

## Appendix 5. MARINE FUELS & SHIP EMISSION CONTROLS

### CONTENTS

A5: 1	Introduction .....	2
A5: 2	Bunkering Practice and Strategy .....	2
A5: 3	Fuel Consumption.....	3
A5: 4	Reducing sulphur in bunker fuels - ship technical aspects .....	4
A5: 5	Mixing fuel qualities.....	5
A5: 6	Shipboard technical improvements to reduce SO <sub>2</sub> and NO <sub>x</sub> emissions	6
A5: 6.1	SO <sub>2</sub> emissions .....	7
A5: 6.2	NO <sub>x</sub> emissions.....	8
A5: 7	Refinery Issues.....	10
A5: 8	Price differentials between high and low sulphur fuels.....	11
A5: 9	Costs of technological options .....	14
A5: 9.1	Reduction in NO <sub>x</sub> emissions.....	14
A5: 9.2	Reduction in SO <sub>x</sub> emissions.....	16
A5: 10	References.....	17

## **A5: 1 Introduction**

This appendix considers the ship technical aspects of policies to reduce emissions of SO<sub>x</sub> and NO<sub>x</sub>.

The technical aspects are those that relate to modified combustion, burning different quality fuels, carrying different quality fuels, scrubbing exhaust emissions to reduce sulphur emission and other exhaust treatments.

Some of these matters relate to ship operations, in addition to equipment and maintenance, and it is appropriate to commence with a brief description of the operational issues confronting a ship when taking on board fuel (bunkering).

## **A5: 2 Bunkering Practice and Strategy**

Decisions regarding bunkering strategy will depend upon such factors as:

- Safety
- Deadweight
- Loadline
- Compatibility
- Price

**Safety:** No vessel should undertake a voyage without sufficient fuel to complete that voyage plus some reserve. A reserve of 3 to 5 days over and above required consumption estimates is normally considered sufficient. Voyages may be broken for bunkering stops at a number of places en route. A vessel does not therefore need on board on commencement the entire stocks required for the intended voyage.

**Deadweight:** Deadweight is the total weight that a vessel can carry above her light ship displacement until she is loaded to the loadline marks appropriate to her part of the world and season. Deadweight includes fuel, cargo, stores, ballast etc. Lightship displacement plus deadweight is the vessel's loaded displacement. Deadweight is a measure of the vessel's cargo carrying capacity. Too much fuel on board can mean cargo shut-out and loss of earning ability. To maximise cargo lift, fuel stocks have to be minimised. This balance can require careful planning and calculations to ensure that a vessel remains commercially viable without jeopardising safety.

**Loadline:** The International Load Line Rules dictate how deeply in the water any seagoing vessel can be loaded. Each vessel trading internationally is assigned load lines for winter, summer and tropical zones beyond which she may not be loaded. For example, a vessel loading to her marks in European winter will be constrained by her winter loadline. If that vessel proceeds on voyage to Singapore, she will move progressively into the adjacent summer and then tropical zones. The corresponding loadlines for that vessel will mean that more deadweight will become available, both by consumption of bunkers already on board and by the increased deadweight allowance. She may therefore be bunkered to her deeper marks with more fuel in those latter zones.

Conversely, if moving from tropical through summer to winter zones, she might have more deadweight than her assigned marks permit. This can have a severe limitation on the fuel able to be carried.

**Compatibility:** Not all bunker fuels are compatible with one another. Two incompatible fuels if mixed in the same storage tank can cause problems such as sludge formation. For this reason, fuel from different sources should be segregated on board and held in separate tanks. Separate and empty tank space may dictate the quantity of bunkers that can be lifted on any occasion.

**Price:** Operators of vessels trading on long international voyages will try to avoid purchasing bunkers in expensive parts of the world and maximise bunker purchases in areas where fuel is cheaper. They will try to purchase sufficient low cost fuel to ensure that purchases in higher cost areas are avoided or minimised.

The master and those operating a vessel will need to consider the above factors before deciding where a vessel will bunker and how much fuel will be lifted.

In the European context, some ships will be on short coastal voyages and not all of these factors will apply. However, Europe spans both winter seasonal zones (north of Capo Toriñana on north-west Spain); summer zones to the south and in the Mediterranean; the Canary Islands are in the tropical zone. Vessels voyaging from northern Europe to the south may be able to take advantage of loadline zones by maximising bunker lifting when leaving Europe. This is one reason why Las Palmas on Grande Canaria has grown up as a popular bunker station.

### **A5: 3 Fuel Consumption**

Fuel consumption of ships depends on a number of factors related to size, speed and power plant. Detailed information on fuel consumption for different engine types and speed of operation is readily available from manufacturers and in summary form in publications such as *MER (Marine Engineers Review, I Mar E, London)*.

While fuel consumption does relate to vessel size, it is not the only parameter that is important in practice. Nevertheless, the fact that ship dues are at times related to tonnage<sup>1</sup> means that correlations, where available are worth deriving.

The table below is based on average ships, where for each category up to forty ships have been analysed.

---

<sup>1</sup> **Tonnage Definitions:** There are five categories by which tonnage of a vessel is calculated: registered, gross registered, net registered, displacement and deadweight tonnage. **Registered Tonnage** is stated in tons of 100 cubic feet per ton. This is the total internal capacity of a vessel. **Gross Registered Tonnage** is the same as Registered Tonnage. **Net Registered Tonnage** is the part of the Registered Tonnage, which is used to earn money. All spaces which are not revenue producing are deducted from the registered tonnage. **Displacement Tonnage** is the actual weight of the ship and is equal to the weight of water displaced by the vessel. **Deadweight Tonnage** is the carrying capacity of a vessel.

