Operation on Low-Sulphur Fuels
Two-Stroke Engines

Contents:

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Introduction

The average sulphur content of fuel oil used for marine diesel engines is 2.7%. This will undoubtedly change with the coming emission legislation, which will lower the emission limits of SO_x, NO_x, particulate, HC and CO.

So far, the authorities have reduced the SO_x content in the exhaust gas by introducing limits on the content of sulphur in the fuel oil used. This is a much more efficient and straightforward solution, obtained from the refining process, than the installation of separate complicated SO_x cleaning facilities 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 fuel oil 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.

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

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 IMO

The IMO Annex VI of MARPOL 73/78, Regulations for the Prevention of Air Pollution from Ships, has just been ratified and will take effect as from May 2005.

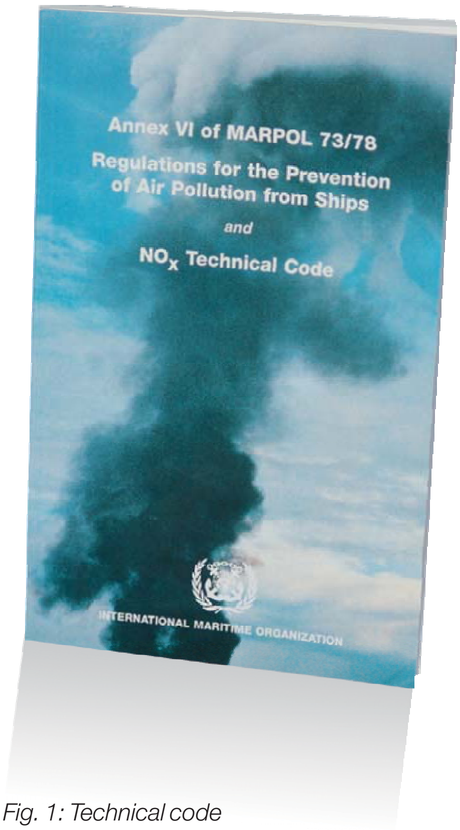

Fig. 1: Technical code

Thus, the SO_x limit applies to all vessels in the category of ships with an engine power output of more than 130 kW. The NO_x limit is only for vessels where the keel was laid after 1 January 2000.

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

However, in restricted areas like the Baltic Sea, the English Channel and the North Sea, the limit is 1.5% sulphur, which will be enforced as from 19 May 2006.

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

The EU

The EU has introduced separate regulations to cut sulphur dioxide (SO_2) emissions from ships.

In reaching a political agreement on the Commission's marine fuel sulphur proposal, the Environment Council has agreed to reduce ships' yearly SO_2 emissions in the EU by over 500,000 tonnes from 2007, to the benefit of human health and the environment.

Currently, marine fuel has a maximum sulphur content of 5% or 50,000 parts per million (ppm), compared with petrol for cars, which will have 10 ppm from 2007. As part of its 2002 ship emissions strategy, the Commission presented a proposal for a directive to reduce the sulphur content in marine fuels used in the EU. The main provisions were:

- a 1.5% sulphur limit on fuels used by all ships in the Baltic Sea, the North Sea and the Channel. Today's political agreement incorporates this provision, and sets implementation dates starting on 19 May 2006
- the same 1.5% sulphur limit on fuels as used by passenger vessels on regular services between EU ports from 1 July 2007. EU Ministers have rubber-stamped this and brought the deadline forward to 19 May 2006
- a 0.2% sulphur limit on fuels used by inland vessels and seagoing ships at berth in EU ports. The Council has agreed to delay a tighter 0.1% limit until 1 January 2010, to allow single-fuel ships time to adapt their fuel tanks. A further two year delay was offered to 16 unifuel ferries serving the Greek islands.

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 a test for larger engines.

At the same time, some companies are talking about emission trading which, in principle, means that the possibility of polluting more than the specified limits can be bought from ships that are polluting less than they are allowed to, see Fig. 2. Whether emission trading can be applied in the marine sector in the same way as emissions trading between power stations is still rather unclear, as the administrative load would be extensive, and the possibility of checking for compliance with such trading rules would be limited.

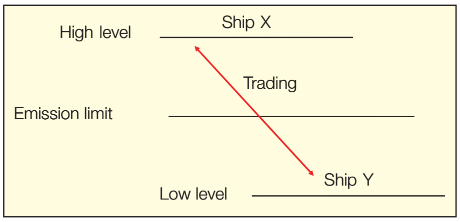

Fig. 2: Trading of emission between X and Y

Incompatibility of Fuels

In near future, ocean-going ships entering coastal waters will have to switch from a heavy fuel oil (HFO) to a lower viscosity distillate fuel, in order to comply with the low-sulphur requirement if a low-sulphur HFO is not available.

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

Table I: Average bunker prices in US$/ton, October 2005

Grade	IFO380	IFO180	MDO	MGO
Fujairah	298	313	552	555
Houston	291	313	689	
Rotterdam	265	285	523	580
Singapore	323	335	538	543

Source: www.bunkerworld.com/prices

Low-sulphur HFO will, expectedly, have a somewhat higher price than the HFO on the market today, due to increasing demand and the cost of the desulphurisation process.

When switching from HFO 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 HFO are likely to precipitate as heavy sludge, with filter clogging as a possible result, which in turn will cause fuel starvation in the engine.

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-sul-phur fuel more cases of incompatibility might be seen.

