefore, we recommend that the low-BN cylinder oil type is selected very carefully. All the major oil companies have low-BN cylinder oils available today.

For how long the engine can run on low-sulphur fuel and BN70 cylinder oil is individual, but it is not expected to result in any unsatisfactory conditions in the course of the first weeks, where the engine can be inspected for optimisation of the feed rate and lube oil BN level.

Practical Approach

Low BN oils should be chosen for low- sulphur fuels, and high-BN oils for high-sulphur fuels.

BN	Sulphur
40-50	<3.5%
60-70	>2.5%.

see also Fig.6.

Recommended cylinder lubrication feed rate for large bore, high top-land engines as a function of the fuel oil sulphur content for selected lubricating oils (BN40 - BN70), Ref. [2].

However, MAN Diesel & Turbo recommends the following practical approach:

As some corrosion is beneficial to the cylinder condition as this keeps an

open graphite lamella structure of the cylinder liner surface from where the cylinder lubricant can spread. The purpose is therefore not to avoid corrosion but to control corrosion. This is done by adjusting the amount of base, i.e. by either using BN40 cylinder lube oil (instead of BN70 as normal for operation on HFO), by optimising the cylinder oil feed rate to the actual fuel sulphur level or a combination of both.

For high topland engines (high topland pistons are pistons where the topland is significantly higher than the ringland), MAN Diesel recommends to change to a BN40 cylinder oil at minimum feed rate operating for extended periods (typically more than two weeks) on low sulphur fuel in e.g. ECAs.

We have reports of older low topland engines operating continuously on low sulphur fuels and with BN70 cylinder oil without problems. In such cases, it is subject to owner decision whether to change to a BN40 cylinder oil.

We refer to our service letters Nos. SL385, SL479 and SL507 for more information and recommendations on cylinder oil feed rate for specific engine types. For future reference, please always check our latest service letters.

Distillates

The lowest viscosity suitable for two-stroke diesel engines is 2 cSt at engine inlet, see Fig. 7. However, this viscosity limit cannot necessarily be used as a fuel specification for purchasing the fuel, as the viscosity in a purchase specification is tied to a reference temperature. This is due to the fact that the external fuel systems have an individual effect on the heating of the fuel and, thereby, the viscosity of the fuel when it reaches the engine inlet.

The external fuel oil systems on board today have been designed to keep a high temperature for heavy fuel operation. This can make it difficult to keep the fuel system temperature as low as possible, and thereby as high a viscosity as possible, when changing to distillate MDO and MGO operation. The crew must therefore make an individual test.

Many factors influence viscosity and its influence on the engine, such as engine condition and maintenance, fuel pump wear, engine adjustment, actual fuel temperature in the fuel system, human factors, etc. Although achievable, it is difficult to optimise all of these factors at the same time. This complicates operation on viscosities in the lowest end of the viscosity range.

To build in some margin for safe and reliable operation, MAN Diesel & Turbo recommends operators to test the engine's and external systems' sensitivity to low viscosity. Furthermore, the necessity for installation of a cooler or cooler & chiller should be evaluated before purchasing fuels with the minimum level of viscosity necessary.

In principle, fuels according to the specified grades DMX/DMA/DMB (ISO 8217) can be purchased, if the engine and external system are designed to keep a

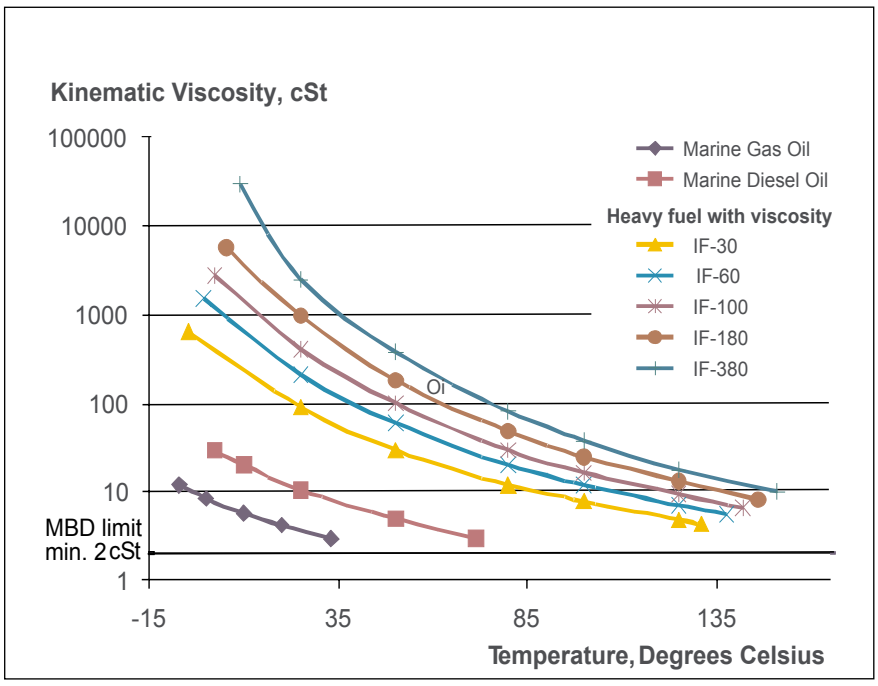


Fig. 7: Marine fuel viscosities. Viscosity of marine fuels depending on temperature

minimum viscosity of 2 cSt at engine inlet. If 3 cSt can be obtained, this is preferred to ensure a higher safety margin.

ISO 8217

According to ISO 8217-2010, distillate grades DMX/DMA/DMB can be sold with a viscosity down to 1.4 or 2 cSt at 40°C, respectively. This will especially be the case if the <2 cSt DMX/DMA provided origins from automotive gas oil. The 2 cSt can only be applied if the distillate is cooled/chilled down correspondingly to reach the 2 cSt minimum viscosity at engine inlet.