SHIP TYPE	TYPICAL GRT	TYPICAL INSTALLED POWER (HP)	ENGINE TYPE	TYPICAL INSTALLED POWER (kW)	TYPICAL OPERATIONAL RATING (kW)	RATING %	TYPICAL DESIGN SPEED (KNOTS)	SP. FUEL CONSUMPTION (g/kWh)	TYPICAL FUEL CONSUMPTION PER HOUR (KG)	TYPICAL FUEL CONSUMPTION (KG/HR)	MAX. FUEL CONSUMPTION (t/GRT/YR)	WORLD AVERAGE (t/GRT/YR)
Tanker	46,466	20,300	S	15,144	9,086	60%	15.5	210	1,908	0.041	0.4	0.35
Bulk	37,282	15,500	S	11,563	6,938	60%	15.5	210	1,457	0.039	0.3	0.35
Cruise	59,652	78,403	M	58,489	46,791	80%	22.5	195	9,124	0.153	1.3	0.35
Ferry	26,433	31,405	M	23,428	21,085	90%	22.0	190	4,006	0.152	1.3	0.35
Container	23,691	24,390	S	18,195	15,466	85%	20.0	205	3,170	0.134	1.2	0.35
Dry cargo	3,388	3,535	M	2,637	2,110	80%	13.0	195	411	0.121	1.1	0.35
Reefer	10,629	15,498	S	11,562	9,827	85%	21.0	205	2,015	0.190	1.7	0.35
Fishing Factory	4,407	7,000	M	5,222	4,178	80%	16.0	195	815	0.185	1.6	0.35

#### A5: 4 Reducing sulphur in bunker fuels - ship technical aspects

There are three possible scenarios for technical consideration:

- a regime that imposes limits on the sulphur content on fuels sold from ports within the EU
- a regime that requires vessels trading within specified sea areas to consume bunkers with a limited sulphur content
- a regime that imposes limits on the stack emissions of SO<sub>x</sub> and/or NO<sub>x</sub> within specified sea areas

For the purposes of this section “regime” generally includes both regulatory and economic incentive instruments. For low sulphur fuels there will, irrespective of regional policies, be a requirement to use fuel with no more than 1.5% sulphur content in the North Sea and Baltic SO<sub>x</sub>ECA's when MARPOL Annex VI comes into force.

Imposing limits on the sulphur content of fuel sold within the EU or parts thereof would have a direct effect on SO<sub>x</sub> emissions, subject to the considerations in section 2 above. It is quite possible for ships to operate on low-sulphur fuels. For some time it has been policy for NATO warships to operate on MDO (marine diesel) or MGO (marine gas oil) [NATO F-76 fuel standards require 1% sulphur fuels], and at times most merchant vessels operate on diesel<sup>2</sup>, so, technically, this philosophy could be applied to any vessel. The adoption of low sulphur fuel burning in Sweden (Appendix 3) is further clear evidence.

<sup>2</sup> Traditionally merchant ships burning heavy fuel oil on sea passages, nonetheless burned diesel when manoeuvring in port. The changeover usually preceded pilot pick-up by something like one hour, during the period that the vessel was slowing down (i.e. over a distance of the order of up to 10 nautical miles). The reasons for using diesel were the greater reliability of the propulsion system that this produced during critical manoeuvring in confined waters. The control issues involved in the use of heavy fuel include fuel and cooling water temperature control and the absence of need to pre-heat the fuel before re-starting the engine. The advantages to compensate for burning more expensive fuel were seen as reduced engine wear from significant heat changes in the engine and ease of in port maintenance on the fuel system if filled with diesel rather than a dirty and viscous fuel. The trend in recent times, however, has been towards the greater use of heavy fuel oil for manoeuvring in port. As heat control systems have improved so the reliability of using heavy fuel oil in changing load conditions has improved also.

For vessels trading solely within EU waters such as harbour and service vessels, ferries, short-sea container feeders and ro-ros, there would be minimal technical problems as the vessels would only be consuming a single grade of fuel and could use appropriate lubricants.

Vessels that trade in and out of EU ports to other parts of the world, may, typically, bunker on departure for the EU and then take on more bunkers for the return voyage. This pattern would be very typical for tankers (crude carriers) and deep-sea container vessels. Thus inward-bound vessels would be burning bunkers loaded at non-EU ports and outward-bound vessels would be burning bunkers from the EU ports. For a further discussion on bunkering strategy see Section 2 above

The shipowner may have to make the decision of whether to go over completely to low-sulphur bunkers, or whether to make arrangements to carry two separate grades of bunkers and decide upon a compromise regarding lubricants.

Some owners will try to obtain their bunkers at low-price ports irrespective of the sulphur content, and may trade in and out of an EU port without taking on further bunkers, subject to available cargo capacity and deadweight limitations as discussed in section 2.

Requiring vessels to only consume low-sulphur bunkers within specified EU waters raises similar technical issues. Once again, it is relatively easy to manage for captive traffic such as short-sea and ferry traffic, but does cause some technical and logistic issues for vessels that have bunkered elsewhere. As with the first option, it creates a decision for owners whether to only load low-sulphur bunkers inbound to the EU, or whether to install a two-grade system. If a two-grade system is installed, there are immediate problems of determining the changeover point to low-sulphur on entering any specified EU sea area, particularly as there will be an economic incentive to continue to use cheaper high-sulphur fuel for as long as possible. The ship operators are, of course, required to maintain suitable records (logs), but there is a period of time during changeover when one fuel is being flushed out and replaced the second.

