

Experiences from use of some techniques to reduce emissions from ships



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Gun Lövblad

Erik Fridell

Contents

1. Possibilities of reducing emissions from ships	4
2. Present requirements and incentives for emissions reductions	5
3. Sea transport and long range trans-boundary air pollution	8
4. Technical measures to reduce nitrogen oxides emissions	13
5. Costs for reducing nitrogen oxides emissions from ships	24
6. Methods to reduce SO ₂ emissions from ships	28
7. Contacts	31
8. References	32

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The report is also available at <http://www.profu.se>.

The authors assume sole responsibility for the contents of this report, which therefore cannot be cited as representing the views of the Swedish Maritime Administration and Region Västra Götaland.

1. Possibilities of reducing emissions from ships

Low-emission combustion technique has been an issue since the 1970s for stationary, as well as mobile sources. Sulphur emissions are directly proportional to the sulphur content in the fuel and emissions reductions can consequently be achieved by changing to a fuel with less sulphur. Also exhaust gas treatment is, however, a technique used to reduce sulphur dioxide emissions. To reduce emissions of nitrogen oxides either the combustion conditions must be changed or the exhaust gases must be treated. Many of the techniques used influence the formation of nitrogen oxides emission by lowering the combustion temperature.

A number of effective techniques are presently available to reduce nitrogen oxides emissions from ships. Control techniques developed and tested at power plants and industries have since more than two decades also been tested and used to reduce emissions from large marine engines. During the latest decade some of the techniques tested have become more or less commercial. Many of the new ships presently produced in ship-yards over the world are equipped with nitrogen oxides emission reduction units or prepared for later installation of control equipment.

Control measures for sulphur and nitrogen oxides emissions have been summarised in two recent reports prepared for the European Commission. The reports by Entec

(2005 a, b) present an overview of the present status of different control techniques. In addition, the Norwegian Environmental authority "Statens Forurensningstilsyn" (2006) and Det Norske Veritas (2005) have evaluated the different techniques possible for reducing the NO_x emissions from ships as a basis for Norwegian national strategies in order to comply with the NEC directive in 2010.

This report is elaborated with the aim of showing the possibilities available today for reducing emissions and the experiences gained during daily operation of different equipments to reduce emissions from ships. The experiences gained has been collected via contacts with ship owners, companies chartering the ships and ship crew, but also via published reports and data from manufacturers of reduction equipment. The report provides a summary of the most commonly used techniques, associated costs and experienced benefits and disadvantages.

The report will only provide information on currently available techniques and the reductions possible to reach at present. How to achieve an extensive use of control techniques is not dealt with. Various instruments, such as legislation, economic incentives and emission trading can be used separately, or in combination, to initiate the emission reduction.

2. Present requirements and incentives for emissions reductions

Requirements for sulphur emissions according to IMO and EU

Gradually the international community has initiated the work on reducing emissions from shipping. Within the International Maritime Organization (IMO) an annex to the MARPOL Convention has been elaborated to limit emissions of air pollutants from international shipping. Annex VI was adopted in 1997, and by 19 May 2005 it was ratified by a sufficient number of parties to enter into force. The annex states that within one year from the coming into force, the sulphur content of the fuel should never be higher than 4.5 % by weight. In so called "Sulphur Emission Control Areas" (SECA), the fuel used shall contain not more than 1.5 % sulphur. The first SECA area is the Baltic Sea where use of high-sulphur fuel will be restricted from 19 May 2006. The 11 August 2007, use of fuel with 1.5 % sulphur will apply in the North Sea and the English Channel for all ships carrying EU flag. In the next step, the 22 November 2007, also the North Sea and the English Channel will become a SECA area and the rules will apply to all ships independent of flag.

In November 2002 the European Commission presented a Community strategy to reduce air pollution from ships, which among others resulted in restrictions on the sulphur content of marine fuels. (EU 2002). The directive 2005/33/EC states that the sulphur content in marine fuels used in the Baltic Sea and the North Sea is to be limited to 1.5 %. The limit will apply from 11 August 2006 in the Baltic Sea, and from 11 August 2007 in the North Sea including the English Channel. The limit will also apply to ferries in traffic on all EU sea areas from 11 August 2006. As from 1 January 2010, all inland waterway vessels and ships at berth in Community

ports must use fuels with a sulphur content of maximum 0.1 %, and from the same date, the sulphur content in the marine gas oils sold in the EU member states should not exceed 0.1 %.

A review of this directive is foreseen by 2008. As part of that review the Commission shall consider the designation of additional SO_x Emission Control areas, and the reduction of sulphur limits for marine fuels used in such areas down to 0.5 %.

Use of 1.5 % sulphur fuel instead of the current average in Europe of 2.6 % will reduce the sulphur emissions from ships by 40 - 50 %. In reality, however, the local reduction in Scandinavian waters will not be as large, since many of the ferries and ships in coastal traffic for several years already have used low sulphur fuels. Fuel change is, however, not the only possibility to reduce sulphur emissions. Exhaust gas cleaning by sea water scrubbing, (see for example Entec, 2005 b) is a technique under development. The EU directive 2005/33/EC states that the member states may approve trials of emission reduction techniques, while fuels with higher sulphur content are used. The published test of sea water scrubbing is so far limited to one case. Further, the technique may, with an increasing demand for low sulphur fuels on the market and consequently increased fuel prices, become an economically competitive alternative.