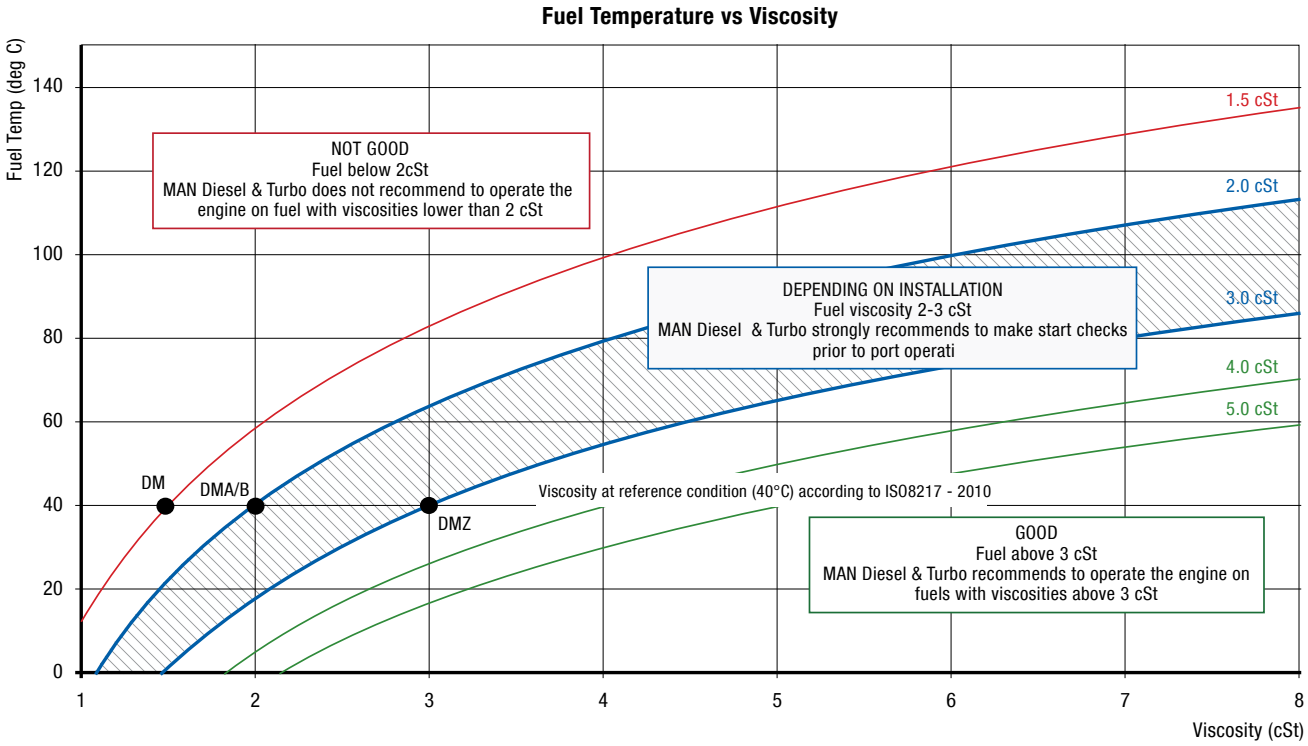
The latest distillate introduced in ISO 8217-2010 is DMZ with min. 3 cSt at 40°C, which gives some margin.

Influence of fuel lubricity and viscosity at engine inlet

Lubricity

The refinery processes intended to remove, e.g., sulphur from the oil result not only in low viscosity, but also impacts the lubricity enhancing components of the fuel. Too little lubricity may result in fuel pump seizures.

Although most refiners add lubricity-enhancing additives to distillates, MAN Diesel & Turbo recommends testing the lubricity before using fuels with less than 0.05% sulphur. Independent fuel laboratories can test lubricity according to ISO 12156-1 (High-Frequency Reciprocating Rig, HFRR). The HFRR wear scar limit is max. 520 µm.



The horizontal axis shows the bunkered fuel viscosity in cSt, which should be informed in the bunker analysis report. If the temperature of the MGO is below the lower blue curve at engine inlet, the viscosity is above 3 cSt.

The black thick line shows the viscosity at reference condition (40°C) according to ISO8217. Minimum viscosity for marine distillates DMX, DMA, DMB and DMZ are indicated.

Example: MGO with viscosity of 4 cSt at 40°C must have a temperature below 55°C, at engine inlet to ensure a viscosity above 3 cSt.

Example: MGO with a viscosity of 5 cSt at 40°C is entering the engine at 50°C. The green curves show that the fuel enters the engine at approximately 4.0 cSt.

Example: MGO with a viscosity of 2 cSt at 40°C needs cooling to 18°C to reach 3 cSt.

Fig. 8: Fuel temperature vs. viscosity

So far, we have not had a single report of lucbricity-related problems. However, as the market will shift towards running on more distillates, we might see pure marine distillates on the market. These fuels might be without in-land, automative lubricity additives or bio fuels. To test our equipment ability to run on this type of fuel, we are planning a test on a low viscosity, low sulphur, low lubricity type of fuel. The test will include our standard fuel equipment and a special non-stick coating.

Viscosity

A low-viscosity fuel oil challenges the function of the pump in three ways:

1. Breakdown of hydrodynamic oil film (resulting in seizures),
2. Insufficient injection pressure (resulting in difficulties during start and low-load operation), and
3. Insufficient fuel index margin (resulting in limitation in acceleration).

We have tested our standard equipment ability to run on very low viscosity fuel in our in-house test rigs.

The tests confirmed the robustness in our equipment running on the fuels available on the market today.

Due to the design of conventional pumps versus the pressure booster, ME/ME-C/ME-B engines are more tolerant towards a low viscosity compared with the MC/MC-C engines.

Many factors influence the viscosity tolerance during start and low-load operation:

- Engine condition and maintenance
- Fuel pump wear
- Engine adjustment
- Actual fuel temperature in the fuel system
- Human factors, etc.

Although achievable, it is difficult to optimise all of these factors at the same time. This complicates operation on viscosities in the lowest end of the viscosity range. To build in some margin for safe and reliable operation, and availability of high-viscosity distillate fuels, it is expected that installation of coolers or cooler & chiller will be necessary for many operators.

Fuel oil pump pressure

Worn fuel pumps increase the risk of starting difficulties, as the fuel oil pump pressure needed for injection cannot be achieved. An indication of fuel pump wear can be achieved by reading the actual fuel pump index for comparison with the test bed measurements. As a rough guideline, we consider the pump worn out when the index increase is 10 or more for heavy fuel. Such fuel pumps should be replaced for better engine performance.

Start checks are always recommeded to be done at regular intervals. However, as distillates of required minimum viscosity may not be available in all ports, it is particurlarly important to make start checks before entering high-risk areas (e.g. ports and other congested areas), so as to determine the individual low-viscosity limit for the engine. MAN Diesel & Turbo recommends that such checks are perfomed on a biannual basis, as described in the following:

- In an area for safe operation, change fuel to an available distillate.
- At different operating conditions, e.g. start, idle, astern and steady low rpm, gradually change the temperature of the fuel at engine inlet, corresponding to respectively 2, 2.5 and 3 cSt, see Fig. 8 for the typical viscosity and temperature relationship.
- Test start ahead/astern from the control room. If the engine does not start at the first attempt, cancel and repeat the start attempt. If the start ahead/astern functions properly with cancelled limiter, this solution can be used in emergency until either new fuel pumps are installed or a higher viscosity fuel becomes available.