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 are comparing 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.

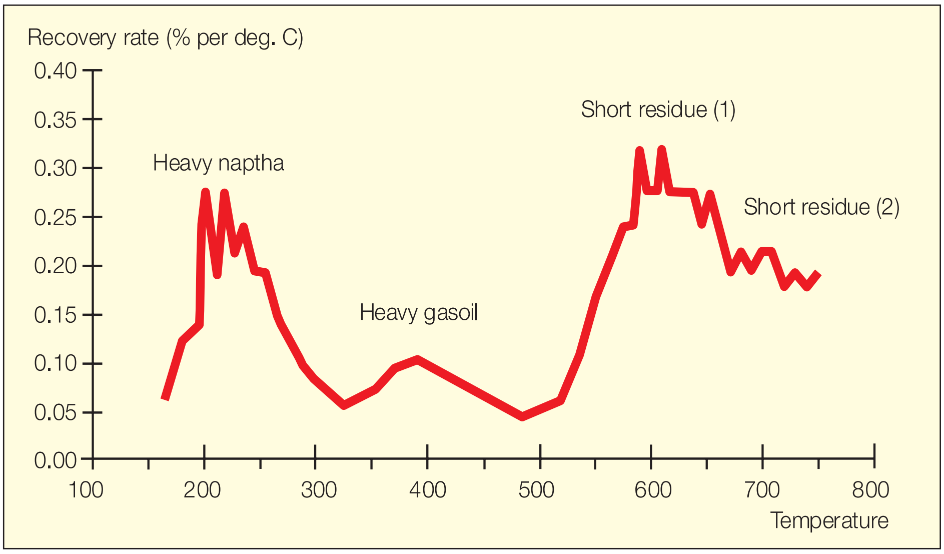

Fig. 3: SIMDIST (simulated distillation) recovery rate

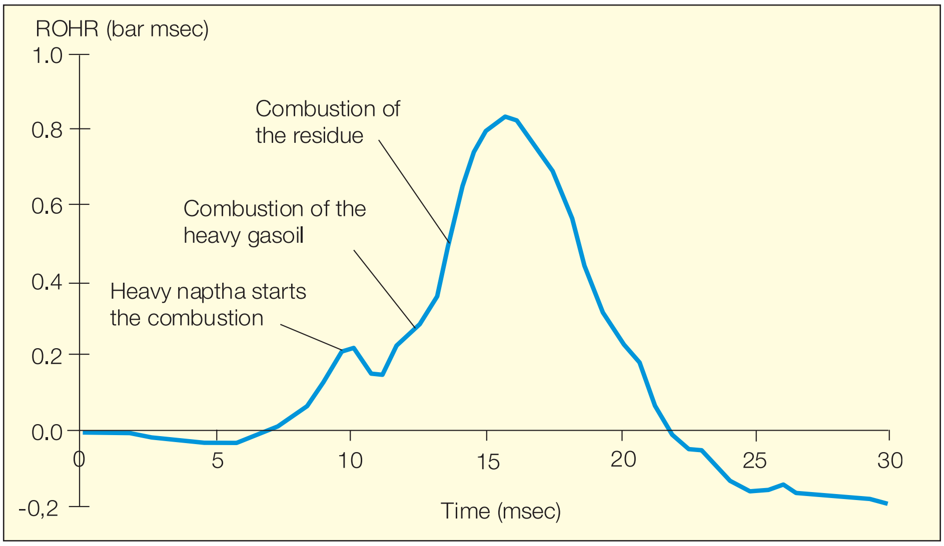

Fig. 4: ROHR (rate of heat release) curve

The below test results (Figs. 3 and 4), of the ignition and combustion properties measured on a FIA-100 Fuel Combustion Analyzer, show the effects of a mixture of fuels, Ref. [3]. 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. 3 apparently shows the three distinct fractions used in blending the fuel, i.e.:

- heavy naphta (bp ≈ 190-270°C),
- heavy gasoil (bp ≈ 350-450°C), and
- 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 auxiliary engines were difficult to operate, or damage to the combustion chamber was found. In addition to the traditional CCAI or CCI values, which are not considered being reliable, it is being considered to introduce the ignition characteristics in the CIMAC fuel recommendation and the ISO 8217 fuel standard.

One step was taken earlier this year when interested companies formed a group that could provide for the definition and measurements of ignition and