Imposing limits on the SO<sub>x</sub> and NO<sub>x</sub> emissions within specified sea areas becomes a matter of monitoring (particularly for SO<sub>x</sub>) and / or certification (particularly for NO<sub>x</sub>).

### **A5: 5 *Mixing fuel qualities***

If a vessel carries two grades i.e. high (standard, say 3%) and low sulphur fuel, there are some specific problems, particularly in the case of vessels such as large tankers (VLCCs) and container vessels which do not have the range to perform a complete round trip, and require to bunker at both ports or one port and an intermediate port.

It follows then that such vessels would need to have adequate bunker capacity to work on either high or low sulphur bunkers. It might be theoretically possible to carry just sufficient low-sulphur fuel for transiting an EU special area, but the vessel would need to take on both high and low sulphur fuel at the EU port, providing there was no regulation restricting bunker sales to low-sulphur fuel, only. There is therefore the possibility that vessels engaged on long-distance trading might have to have two-grade segregated bunker tanks, with an aggregate capacity well in excess of that normally provided. This could be accommodated in new-build vessels, but at an obvious increase in capital cost, and/or a reduction in cargo carrying capacity. There would obviously also have to be separate fuel systems and day and settling tanks..

There are also difficulties associated with lubricants. Residual fuels contain not only high levels of sulphur, but also between 2% and 11% by weight (depending on the crude and the refining process) of asphaltenes (heavy high molecular weight components of limited solubility).

Two-stroke slow speed engines (typically MAN B&W and Sulzer) require two types of lubricant: one for the upper cylinder (cylinder oil) and one for the crankcase (system oil). The duty of the cylinder oil is arduous and typically requires a heavy oil (SAE 50) with high film strength and thermal stability, because it is required to lubricate the piston rings at high temperature. If the engine is operating on high-sulphur fuel, the cylinder oil also has to be immune to the SO<sub>x</sub> being created by combustion, and to the asphaltenes that are left behind. It also has to be compatible with the system oil, which is usually of a slightly lighter grade (typically SAE 30). Four-stroke engines (typically Wartsila, Pielstick, MAN B&W and Mak) only require a single grade of engine oil, but this has to be a compromise between cylinder and crankcase duty (typically SAE 30 to 40), and so still has to handle the acid cylinder conditions. The net result is that oils formulated for high-sulphur residual fuels have additives to handle both the acid conditions and the asphaltenes, and are not generally compatible with the oils used for low-sulphur applications.

If lubricating oils formulated for high-sulphur residual fuels are used with low-sulphur fuel, there will no longer be the same level of acid to deal with in the cylinders, and the lubricant will tend to be too alkaline, with attendant corrosion problems. Normally this does not present a problem for short periods (e.g. when manoeuvring on MDO), but extensive continuous operation would cause difficulties.

If a ship were to be working on alternate high and low-sulphur bunkers, unless some satisfactory compromise could be found on lubricants, there would need to be two separate lubrication tank systems that could be interchanged. As the vessel would need to change over to low-sulphur operation on entering the controlled sea area, this suggests that both fuels and lubricants would need to be changed over en route. This would appear to be impractical, and a compromise lubricant would seem to be the only practical solution.

The end result of this section is that we conclude that designing ships to be able to operate for **significant** periods on both high and low-sulphur bunkers is fraught with difficulties, so requiring low-sulphur bunkers in EU waters might under some circumstances make it necessary for some vessels to switch to complete low-sulphur operation. The logistics, of course, depend on the extent of any regulation. A limited requirement to burn low sulphur fuel in ports could be accommodated by reverting to the traditional practice of using MDO or MGO for manoeuvring only.

#### **A5: 6 *Shipboard technical improvements to reduce SO<sub>2</sub> and NO<sub>x</sub> emissions***

In view of the difficulties of monitoring the emissions from a vessel, there are obvious advantages in:

- Encouraging the use of prime movers and exhaust gas treatment systems that are inherently capable of producing low emissions of SO<sub>x</sub> and NO<sub>x</sub>
- Encouraging the use of exhaust gas monitoring systems that can provide a record of emissions.

**A5: 6.1 SO<sub>2</sub> emissions**

The SO<sub>2</sub> (and to a lesser extent the SO<sub>3</sub>) content of exhaust gas is directly related to the sulphur content of the fuel. It therefore follows that in order to reduce the SO<sub>2</sub> content of exhaust gas there are only two options:

- Reducing the sulphur level in the fuel oil
- Treating the exhaust gas stream

The issues are the same as for land based combustion plants, including power stations.

The first option creates no real technical problems for ships, as discussed in sections 3 and 4 above, provided that the vessel that is operating on low-sulphur fuel is using appropriate lubricants. Difficulties arise only if the trading pattern of the vessel means that it is alternating its use of high and low sulphur content bunkers, which might necessitate a fuel oil system capable of storing segregated grades of bunkers and potentially different lubricants (see above section 4).

There would be additional benefits in the use of low-sulphur fuel in that there could be some reduction in maintenance costs, and a possible reduction in breakdowns, although much of the evidence for this is related to operating experience of using MDO compared to use with HFO, and the residual content is the main cause of problems (CIMAC Exhaust Emission Controls Working Group: *The implications of sulphur in fuel oils*: MER Nov 1996). In many ways, it may be more cost-effective to burn MDO than to burn de-sulphurised residual fuel, which still contained unpredictable substances, but this will largely revolve around the market established fuel price with changing demand (see Appendices 1 and 7).