An outcome of the test might be that the specific engine requires a viscosity that cannot be kept due to the influence from the many factors. If the fuel pumps are worn, they must be replaced and the start check repeated.

Installation of cooler or cooler & chiller

To be able to maintain the required viscosity at the engine inlet, it can be necessary to install coolers in the system. Fig. 9 shows the recommended locations to install coolers, however, the coolers can also be installed in other locations. PrimeServ can be contacted for tailormade solutions on email, primeserv-cph@mandieselturbo.com.

For the lowest viscosity distillates, a cooler may not be enough to cool the fuel sufficiently due to the cooling water available onboard. In such a case, it is recommended to install a so-called ‘chiller’. The chiller principle is shown in Fig. 10.

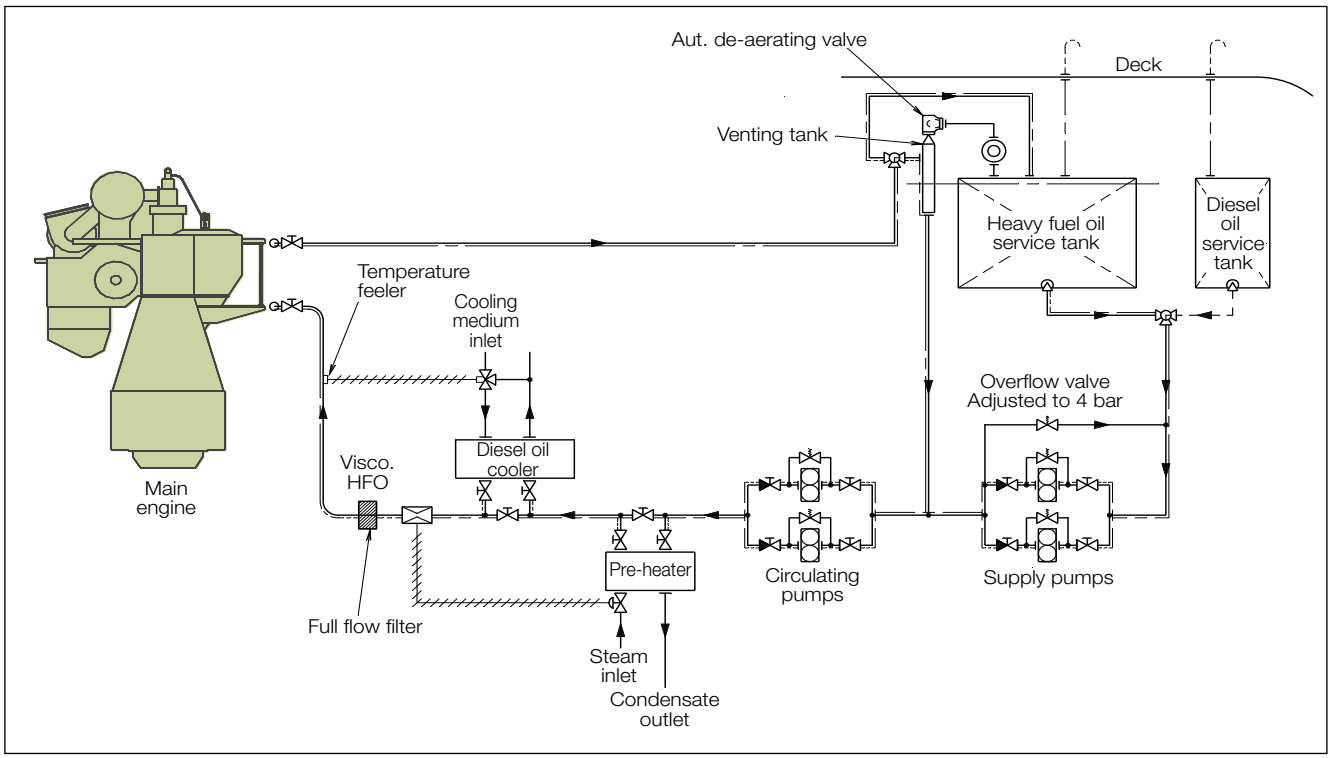


Fig. 9: Fuel system (in this example the cooler is installed after the circulating pumps)

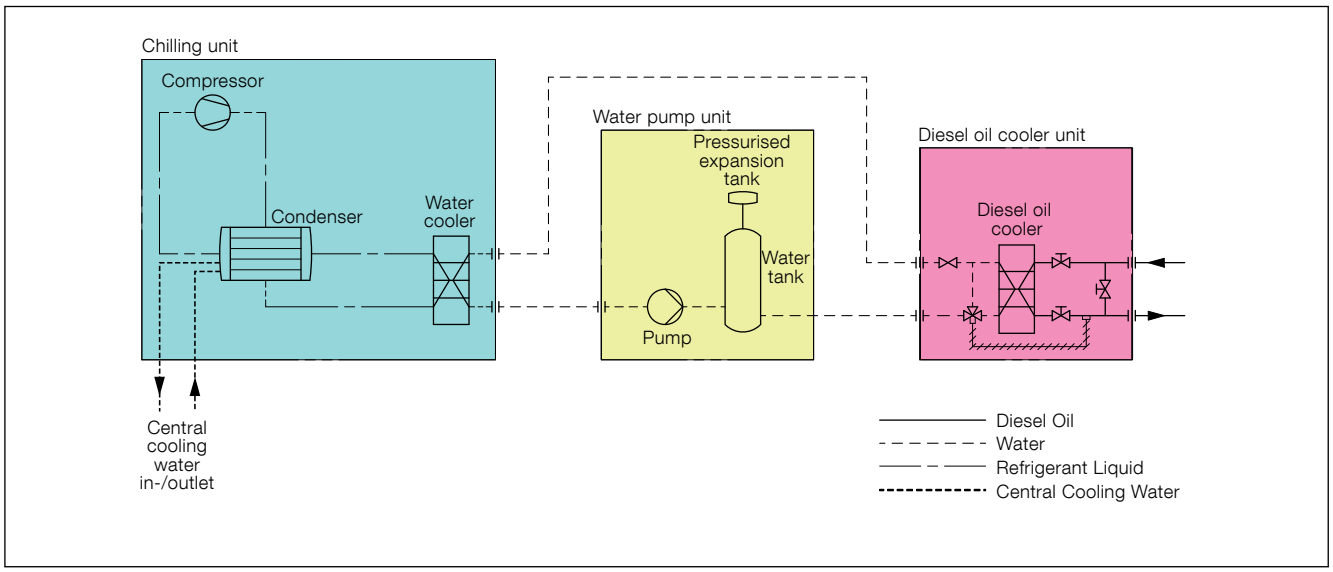


Fig. 10: Chiller principle

Other considerations when operating on distillates

External pumps

Not only will the engine fuel pumps be influenced by the fuel viscosity. Also most pumps in the external system (supply pumps, circulating pumps, transfer pumps and feed pumps for the centrifuge) need viscosities above 2 cSt to function properly, see also Fig. 9. We recommend contacting the actual pump maker for advice.