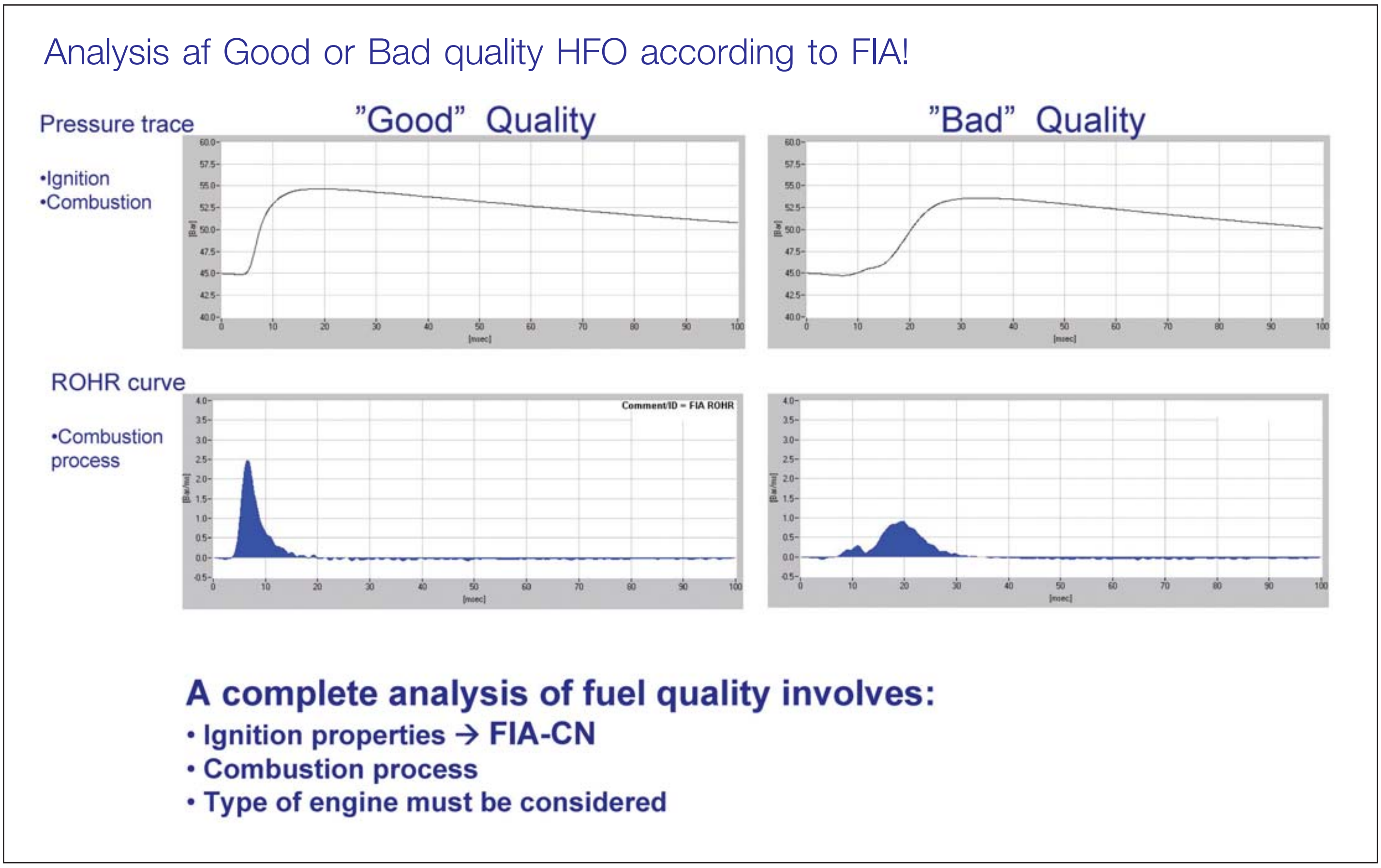

Fig. 5: FIA test method

Source: Fueltech AS

combustion characteristics of residual fuels in a standardised approach, with the aim of producing IP test methods.

The group's name is EI Task Force ign/comb characteristics.

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.

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 dual fuel 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 quality 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.

Changeover between High and Low-Viscosity Fuels

To protect the injection equipment against rapid temperature changes, which may cause sticking/scuffing of the fuel valves and of the fuel pump plungers and suction valves, the changeover is to be carried out according to a specific MAN B&W changeover procedure.

Today, a changeover between fuels with major differences in viscosity is very rare, and is normally only carried out before a major overhaul of an engine, or during a long stop of the engine. Thus, in future this would call for a more frequent number of changeovers according to the changeover procedure on board, which causes a reduction of load and a slow change in the temperature, becoming higher or lower, depending on the viscosity of the fuel changed to.

Case story – changeover from DO to HFO

It is the rising of the diesel oil temperature that represents the time limiting factor deciding when the diesel oil can be replaced with HFO.

According to the instruction manual, the temperature should not be changed by more than max. 2°C/min.
For example, diesel oil is to be changed to HFO:

1. The system contains 40°C diesel oil

2. The diesel oil is heated to 80°C before adding the HFO.
   This takes (80 – 40)/2 = **20 min.**

3. HFO is added at a temperature of max. 25°C higher than the diesel oil, i.e. at 105°C

4. However, the temperature rise should still be max. 2°C/min.
   Therefore, it takes an additional (105 – 80)/2 = **12.5 min.**

5. From now on, there should be only HFO in the system

6. The temperature is now raised from 105 to 150°C = **22.5 min.**

We therefore conclude that it takes 20 + 12.5 min. = 32.5 min. from the start of the changeover until HFO is in the system. Moreover, it takes another 22.5 min., i.e. 55 min. from the start of the changeover, before the system is running on HFO at 150°C.

In order to make the changeover process more secure and easy, MAN B&W Diesel suggests the use of an automatic control system.

However, if so desired, this process can still be carried out manually in accordance with MAN B&W Diesel procedure.

For your guidance, we have calculated the changeover time for a 380 cSt HFO and a marine diesel oil.