Flue gas de-sulphurisation can be achieved in a number of ways. The most likely method of treating the exhaust gas would be a simple salt-water scrubbing system, which would simply wash the SO<sub>2</sub> out of the exhaust stream. The obvious disadvantages to this are:

- The exhaust gas scrubber and drain pipework create dilute acid, and this causes inevitable corrosion problems.
- There is a continuous use of fresh water, which would cause greater load on water making capacity, with a resultant small increase in fuel consumption.
- The system will be returning sulphur to the sea. The total sulphur inventory of the ocean exceeds the sulphur content of all known oil reserves by several orders of magnitude, but returning sulphur to the sea may be deemed environmentally unacceptable, particularly in confined waters and harbours.
- A sulphur scrubbing system will also add volume and cost to the exhaust system, particularly if combined with a selective catalytic reduction (SCR) system for NO<sub>x</sub> reduction. Swinden (*Shipping, air pollution and bunker fuels*: 17<sup>th</sup> Motor Ship Annual Marine Propulsion Conference 1995) estimates that even when designed from new, it will still cost the equivalent of about \$25 extra per tonne of fuel consumed, and consumption itself would be increased by about 3%.



It is evident that the scope for retrofitting scrubbing systems to existing tonnage is extremely limited, due to space considerations in way of the uptakes and the need for additional fresh water making or storage. Manufacturers of SCR for NO<sub>x</sub> have not generally anticipated a comparable and significant FGD market for ships (ABB private communication). This is in spite of the fact that FGD is in principle capable of effectively removing SO<sub>x</sub> (97.5% Smit Gas private communication) and scrubbers are used on tankers in the production of inert gas – see insert). Swinden (95) suggests a cost of around \$30 per tonne (including extra fuel consumption) in a system installed from new.

It is relatively easy to monitor bunker quality and sulphur content by testing. There is also a new obligation under MARPOL for bunker suppliers to provide a Bunker Delivery Note (specifying quality as well as quantity) and a sample of the bunkers supplied to the vessel. The bunker delivery note is to be retained onboard for three years and the sample for one year "under the ship's control". There should therefore be full traceability of the bunkers used by a vessel.

A scrubbing system would require some form of exhaust gas monitoring as part of the control system, and therefore it would be practical for exhaust gas contents to be recorded and logged automatically.

#### Flue inert gas systems



This system, which is specifically designed for the exhaust gas from oil-fired boilers, is primarily used on crude oil tankers. The flue gas is extracted from the existing boilers by fans and is drawn through a scrubber where it is cooled and washed before being delivered to the cargo tanks.

Smit Gas Systems  
P.O. Box 6664  
6503 GD Nijmegen  
The Netherlands

#### A5: 6.2 NO<sub>x</sub> emissions

The IMO regulation curve for NO<sub>x</sub> (*Technical Code on Emission of Nitrogen Oxides from Marine Diesel Engines*) has been formulated to give a limit curve which is related to rated engine speed, effectively allowing a higher specific emission of NO<sub>x</sub> for slower speed engines, up to a ceiling of 17 g/kWh, when burning MDO (ISO 8178 Test Procedure). The IMO curve will apply to all new builds after January 1, 2000 with a power output of more than 130kW. Chapter 2 of the NO<sub>x</sub> Code prescribes that machinery will be subject to a certification and survey scheme as follows:

- Engine type pre-certification, based on family "parent" prototype testing: the Engine International Air Pollution Prevention (EIAPP) Certificate.
- Certification of the prime movers on board as a basis for the ship's International Air Pollution Prevention (IAPP) Certificate, and provision of a "technical file" for each prime mover giving details of all required engine variables and settings to ensure minimum NO<sub>x</sub> emissions.
- Periodical surveys to ensure continued compliance
- Nitrogen oxides in diesel exhausts originate from two sources: oxidation of N<sub>2</sub> from the combustion air at high temperatures (thermal NO<sub>x</sub>) and oxidation of nitrogen compounds in the fuel itself (fuel NO<sub>x</sub>). The emissions of NO<sub>x</sub> are not



related to fuel quality, and are a function of engine design, operation and maintenance. The limitation of sulphur content in bunkers does not have any major effect on the emissions of NO<sub>x</sub>.

Emission reduction methods include:

- Primary or internal methods, aimed at reducing the amount of NO<sub>x</sub> formed during combustion
- Secondary methods: treating the exhaust gas stream

Most modern marine diesels engines are now being designed for low NO<sub>x</sub> combustion, and this has been achieved by largely by the optimisation of engine design (Ref: *NO<sub>x</sub> reduction - a technical challenge for marine diesel engine manufacturers*: F Fleischer MAN B&W: IMAS Conference 1996, *Implications of the IMO exhaust emission control proposals*: G Hellen. Wartsila Diesel IMAS Conference 1995). Such optimisation measures include the variation of design parameters including:

- Injection timing. Retarding ignition is a long established and method of reducing emissions but at the expense of increased fuel consumption. However, when used together with other design optimisation it is of assistance, particularly if active electronic control systems are used.
- Injection rate. Research demonstrates that there is an optimum injection rate to minimise emissions, but this is, of course related to the other parameters.
- Compression ratio. A combination of higher compression ratio, combined with a higher injection pressure and rate can have beneficial effects.
- Exhaust gas re-circulation (EGR). This is an established procedure for automotive diesels and test results indicate that it can be beneficial for large bore marine diesels, but there are problems of cooling and cleaning re-circulated exhaust gas, and acid content may give rise to turbocharger compressors and air coolers (these would largely be avoided if low-sulphur fuel was being used)
- Fuel-water emulsion or direct water injection. By adding fresh water to the fuel and emulsifying or by separate water injection, substantial reductions can be obtained. Fliescher (MAN: see above) quotes 10% reduction for 10% water content with a penalty of 1% increase in fuel consumption. It is obviously relatively easy to design an emulsion injection system to an existing engine range, whereas separate water injection requires a separate system.
- Pre-treating combustion air. The HAM (humid air motor) system offers NO<sub>x</sub> reduction of 70% (*MER May 1999*) using combustion air that has been humidified and chilled, powered by waste heat and consuming only sea water. Engine efficiency is claimed not to be compromised.