- It has been experienced from many ships that the circulation and supply pumps installed in the external fuel system have troubles in keeping the pressure if viscosity is too low. Some pumps need 5 cSt, which is far from the 2 cSt specified at engine inlet when operating on distillates. MAN Diesel & Turbo has been in contact with pump manufacturers that can deliver external pumps for fuels with viscosities below 2 cSt. Our Engine and System Application department in Copenhagen can be contacted for further information.
- Poor point restrictions: Distillates should not be cooled below 10°C above the pour point.

The poor point is a rough estimate for the lowest temperature at which the fuel will flow and be readily pumpable.

Change-over between heavy fuel and distillates

For specific change-over procedure, reference is made to our general instruction for changing over from heavy fuel to distillate and back in our Operation Book plate 4245-0120-0003 (older manual: Plate 705-03).

Before the intended change-over, we recommend checking

- The compatibility of the two fuels – preferably at the bunkering stage
- The wear in the fuel pumps, as leakage will increase when operating on low-viscosity fuel

Change-over of fuel can be somewhat harmful for the fuel equipment, because relatively cold distillate is mixed with hot heavy fuel. The process therefore needs careful monitoring of temperature and viscosity and during change-over two factors are to be kept under observation:

- The viscosity must not drop below 2 cSt and not exceed 20 cSt
- The rate of temperature change of the fuel inlet to the fuel pumps must not exceed 2°C/min to protect the fuel equipment from thermal shock.

Special care must be taken when operating fuel heater and cooler that above mentioned limits are not exceeded. Automatic operation also has to be kept under observation for correct and safe operation.

The engine load must be reduced during the change-over procedure. We recommend 25-40% load to ensure a slow reduction of the temperature. The load can – based on experience – be changed to a higher level – up to 75% load as described in our Operation Book. For operational assistance, please contact our LEO……???

A change-over of the main engine's fuel will result in a dilution of the fuel already in the booster circuit. A complete change of fuel (e.g. only distillate in the system) can therefore take several hours, depending on engine load, system layout and volume of fuel in the booster-circuit. Change-over can be confirmed by taking a fuel sample at main engine inlet.

Before manoeuvring in port, it should be tested that the engine is able to start on distillate.

Table I: Average bunker prices in USD/ton, July 2010

Grade	High sulphur, Heavy fuel (viscosity:380)	Low sulphur (max 1%) Heavy fuel (viscosity:380)	High sulphur, Heavy fuel (viscosity:180)	Low sulphur (max 1%) Heavy fuel (viscosity: 180)	Marine Diesel Oil	Marine Gas Oil
Fujairah	453		466		-	728
Houston	440		459		665	-
Rotterdam	438	479	461	503	-	662
Singapore	447	487	457	497	642	655

Source: www.bunkerworld.com/prices

Ignition and Combustion Characteristics of Low-Sulphur Fuels

The interest in fuel oils' ignition quality on the basis of the calculated CCAI or CCI values, or by measuring the fuel in an ignition instrument such as the FIA (Fuel Ignition Analyser), has never, in our experience, been greater than now. In the CIMAC Heavy Fuel Oil Work Group, we have compared fuel samples and service experience and, today, there are definitely more reports of cases where a poor liner and piston ring condition is thought to be due to a low ignition quality. The investigations indicate that a low-sulphur fuel has often been used when this happens, and the question is whether new oils from the spot market have characteristics which have so far been overlooked and, therefore, ought to be investigated further.

When focus is narrowly on the fuel oils, the drawback can be that some operators, when experiencing unacceptable conditions in the combustion chamber, may be prompted to blame the fuel without taking other possible causes into consideration, such as insufficient cleaning of the fuel oil, type of cylinder lube oil and feed rate.

The test results (Figs. 11 and 12), of the ignition and combustion properties measured on a FIA-100 Fuel Combustion Analyzer, show the effects of a mixture of fuels, Ref. [4]. Whether or not this fuel would have a negative effect on the performance of a two-stroke engine is open to doubt, but the test unquestionably illustrates that the fuel consists of a mixture of very different fuels with very different flashpoints, resulting in an irregular heat release in the test set-up.

The high temperature analysis illustrated in Fig. 11 apparently shows the three distinct fractions used in blending the fuel, i.e.:

- Heavy naphta
  boiling point (bp) ≈ 190-270°C
- Heavy gasoil
  bp ≈ 350-450°C
- Residue
  bp > 580°C.

A series of tests with fuels with expected low ignition qualities have been performed on MAN B&W two-stroke engines and, so far, we do not have any evidence to show that the ignition quality has any influence on the engine performance.

Lately, however, we have received reports from ships with dual fuel systems, where either the four-stroke auxiliary