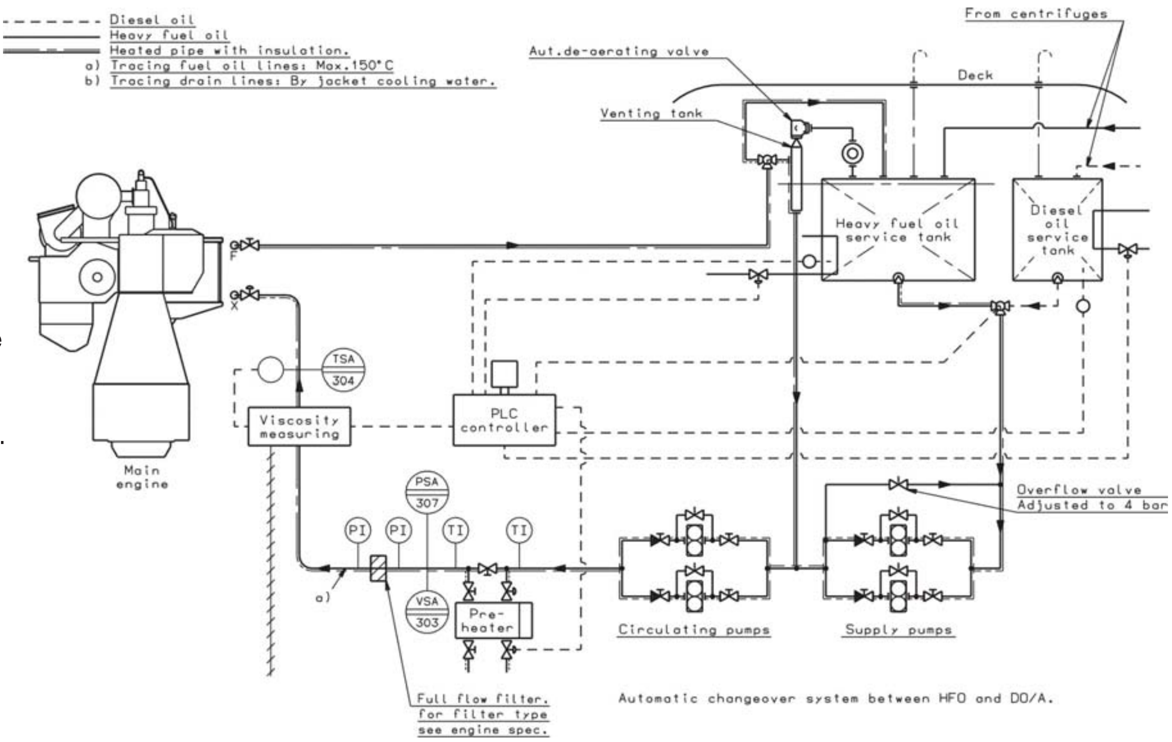

Fig. 6: Automatic system for changeover between fuels of different viscosity

Fuel Viscosity at Engine Inlet

In various chemical combinations, the sulphur in the fuel oil has a lubricating effect.

The use of DO and GO with a sulphur content close to zero and, at the same time, a low viscosity might cause fuel pump and fuel valve wear and, consequently, the risk of sticking (Fig. 7). But this situation needs to be considered also from a hydrodynamic point of view, so if the viscosity and, thereby, the oil film is thick enough, also low-sulphur fuels can be used.

This risk limits the viscosity at the engine inlet to min. two cSt. In special cases, with a very low viscosity gas oil and high ambient temperatures, this might call for cooling of the diesel oil before the proper viscosity can be obtained at the engine inlet. The viscosity of typical fuels is shown in Fig. 8.

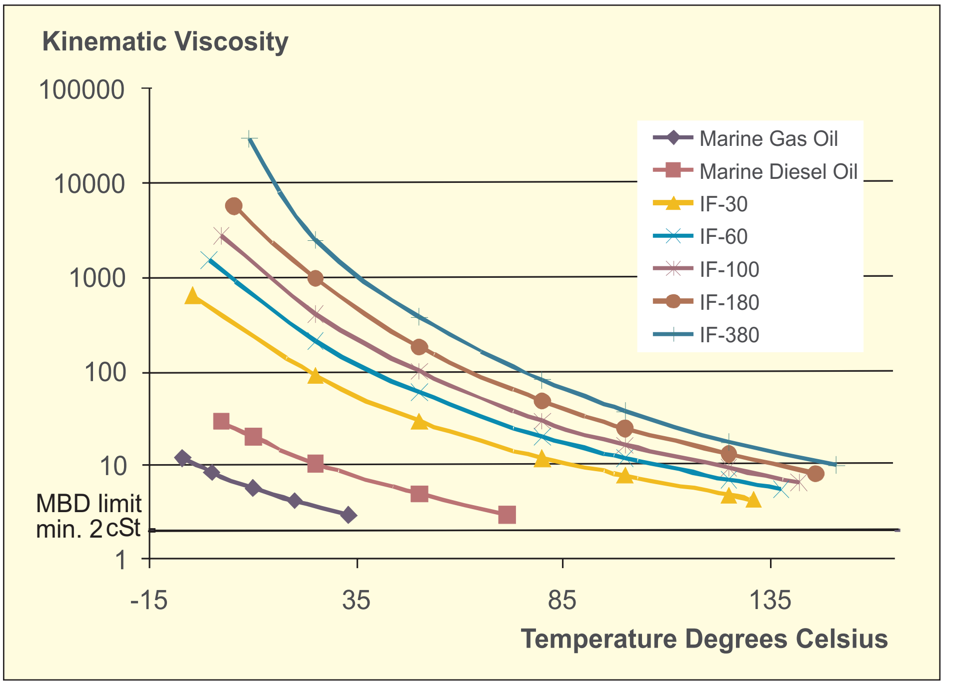

Fig. 8: Marine fuel viscosities

Fig. 7: Fuel pump plunger sticking

Correlation between Low-Sulphur Fuel, Cylinder Lube Oil BN and Cylinder Lube Oil Feed Rate

Our experience with 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 and, therefore, should be considered on a case-to-case basis.