Treating the exhaust gas to remove emissions can be carried out by a selective catalytic reduction (SCR) system. The system mixes the exhaust gas with ammonia or urea before passing through a layer of catalyst, splitting the NO<sub>x</sub> into N<sub>2</sub> and H<sub>2</sub>O.

This system is well established for both land-based and marine power plants, and can achieve over 90% reductions in NO<sub>x</sub> levels (Schlemmer-Kelling et al.: *Exhaust Gas Aftertreatment Systems Onboard Seagoing Vessels*: CIMAC Conference 1998).

Early systems used ammonia as gas, but later implementations have stored an aqueous solution of urea, which is sprayed into the exhaust stream, where it hydrolyses into ammonia. The SCR catalytic section can be fitted into the space that would normally be occupied by the exhaust silencer and can fulfil the same acoustic function. There are obviously considerable capital and operating cost penalties involved with an SCR system and whilst it may be appropriate for a "captive" trading ferry of relatively low power, it may not always be appropriate for continuous use on large deep-sea vessels.

There are additional problems if an SCR system is used with a high-sulphur fuel in that the catalyst can get blocked by ammonium sulphite, which is produced by the reaction of the ammonia with the inevitable SO<sub>2</sub> in the exhaust gases. There is some scope for an SO<sub>2</sub> scrubber followed by the SCR unit, but such equipment would get progressively bulkier and more expensive.

A review of NO<sub>x</sub> emission reduction methods is given in *MER May 1999*.

### **A5: 7 Refinery Issues**

Fuels for marine use are prescribed in ISO 8217 Petroleum Products - Fuels (Class F) - Specifications of Marine Fuels, which lays down minimum standards for both residual fuels and distillate fuels. The most commonly used residual bunker fuels are the IFO range, typically IFO40, IFO80, IFO180 and IFO380, where the number refers to the kinematic viscosity in centistokes at 50 Celsius.

Distillate fuels are generally referred to as Blended Marine Diesel (DMC), which contains a controlled amount of residual, and Marine Diesel (MDO or DMB) which does not. Both are specified as containing less than 2% sulphur, but the content supplied in MDO will normally be less than 1.5%. There is a lighter distillate referred to as Marine Gas Oil, used for small prime movers and gas turbines, with a specified sulphur content of 1.5%, but frequently supplied at 1% or better. MDO will generally be carried in the same tanks of a bunkering vessel that have been used for IFO grades, and there may be some minor contamination and discoloration. MGO is supplied from segregated tanks as "white" oil.

Residual fuels are exactly what they say they are: they comprise the residual heavy ends of the barrel after the lighter products have been distilled off. In areas where there is a high demand for light ends such as gasoline, the feedstock is often "cracked" to provide more light ends, with the result that the resultant residual fuel can be even heavier and more viscous. The residual fuel will also contain unpredictable amounts of other elements and may also contain waste oil and particulate matter. The most basic type of residual fuel is referred to as heavy fuel oil (HFO) or Bunker C, and this is only used for boilers. The fuels used for diesel engines are referred to as intermediate fuel oils (IFO) and are available in a range of viscosities and sulphur contents.

The basic sulphur levels of crude oil can vary from 0.1% to in excess of 4%. The refining process will accentuate this, and the sulphur will tend to remain with the residual, and it is from the residuals that the fuel oils are blended, within the limitations of the ISO standard. Average sulphur levels for IFO based on North European crude has tended to be around 3.5%.

There are two ways in which low-sulphur bunker fuels could be produced:

- Use only the residuals from low-sulphur ("sweet") crudes
- De-sulphur and blend from generic crude oils

The use of low-sulphur crudes is the ideal method to provide low-sulphur fuel, except that there would be a supply problem in general. The present world-wide production of low-sulphur fuel oils is already taken up by environmentally sensitive land-based plants, and a surge of demand for low-sulphur fuel oil would inevitably force up the price differential between low-sulphur and conventional bunkers. Presently only 4% of bunkers supplied world-wide have a sulphur content less than 1.5% (Liddy, 1998)

Sulphur can be removed at the refinery by a number of possible residue de-sulphurisation processes. The technology is established, but is not widely used, for two main reasons:

- Cost, and the problem of disposal of solid waste sulphur. Liddy,98 suggests the refinery investment required for refineries supplying the European bunker industry lies between \$4 billion and \$10 billion. Alternative refinery investments are available that may prove more attractive to oil refiners and in the longer term alternative energy sources (e.g. fuel cells) will radically change the investment options.
- The marine bunker fuel industry has always provided a useful "sink" for the bottom of the barrel.