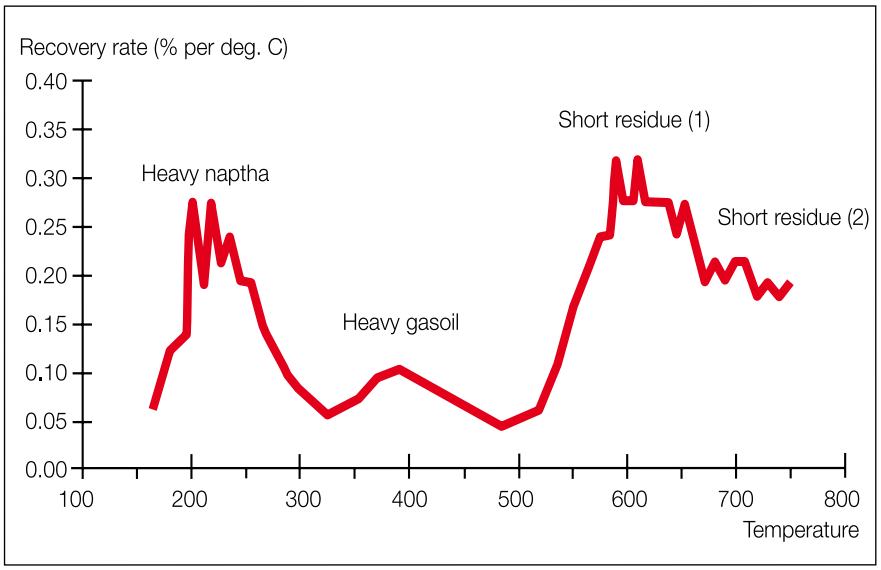


Fig. 11: SIMDIST (simulated distillation) recovery rate

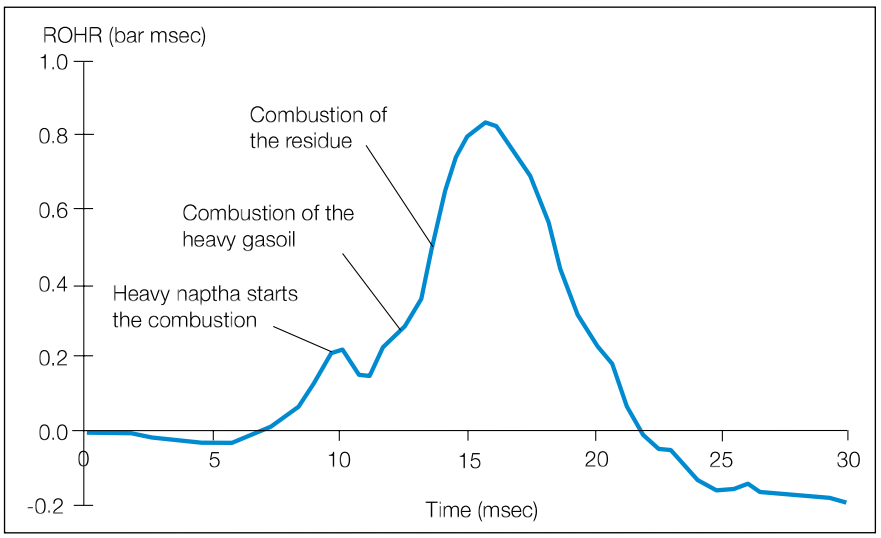


Fig. 12: ROHR (rate of heat release) curve

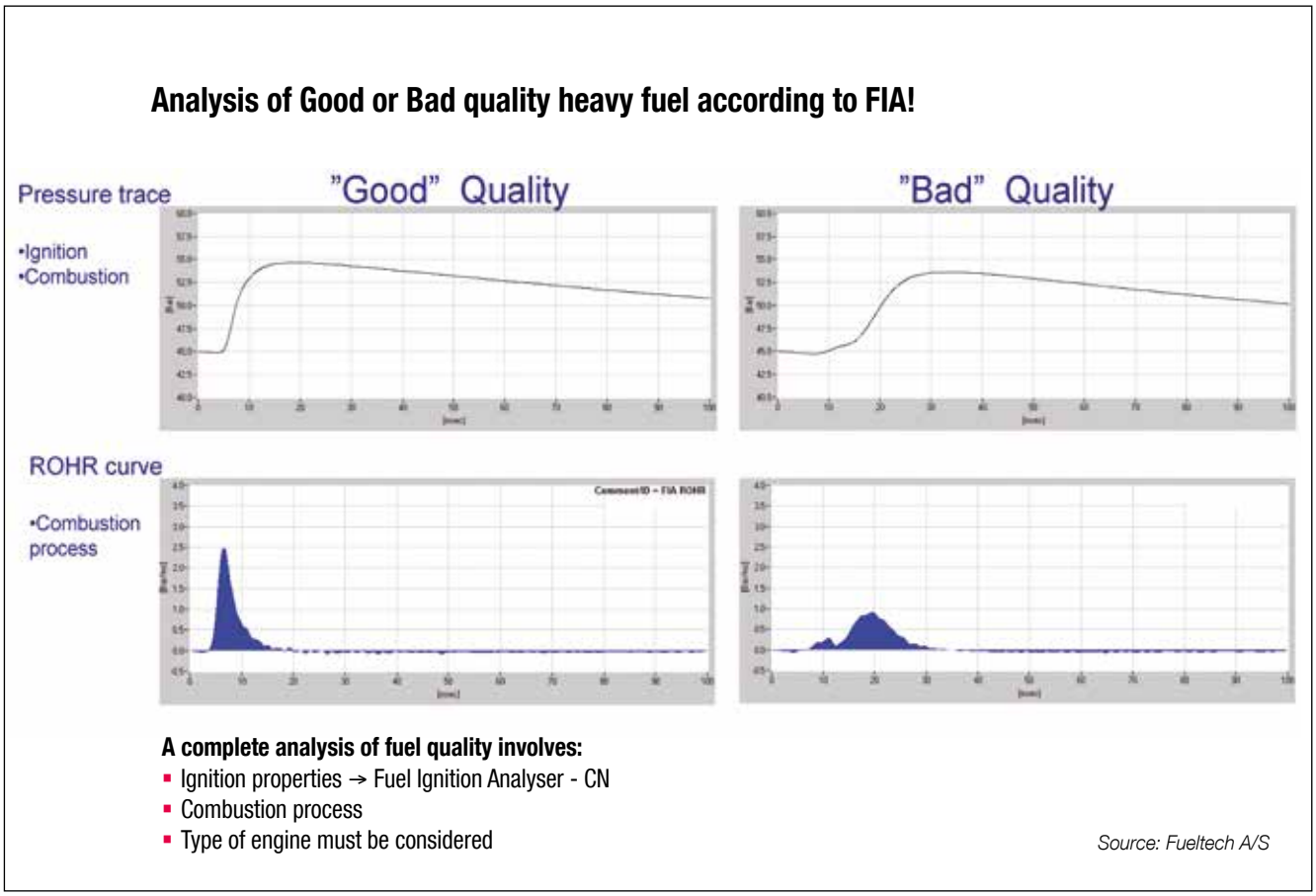


Fig. 13: FIA test method

engines were difficult to operate, or damage to the combustion chamber was found.

One step was taken in 2009 when interested companies formed a group that could provide for the definition and measurements of ignition and combustion characteristics of residual fuels in a standardised approach, with the aim of producing IP (Institute of Petroleum) test methods.