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 HFO 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. 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 sulphur.

In order to neutralise the acid, the cylinder lube oil contains alkaline components – usually calcium salts. The Base Number (BN or TBN) is a measure of

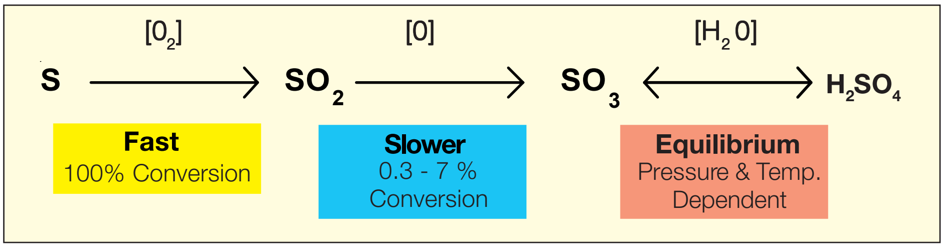

Fig. 9: Chemical conversion of S to H_2SO_4

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. 10 shows the same cylinder liner, first where BN70 has been used, and then where BN40 has been used for the same type of low-sulphur fuel.

Based on experience, MAN B&W Diesel 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 hydrodynamic 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 the sulphur content (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 = 0.21-0.25 g/bhph, based on a BN70 cylinder oil. The minimum feed rate for proper oil distribution and oil film thickness has so far been set to 0.5 g/bhph,

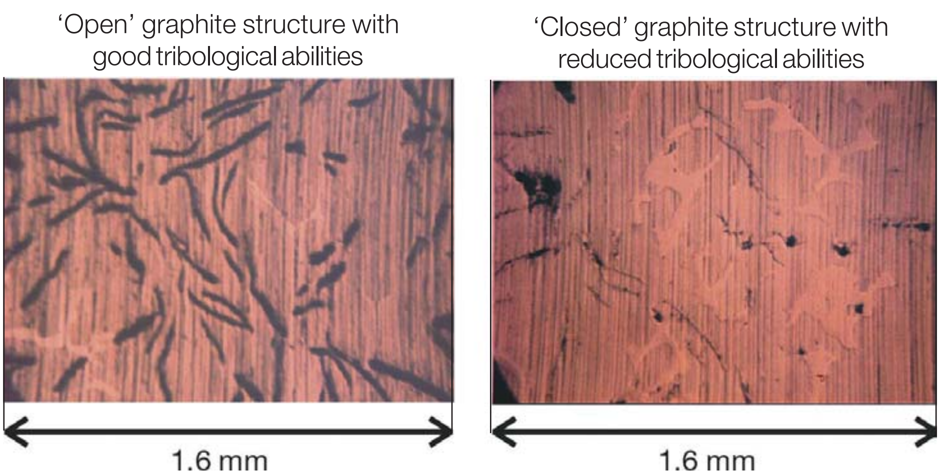

Fig. 10: Cylinder liner surface

which at the above-mentioned equation will be reached at 2% sulphur. This means that the theoretical limit, using an ordinary BN70 oil, is 2%.

As an example, an engine using 1% sulphur fuel at a dosage of 0.5 g/bhph would be overadditivated.

Therefore, 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 (BN40-50).

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.11, which is used for cylinder lubrication on MAN B&W engines, has shown that a lube oil feed rate down to 0.5 g/bhph 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.

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 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.

However, MAN B&W Diesel recommend the following practical approach.

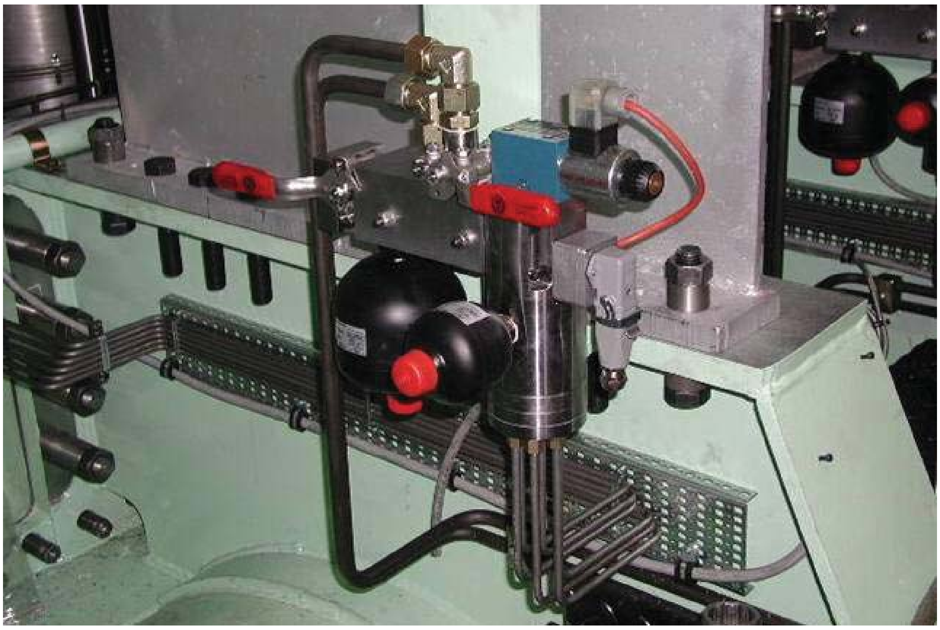

Fig. 11: Alpha Lubricator

Practical Approach

The correlation between fuel sulphur level and cylinder oil can be shown as follows:

Fuel sulphur level <1%:	BN40/50 recommended Changeover from BN70 to BN40/50 only when operating for more than one week on <1% sulphur
Fuel sulphur level 1-1.5%:	BN40/50 and BN70 can be used, see Fig. 12
Fuel sulphur level >1.5%:	BN70 is recommended.

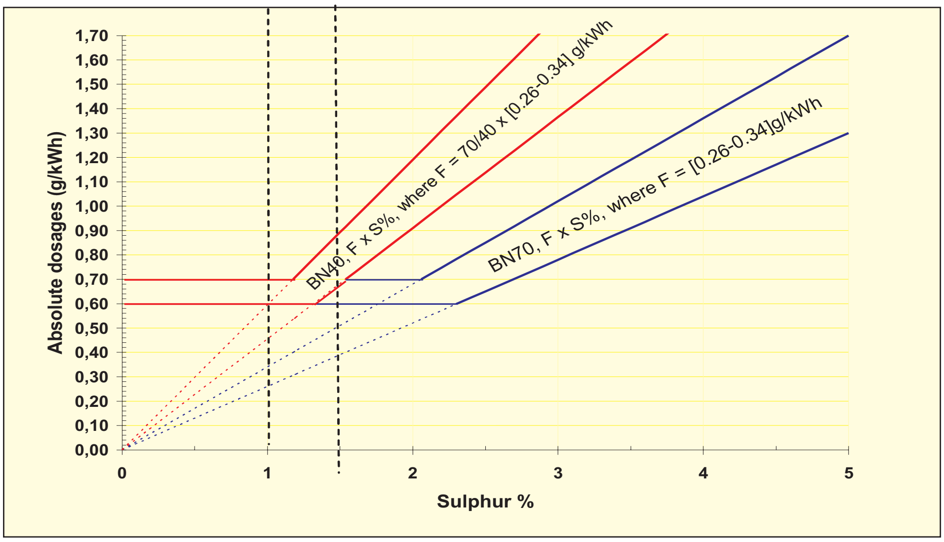

Fig. 12: Use of BN40 vs. BN70 cylinder oils

Fuel and Cylinder Lube 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 B&W Diesel 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 (unbiased):

Fuel oil system, No. 1

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.