#### **A5: 8 Price differentials between high and low sulphur fuels**

CONCAWE (1994) have estimated that the costs of reducing the sulphur content in bunker fuel oils would be of the order of:

TARGET BUNKER FUEL OIL SULPHUR CONTENT	INVESTMENT REQUIRED US \$ BILLION (1994)	ADDITIONAL COST \$/TONNE
2.0%	4.2 to 6.4	35 to 52
1.5%	5.6 to 8.2	46 to 68

Bunker prices constantly fluctuate due to market forces and the cost of the crude oil, but for indication, the cost of bunkers at Rotterdam was quoted as follows:

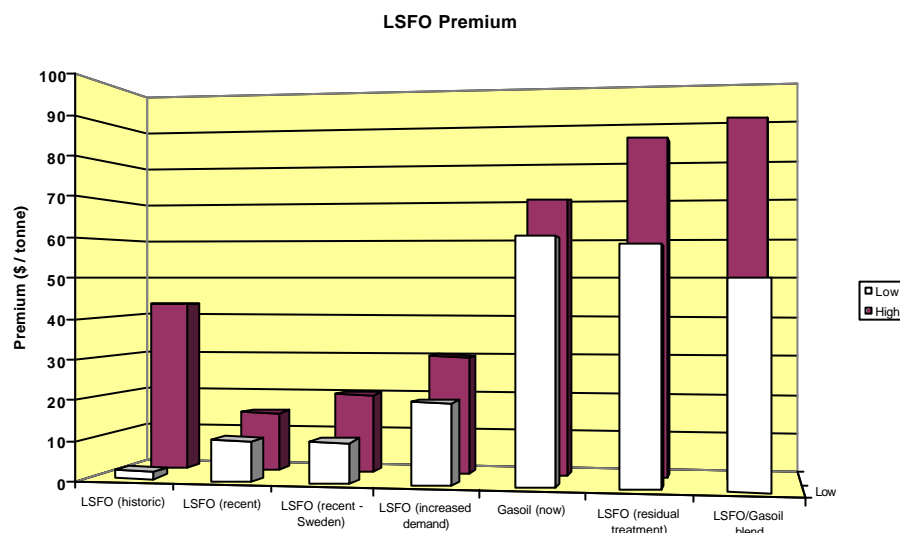
GRADE	11 JUNE 99 QUOTED PRICE \$/TONNE	DIFFERENTIAL AGAINST IFO380 \$/TONNE	06 JAN 00 QUOTED PRICE \$/TONNE	DIFFERENTIAL AGAINST IFO380 \$/TONNE
IFO380	78.50		124.50	
IFO180	81.00	+ 2.50	127.50	+3.00
MDO	108.50	+ 30.00	197.00	+70.00
MGO	121.00	+ 42.50	219.00	+94.50

The article in Schiff and Hafen (10/98) indicated that the long-term differentials between MDO and IFO380 are of the order of \$60-80 per tonne. In the last ten years the bunker price index variation is shown in the graphic below.

Recently (see also Appendix 1) low sulphur to high sulphur fuel oil premiums have been in the region of \$10 to \$20, but this is based on today's situation of relatively low demand.

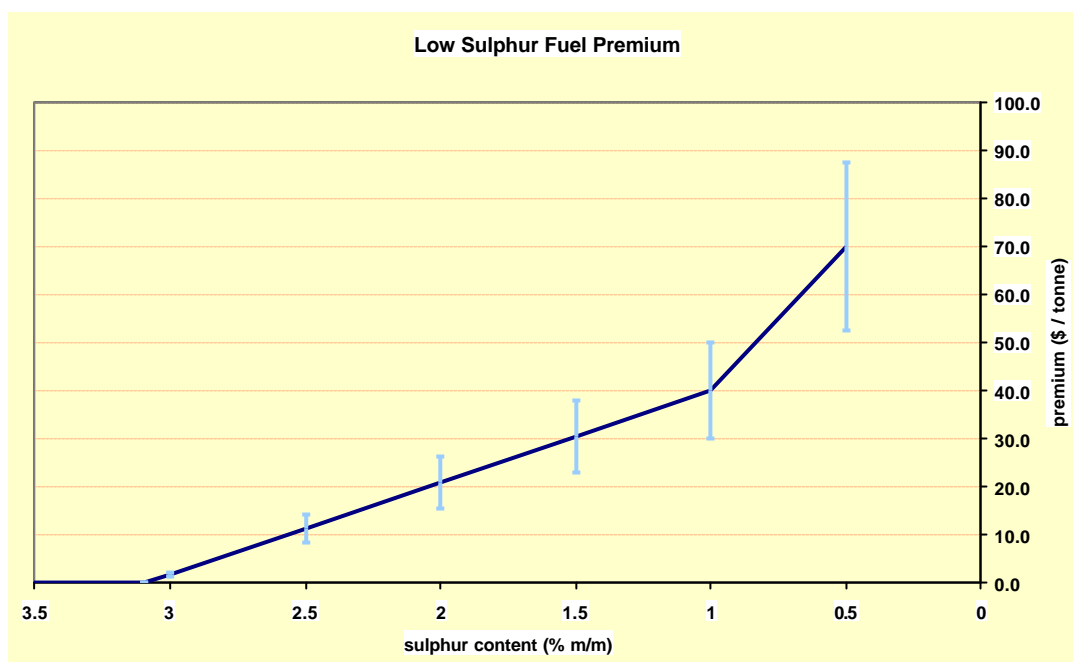


The above information and private oil company communications are summarised in the chart below.