The group is looking particularly at the FIA test methods which, to our knowledge, are so far the best methods for such analyses. But the question is whether it is possible to translate the test results into engine performance.

The real task when using the FIA equipment is to generate a good test report, estimating the expected operation performance on any engine, see Fig.13.

It is obvious that the slower the speed and the larger the dimensions of the engine, the less sensitive it will be to ignition delays, but as an increasing number of ships are designed with unified systems, where the same fuel is to be used in the auxiliary and main engines, both engine types should be able to operate on the fuel available on the market.

The industry therefore needs to follow and consider low-sulphur fuel's introduction on the market.

Case story

A well-known oil company had to pay about USD 5 mill. in compensation to fishing boat owners, after an incident with an environmentally friendly low-sulphur diesel oil from one of their refineries in Europe. The oil company's investigation showed that the problem was probably related to heavy blending components causing incomplete combustion, deposits and, eventually, engine failure on the fishing vessels' four-stroke medium speed engines. It should be mentioned that some of the fishing boats had older-type diesel engines installed.

One possible reason for the bad fuel performance was thought to be a qual-

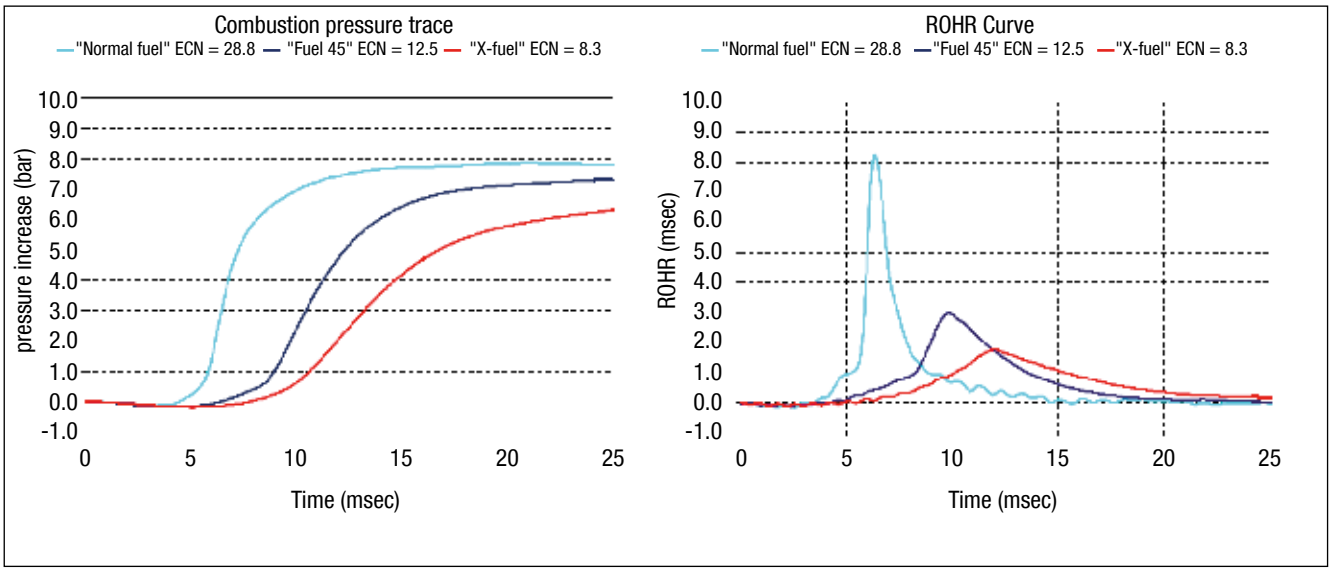


Fig. 14: FIA tests for combustion and heat release of three different fuels

ity slip during operation of the desulphurisation unit, and the oil company had to adjust the process in consequence of this incident.

The important message to the fuel companies is, consequently, that low-sulphur fuels must not jeopardise the operational reliability of the engine.

Fig. 14 illustrates the FIA tests for combustion and heat release of three different fuels, including a low-standard fuel oil (X). The fuel oil X was first tested on four-stroke medium speed and high speed engines showing unacceptable results in the lowest load area. At high load, the engines operated successfully. Even though the FIA-test indicated it as a troublesome fuel, there was no change in performance on MAN B&W two-stroke engines in neither the load area from 0 to 10% engine load, nor at higher engine loads.

ISO 8217 – 2010

Ignition characteristics, as determined by the Calculated Carbon Aromaticity Index (CCAI), must be specified according to the new ISO 8217-2010, Ref. [5].

Fuel Oil Auxiliary Systems

As low-sulphur fuel oil is more expensive, the higher sulphur fuel oil is preferred where accepted to be used. To enable the vessel to operate on low-sulphur fuel in restricted areas and switch to heavy fuel outside restricted areas, a dual fuel system is necessary.

For newbuildings, and as retrofit on existing engines if necessary, MAN Diesel & Turbo proposes three different fuel system configurations for engines operating on both high and low-sulphur fuel oils.

The ship's fuel oil system, from bunkering tanks through the settling tanks, treatment system and service tanks, may be affected by a frequent change in fuel oil type. Therefore, depending on the changeover frequency, various configurations may be relevant, the principal ones being listed below:

Fuel oil system, No. 1 (Fig. 15)

One MDO + one HFO system:
One bunkering, settling, centrifuging and service tank system for MDO, and one for HFO. Often several separate bunker tanks (heated) are available in the ship, enabling use of different bunker oils. Systems are merged before the pressurising (supply) stage leading to the engine circulating system. Auxiliary engines are usually fed from the joined systems, i.e. they burn the same fuels as the main engine. Also referred to as the "Unifuel" concept. It is possible to run the auxiliary engines on a separate fuel, i.e. by closing off the line from the HFO system to the auxiliary engines.