Fuel oil system, No. 2

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,

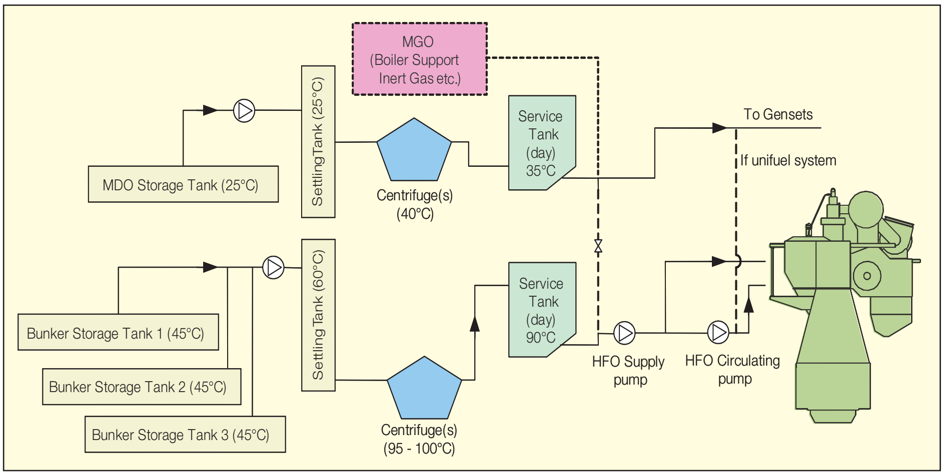

Fig. 13: One MDO settling tank and one HFO settling tank – fo system No. 1

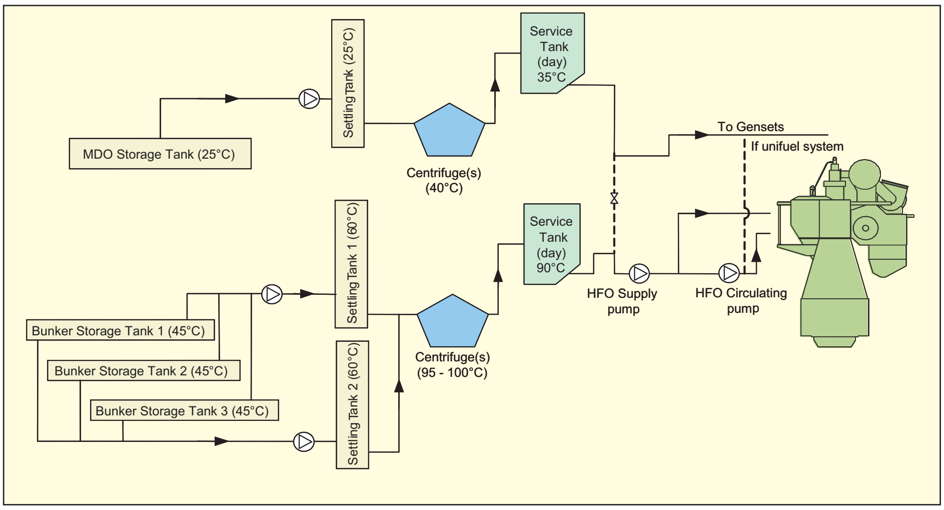

Fig. 14: One MDO settling tank and two HFO settling tanks – fo system No. 2

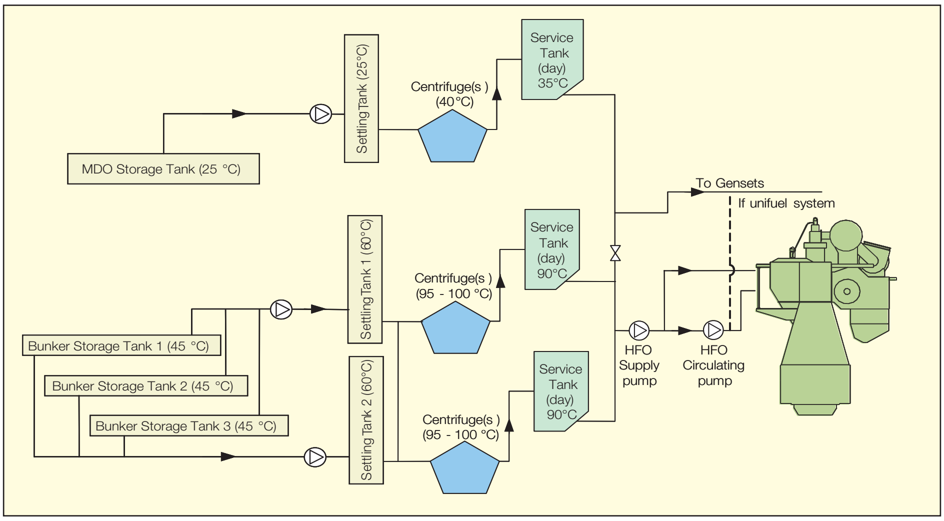

Fig. 15: One MDO settling tank and two sets of HFO settling and service tanks – system No. 3

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

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.

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

One cylinder oil system:
A conventional system, see Fig. 16. Ability to 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

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

Table II: Additional FO 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

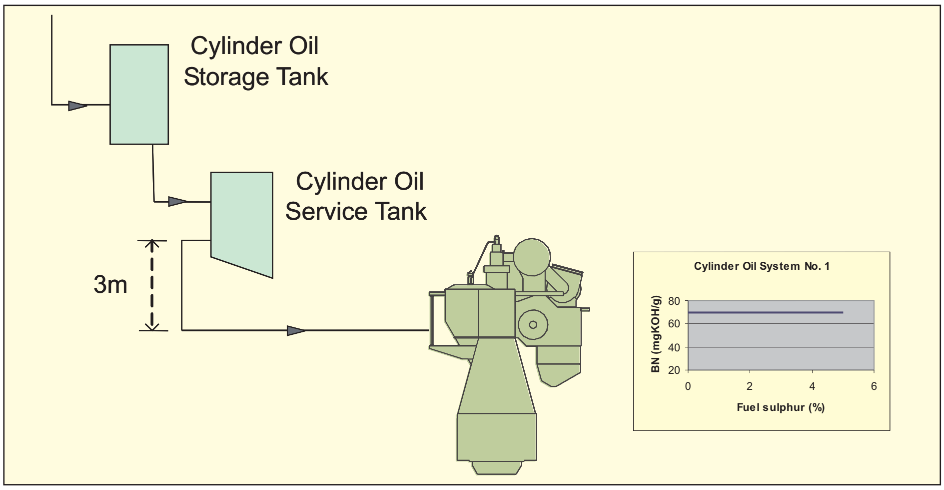

Fig. 16: One cylinder oil system

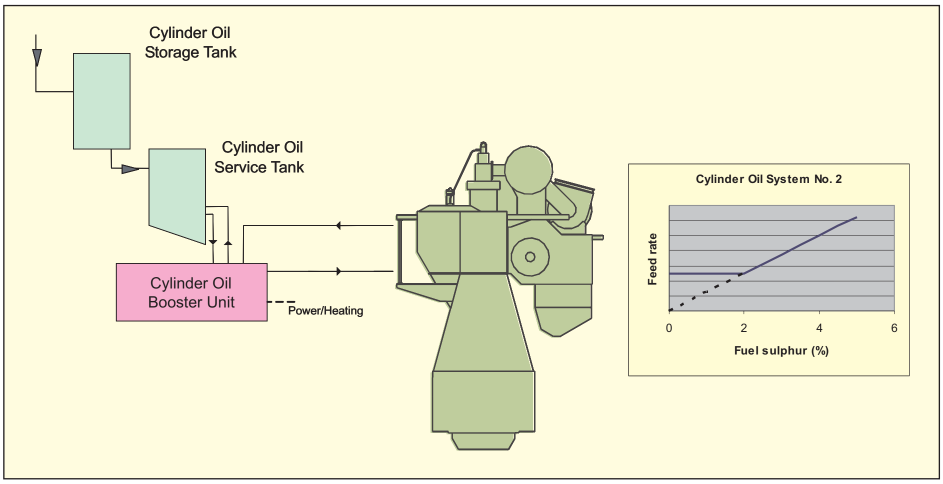

Fig. 17: One cylinder oil system, engine is equipped with

number. The electronic lubricator (very much) eases the adjustment of feed rate and, thereby, the alkalinity influx, see Fig. 17.