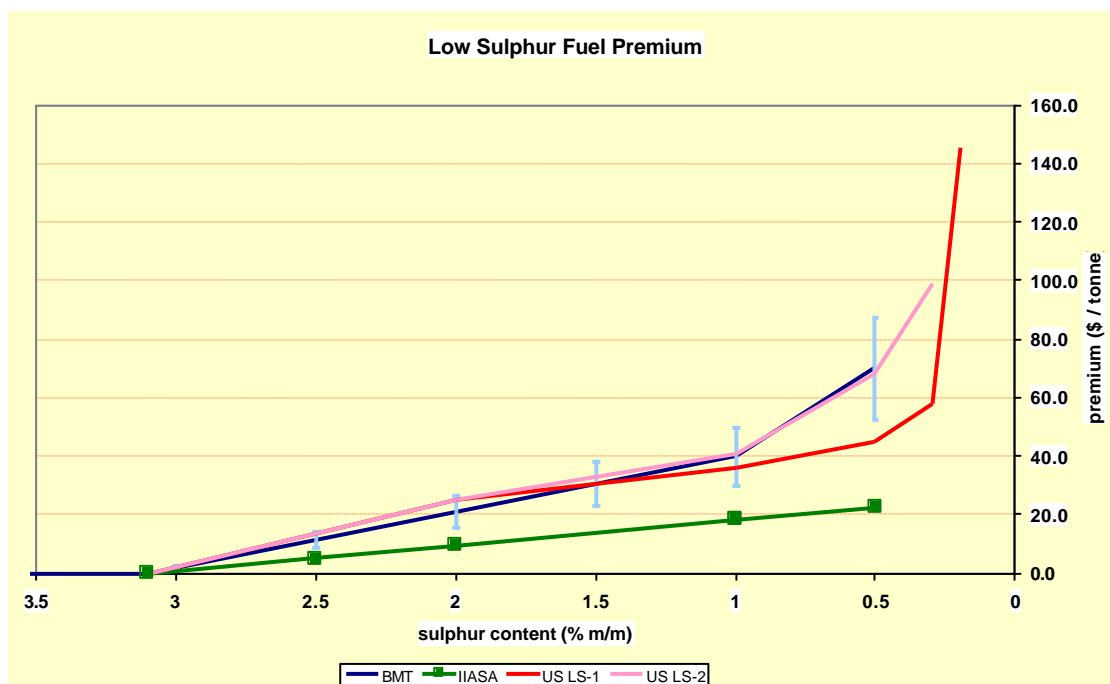


This data can be interpreted as a range of price premium versus sulphur content as in the graph below. This graph is taken to be a model that can be used in the economic assessment of cost and benefit (Appendix 7). The discontinuity at 1% sulphur content indicates the increasing need below 1% to blend fuel with expensive clean gasoil.

This curve does not predict premiums as high as the Concawe (94) estimates. It is suggested as an indicator of price in a market of significantly increased demand for low sulphur products, but not the complete elimination of either the sale or use of residual bunkers.



The estimates of price premium given above are greater than those used by IIASA (Oct. 98 Table 2.8) in their analysis of acidification and ozone control for the European Commission. For comparison purposes a further graph, below, shows the IIASA assumptions plotted against the model used in this work (labelled "BMT"). Additionally differentials from the US low sulphur fuel oil market (down to 0.3%S fuel oil) have been shown. This data, rather arbitrarily, comes from August 2000 (US LS-1) and February 2000 (US LS-2). Evidently, in a tighter low sulphur market, as assumed for Europe in the future, price premia can approximate to this study's model.



## A5: 9 Costs of technological options

### A5: 9.1 Reduction in NOx emissions

The available literature described above contains some estimates of cost. For SCR good manufacturers data is available (e.g. ABB, Siemens), but for other techniques the information is more tentative and in part based on early trials data.

METHOD	NOx REDUCTION	COST
SCR	90%+	\$35,000 - \$75,000 per mW \$3-\$4 per mWh \$0.5 per kg NOx removed
EGR	50%-60%	
HAM	60%-70%	Similar reduction rate to SCR
Water Injection	20%-40%	30% of SCR retrofit, typically of order \$100,000 operating costs of order \$1 per mWh.

Considering reductions from the IMO NOx curve, the costs resulting from the above are approximately:

75% of NOx code	Reduction of 3-6 kg/mWh	Cost \$1-\$2 per mWh	Typically \$10 per tonne of fuel consumed	Between \$0.6 and \$2 per 1,000grt/hr
20% of NOx code	Reduction of 8-12 kg/mWh	Cost \$4-\$6 per mWh	Typically \$23 - \$35 per tonne of fuel consumed	Between \$1 and \$6 per 1,000grt/hr
Comparing with SOx using 1% S fuel, today	Reduction of 7-8 kgSOx/mWh	Cost \$2-\$4 per mWh	Typically \$10-\$20 per tonne of fuel consumed	Between \$0.5 and \$4 per 1,000grt/hr
Comparing with SOx using 1% S fuel, with future enhanced demand or the equivalent by FGD	Reduction of 7-8 kgSOx/mWh	Cost \$6-\$10 per mWh	Typically \$30-\$50 per tonne of fuel consumed	Between \$1.5 and \$10 per 1,000grt/hr

It is clear, of course, that the cost of NOx and SOx emission abatement is a function of operating hours (also distance travelled). The financial burden or incentive (for example Appendix 3) is thus very dependent on the individual ship, its efficiency, trading pattern and revenue profile.

In general operational terms the following considerations will apply:



REQUIREMENT	FACTORS EFFECTING CAPITAL COST	FACTORS EFFECTING OPERATING COST	COMMENTARY
New machinery IMO Curve	Nil	Marginal increase in fuel consumption	No difficulties unless IMO levels eventually reduced. Modern engines can achieve much lower emission levels.
New machinery 75% IMO Curve	Small. Possible cost of EGR or second injection system for direct water injection. SCR not needed at this level.	Marginal basic increase in fuel consumption, plus possibly some penalty due to quantities of water to be made (running evaporators etc)	Possible EGR and/or use of fuel/water emulsion, or direct water injection
New machinery 20% IMO Curve	Primary engine costs small. Potential need for optimised SCR system or HAM installation depending upon basic engine performance.	Marginal increase in fuel consumption, plus urea consumption (SCR).	Consideration of supply & storage of urea and possible reduction in deadweight, which might be significant on long-range deep sea vessels
Existing machinery IMO Curve	Generally small- many engines will meet requirement. Otherwise timing or water injection changes.	Small fuel efficiency issues. Could utilise more expensive, lower temperature fuels (distillates).	Some existing engines working at lower temperatures and compression ratios may well comply with IMO curve without additional work.
Existing machinery 75% IMO Curve	Some retrofit required, unless the engine is already close to emission target. Depending on degree of reduction required more or less expensive retrofit will be required (see table above).	Some increase in fuel consumption, costs of urea feedstock if using SCR (unlikely) plus costs of replacement catalyst.	Water injection likely to be sufficient
Existing machinery 20% IMO Curve	Retrofit required, probably for SCR, possibly HAM depending upon current engine performance.	Marginal increase in fuel consumption, plus costs of urea feedstock for the SCR system, plus costs of replacement catalyst	See "New machinery 20% IMO Curve"