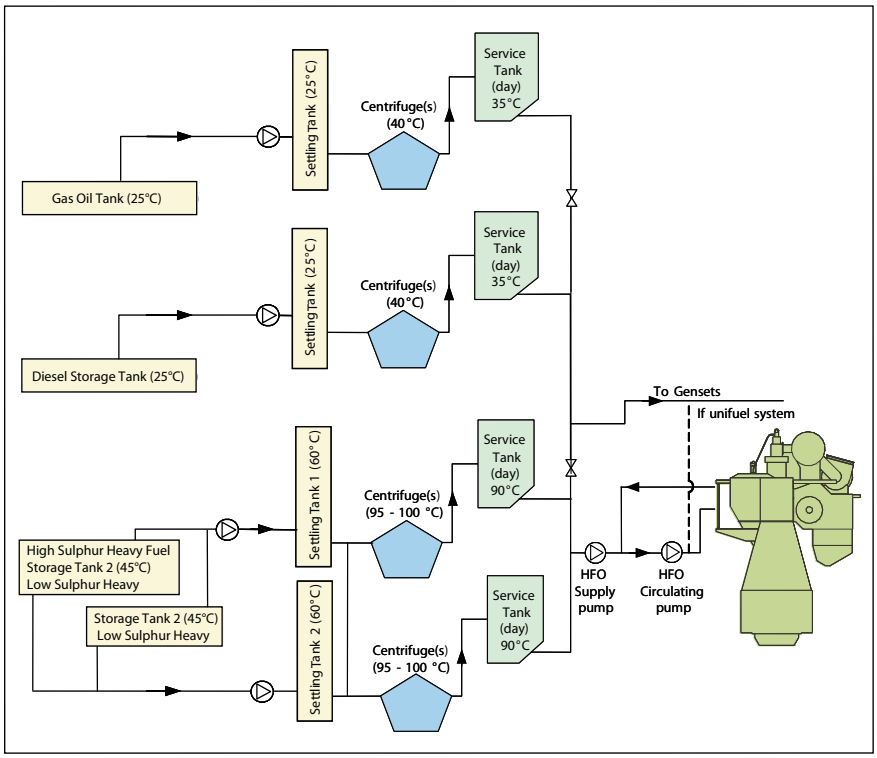


Fig. 17: One MDO settling tank and two sets of HFO settling and service tanks – system No. 3 Two distillate tanks and two heavy fuel tanks

Fuel oil system, No. 2 (Fig. 16)

One MDO + two HFO settling tanks:
One bunkering and settling system for each type of HFO. Possibly with additional bunker tanks. The HFO system is common from centrifuge(s) onwards, i.e. it is identical to fuel oil system No. 1, but with an additional settling tank for alternate HFO types. Unifuel or separate fuel.

Fuel oil system, No. 3 (Fig. 17)

One MDO + two separate HFO systems:
Two separate bunkering, centrifuging and settling and service tank systems for each type of HFO. The two HFO systems are completely separate up to the joining point before the supply pumps pressurising the engine circulating system. Unifuel or separate fuel.

From the onset, the ship's fuel oil system is perhaps one of the most complicated systems on board. Naturally, introducing multiple fuel oil systems implies considerable additional complexity to the ship design in general and to the engine room design in particular. For the three alternatives, the additional equipment listed in Table II is conceptually envisaged.

Cylinder Lube Oil Auxiliary Systems

Regarding the auxiliary system for the cylinder lube oil handling, there are several cylinder lube oil system constellations that could be implemented to allow various degrees of adaptation to any specific bunker oil sulphur content. Below, we have listed the technical solutions used today.

Cylinder oil system, No. 1 (Fig. 18)

One cylinder oil system:
A conventional system that can handle one cylinder lube oil at a time, i.e. running with a fixed base number. The feed rate can be manually controlled and is seldom adjusted.

Cylinder oil system, No. 2 (Fig. 19)

One cylinder oil system where the engine is equipped with electronic Alpha lubricators:
Also ability to handle one cylinder lube oil at a time, i.e. running with a fixed base number. The electronic lubricator (very much) eases the adjustment of feed rate and, thereby, the alkalinity influx.

Cylinder oil system, No. 3 (Fig. 20)

Two cylinder oil systems:
Consists of two cylinder lube oil storage and service tank systems. Systems are joined before the engine flange via a changeover valve. Ability to handle two different cylinder lube oils, a conventional BN oil (usually BN70) and maybe a low-BN oil (e.g. BN50 or BN40).

In general, the complexity of the cylinder lube oil system increases 1 through 3, but not as much as the similar increase for the fuel oil systems, simply because the fuel oil system is more extensive (more components and more space consuming).

One way of preparing the ships could be to install a partition in the cylinder oil storage tank (Fig. 21), instead of arranging two cylinder oil tanks. Thereby, the tank can be filled in the following way:

Table II: Additional fuel oil system equipment

Fuel oil system:	Additional equipment
No. 1	Base case – no additionals
No. 2	Possibly additional bunker tank(s)
	Possibly an additional bunkering system for the additional bunker tank(s)
	Possibly enhanced bunker-heating system to accommodate different fuel characteristics (pumping temperature, flash point, viscosity, etc.)
	One additional settling tank
	One additional transfer pump to the settling tank
No. 3	All of those associated with system No. 2
	Possibly an additional set of fuel oil centrifuges
	Possibly an additional centrifuge room, including sludge tank, etc
	Additional service (day) tank
	Additional piping and instrumentation