Cylinder oil system, No. 3

Two cylinder oil systems:
Consists of two cylinder lube oil storage and service tank systems, see Fig. 18. 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. 19), instead of arranging two cylinder oil tanks. Thereby, the tank can be filled in the following way:

- 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 B&W Diesel in Copenhagen, Denmark, for special requirements, or if further information is needed.

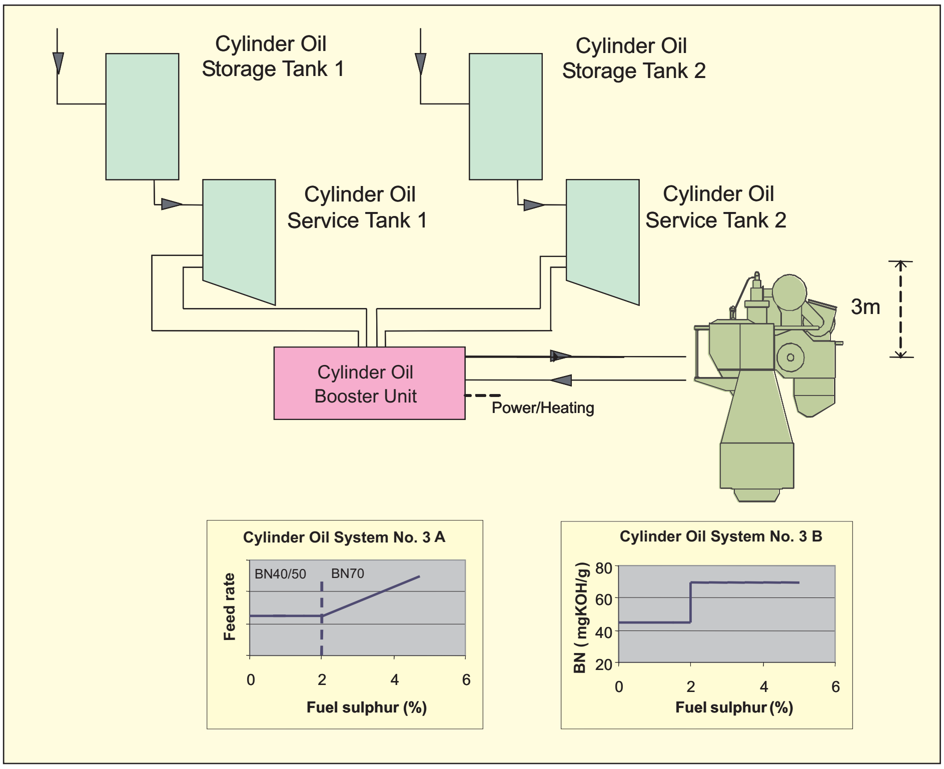

Fig. 18: Two independent cylinder oil systems

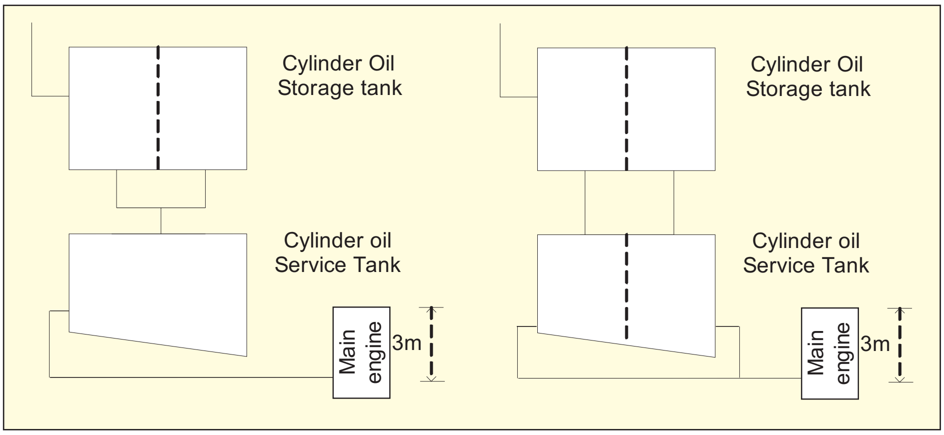

Fig. 19: Partitioning of cylinder oil storage and service tanks

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. This will be the case even though exhaust gas scrubbers and/or emission trading have become possible by the time new regulations are introduced.

On MAN B&W two-stroke engines, no difference in the engine performance is considered between DO/GO and HFO operation, where the HFO used today has a sulphur content of 2.7% on average.

However, operators have to take the necessary precautions, and the marine industry has to consider what general application the new low-sulphur fuels are being designed for, especially with regard to the fuel compatibility between fuels, and ignition qualities.

References

[1] EU, Environment – Air Pollution – Fuel Quality Monitoring

[2] "The Interaction between Low-sulphur Fuel and Lubricants", by Kjeld Aabo, MAN B&W Diesel A/S

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