**A5: 9.2 Reduction in SOx emissions**

OPTION	FACTORS EFFECTING CAPITAL COST	FACTORS EFFECTING OPERATING COST	COMMENTARY
Burning low S fuel in new machinery or in existing machinery	Nil	Increase in cost of bunkers according to S content. Small reductions in operating and maintenance costs (few \$ per tonne vs. few tens \$ per tonne for fuel premium)	No problems / generally benefits from point of view of prime mover. Consideration of correct lube oil required. Traditionally alternation between HFO and diesel has occurred.
Exhaust scrubbers, and disposal of resultant sulphur, new vessel	Significant investment equating to around \$30 per tonne of fuel consumed (sect A5.6.1).	Some small increase in operating costs due to need to make water, plus pumping to scrubber system, maintenance of scrubber and drain system with acid product.	Scrubber produces dilute sulphuric acid, which can either be dumped to deep sea, if acceptable, or retained / processed on board vessel.
Exhaust scrubbers, and disposal of resultant sulphur, existing vessel	Significant investment, in excess of \$30 per tonne of fuel consumed. Space constraints affect practicality and / or retrofit cost.	As for new vessels	As for new vessels
Carriage of two grades of main fuel	Significant effect on long-range deep-sea vessels as may have to provide larger overall bunker capacity, so some possible cargo volume shut-out. In addition, costs of additional pipework, pumps etc.	Cost of low-S bunkers when operating in restricted areas. Assumed that vessel would burn "normal" high-S fuel outside restricted zones	Depends on degree of requirement to burn low S fuel. Vessels have often accommodated diesel and HFO.
Carriage of two types of lubricating oil for high- and low-S operation	Some small effect on build cost, as extra storage and drain volumes needed, plus pipework, pumps, filters etc.	Costs of additional lube oil, plus some additional maintenance.	Probability would be that compromise lube oils could be used. Choice determined by degree of low S vs. high S operation.

## A5: 10 References

*Regulations for the Prevention of Air Pollution from Ships and NO<sub>x</sub> Technical Code: Annex VI of MARPOL 73/78*

*Petroleum fuels for marine oil engines and boilers: British Standard BS MA 100 / ISO 8217 1987*

*Implications of the IMO exhaust emission control proposals: G. Hellen (Wartsila): Marine News (undated)*

*Reducing NO<sub>x</sub> emissions from low-speed engines (unattributed) MER Feb 1991*

*Controlling NO<sub>x</sub> emissions of ships: G. Hellen (Wartsila): VII Congress IMAM 1995 Dubrovnik.*

*Shipping, Air Pollution and Bunker Fuels: A. Swinden (BP Marine Fuels) 17<sup>th</sup> "Motor Ship" Annual Marine Propulsion Conference 1995 Amsterdam*

*The implications of sulphur in fuel oils: A study by the CIMAC Exhaust Emissions Controls Working Group: MER November 1996.*

*NO<sub>x</sub> reduction - a technical challenge for marine diesel engine manufacturers: F. Fleischer (MAN B&W Diesel AG): IMAS Conference 1996*

*Exhaust gas monitoring: C.S. Brookman (Marine Safety Agency) IMAS Conference 1996*

*Onboard measurements of diesel engine exhaust gas components: H-J. Götze (et al.) Germanischer Lloyd: ODRA 97 2<sup>nd</sup> International Conference on Marine Technology Szczecin 1997.*

*Fuels and lubes: at the mercy of refiners and legislators (unattributed) Shipping World and Shipbuilder October 1997*

*The ageing of diesel engine combustion components and their associated effect on performance and emissions: J.McGillivray (Wartsila): IMAS Conference 1997*

*Exhaust emissions from marine diesel engines using residual fuel: K. Maeda (et al.) Marine Engineering Society of Japan Bulletin 1998*

*Exhaust gas aftertreatment systems onboard seagoing vessels: U. Schlemmer-Kelling (et al.): CIMAC Congress 1998 Copenhagen*

*A study on low emission and bw BSFC marine diesel engines: Gu Hongzhong (Shanghai Jiao Tong University) 2<sup>nd</sup> Conference for New Ship & Marine Technology 1998 Hong Kong*

*Environmental aspects - fuel emissions : J. Nurmi (Deltamarin Ltd) Schiff und Hafen 10/1998*

*Diesel engine exhaust gas emissions - research, assessment and certification: H-J. Götze (et al.) Germanischer Lloyd: MarPower Conference 1999 Newcastle*

*IIASA October 1998, Cost-effective Control of Acidification and Ground-Level Ozone – Part A: Methodology and Databases, Sixth Interim Report to the European Commission, DG-XI*

*MER May 1999, Coming clean on exhaust gas emissions Institute of Marine Engineers, London*

*Liddy, J. 1998, Marine Fuels – Today's Quality, Tomorrow's Availability CIMAC Congress*