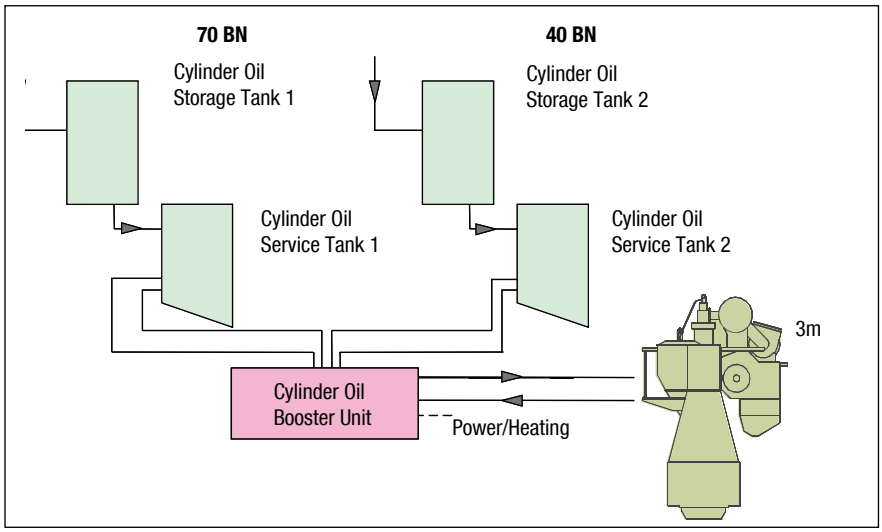


Fig. 20: Two independent cylinder oil systems

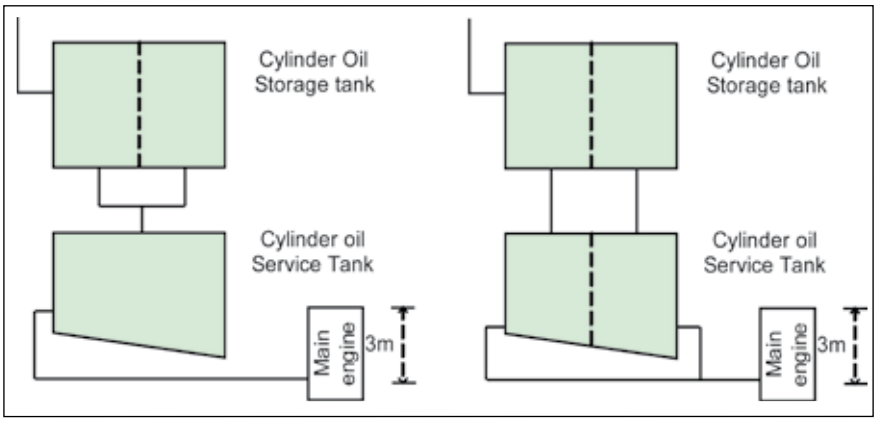


Fig. 21: Two ways of partitioning cylinder oil storage and service tanks

- BN70 cylinder oil on both sides of the partition
- BN40 cylinder oil on one side and BN70 on the other.

In the more complex system, separate piping from each side of the partitioned storage tank can lead to the service tank, which may also be partitioned.

The systems shown can be combined in numerous ways, and variations of the described systems can be chosen. You are welcome to contact MAN Diesel & Turbo in Copenhagen, Denmark, for special requirements, or if further information is needed.

Experience with Wet Scrubbing Techniques and Expectations to Future Use

As previously described, one solution to meet the sulphur legislation is to reduce the SO_x in the exhaust gas. The so-called abatement technology used for many years on power stations all over the world.

Even though scrubbers are not a core business of MAN Diesel & Turbo, six years ago we initiated cooperation with manufacturers and shipowners to look at this technique for the marine market.

Accordingly, we have made more than 170 tests of scrubbers of various designs on a 1 MW four-stroke engine in Denmark.

The first results obtained made it clear that current scrubber techniques need to be optimised and tailormade for marine use.

To begin with, saltwater was used as the agent for removing SO_x from the exhaust gas. Later, freshwater with NaOH was used and both techniques work.

On an Aalborg Industries (AI) boiler, SO_x could not even be measured in the exhaust gas after the scrubbing process with freshwater and NaOH.

This solution seems to be superior to the saltwater solution when it comes to efficiency and the amount of drain and process water, but it will have a consumption of NaOH.

In 2009, an AI scrubber was installed on a DFDS passenger and car carrier with a 20 MW main engine. The scrubber is able to operate on both saltwater and freshwater with NaOH and the long-term service tests show promising results.

The plan is to operate the scrubber in the high-efficient NaOH-mode in coastal areas and in saltwater mode when in open sea, where a lower scrubbing efficiency is required.

This could give the lowest payback time, which for this vessel could be as low as two years, depending on the development in fuel prices.

Fig. 22 shows three of the scrubber solutions tested on two-stroke engines, and the results.

Also according to EGCSA, obtainable results from different scrubber manufacturers are:
PM trapping > 80%
SO_x removal > 98%
(PM: Particulate Matters)

Further information on scrubbers can be obtained at the Exhaust Gas Cleaning Systems Association (www.EGCSA.com).

On the legislation side, IMO has accepted the scrubber solution as an alternative to removing the sulphur in the fuel, and now IMO guidelines exist for the wash water criteria.

However, MAN Diesel & Turbo expects that exhaust gas scrubbers represents a realistic solution for ships operating in coastal areas and, in the long term, also for internationally operating merchant vessels, when the maximum sulphur limit content in heavy fuel is lowered to max. 0.5% in 2020.

Objectives	Participants	Scrubber	Test results	Ship test	Ship test
Development and test of scrubber for after - treatment	Clean Marine MAN Diesel & Turbo		PM trapping: 35% 80% (salts add.) SO_X removal: 73% 95% (salts add.)	Banasol 7S50MC-C 9MW	
Development and test of scrubber for after - treatment	Aalborg Industries Alfa Laval DFDS MAN Diesel & Turbo		PM trapping: 79% SO_X removal: 100% (NaOH)	Tor Ficaria 9L60MC-C 20MW	
Development and test of scrubber for after - treatment and EGR	APM MAN Diesel & Turbo		PM trapping: 73% SO_X removal : 96% (NaOH)	Alexander Mærsk 7S50MC 9MW	

Fig.22: Scrubber solutions tested

Summary

It is inevitable that the exhaust gas emission from marine engines will be further regulated, and we expect that many new engines, and especially existing engines, will eventually have to be operated on low-sulphur fuel.

On MAN B&W two-stroke engines, no difference in the engine performance is considered between distillate and heavy fuel operation. However, operators must take the necessary precautions and follow our service instructions

Abbreviations

ECA: Emission Controlled Areas
BN: Base Number
TBN: Total Base Number
CCAI: Calculated Carbon Aromaticity Index
CCI:
FIA: Fuel Ignition Analyser
IP: Institute of Petroleum
PM: Particulate Matter
IMO: International Maritime Organisation
CARB: California Air Resources Board
MFO: Heavy Fuel Oil
MDO: Marine Diesel Oil
MGO: Marine Gas Oil
SO_x: Sulphur oxides
NO_x: Nitrogen oxides
HC: Hydrocabons
CO: Carbon monoxide
CO_2: Carbon dioxide

References

[1] Service Letter SL09-515 "Guidelines on Operation on Distillate Fuels"

[2] Service Letter SL09-507 "Cylinder Lubrication Update – Guiding ACC Feed Rates for Alpha Lubricator and ME Lube"

[3] “FIA-100 – Fuel Combustion Analyzer for HFO”, by Jan Kjetil Paulsen, Fueltech AS, Norway, November 2004

[4] ISO 8217-2010 Petroleum Products - Fuels (class F) - Specifications of marine fuels, Fourth edition, 2010-06-15.

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5510-0075-01ppr Sep 2014 Printed in Denmark

MAN Diesel & Turbo
Teglholmsgade 41
2450 Copenhagen SV, Denmark
Phone +45 33 85 11 00
Fax +45 33 85 10 30
info-cph@mandieselturbo.com
www.marine.man.eu

MAN Diesel & Turbo – a member of the MAN Group