Requirements for reducing nitrogen oxides

So far there are limited requirements for the NO_x emission reductions from ships. In Annex VI to the MARPOL Convention, IMO prescribes an emission standard for diesel engines with a power outlet >130 kW, where the emission of nitrogen oxides (in g NO_x/kWh) should be related to the rotation speed (in rpm) according to the curve in Figure 1. All ships constructed

after 1 January 2000 must comply with this curve. However, the environmental effect of this has been relatively insignificant, since at least all new engines already comply with these emission levels. Older ships generally have higher emissions. In the analyses made by Det Norske Veritas (2005) the NO_x emissions from ships built between 1990 and 2000 are estimated to emit on the average 17.5 % more NO_x than ships complying with the NO_x curve.

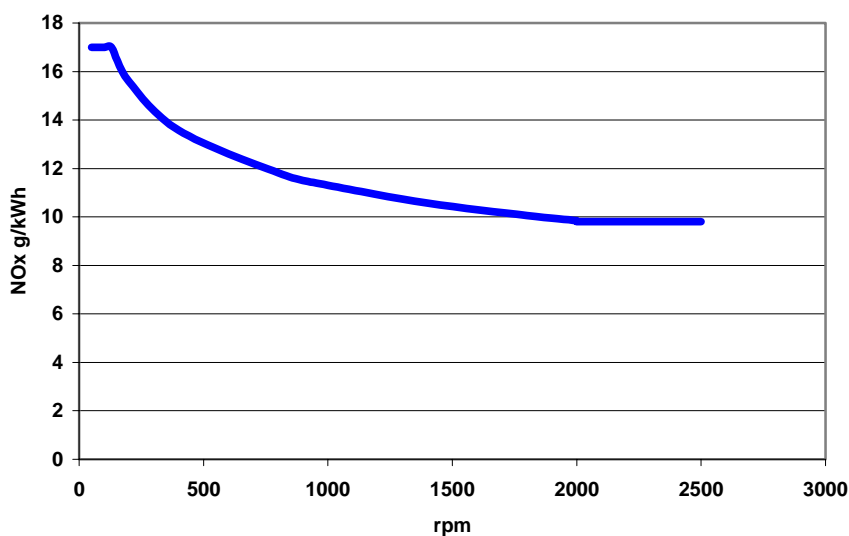


Figure 1:
Emission standard for NO_x according to IMO g/kWh in relation to rotation speed (revolutions per min)

A number of techniques are developed to reduce NO_x emissions from ships. Several of these are commercially available today. Others are not fully commercial and still under development. In addition, work is going on with further development of varieties and combinations of techniques. For the techniques at an early stage of development a limited amount of consistent information is available. There are also larger uncertainties involved when it comes to long term results and estimations of costs.

So far, techniques to reduce emissions have not been widely introduced onboard ships. Some voluntary commitments have been made, but to a limited extent. The resistance against emission control is

mainly due to the costs involved with cleaner fuels and emission reduction equipment. Higher costs for running the ships will give higher prices for goods transportation, which in turn may change the competitiveness between different modes of transportation. The NERA report to the Commission (Harrison, et al. 2005) has provided information on advantages and disadvantages with a number of different market-based instruments to reduce emission from ships by evaluating various economic incentives which at least partly counteracts the costs of abatement. The NERA study included different trading programmes, taxation and charging as well as en-route charging and differentiated dues.

Example - Voluntary commitments

In addition to regulations and economic instruments, voluntary commitments have been made by ship owners and companies chartering the ships for changing the fuel to low-sulphur and to install techniques for NO_x reduction. These commitments have been rather successful at least for some types of ships. As an example, many Swedish forest industries have chartered ships for transporting products to Europe. These ships have used low-sulphur fuel and been equipped with catalytic converters. In this way, the annual emissions from their total ship transports with timber and products to Europe have decrease by 50 % for sulphur dioxide (6 000 tonnes) and by approximately 30 % for nitrogen oxides (5000 tonnes) (Lövblad 2005).

Emission trading systems

The cap and trade system sets a cap over the total emissions in an area where each emitter has its right to emit a certain amount of pollutants. If the emitter undertakes actions to reduce the emission, the right to emit the amount reduced can be sold to facilities having difficulties in reducing their emissions due to high costs or other reasons. Emission trading programmes could also provide tradable credits to facilities that reduce emissions voluntarily below their “business as usual” emission level. In benchmark trading systems a specific emission rate is applied to the activities covered. Credits are then linked to specific emission levels. A ship owner may buy and sell credits in relation to the emissions of the ship and in this way lowering the costs for emission control.

Taxation and charging

Taxation systems involve mainly the taxing/charging the sulphur fuel content in

excess of a given level at the point of sale or in fuel used by each ship. In this way, the sulphur dioxide emissions may be reduced. However, to reduce also the emissions of NO_x a system to tax/charge the emissions by each ship is necessary. The latter system is more complicated - and involves certification and some kind of monitoring - than just taxing/charging the fuel used.

En-route charging

En-route charging is a system which has been used in aviation to provide revenues to fund air-traffic control services. It could be used to charge vessels for emissions en-route in a trip-based or a distance-based approach. This system would require periodic monitoring.

Environmentally differentiated port and fairway dues

Environmentally differentiated port dues and fairway dues have been tested and applied for eight years in Swedish waters, including international waters around Sweden. It takes advantage of the fact that many ports and some countries charge vessels using their facilities and waters.

The NERA report (Harrison et al. 2005) concludes that even if none of the approaches are perfect, there are some which may seem promising for initial use of market-based instruments to promote low-emission shipping in EU. The report also point to the uncertainties involved in the procedure such as monitoring, enforceability, legal issues and political constraints. According to the NERA recommendations, the market-based approaches share a number of advantages in relation to the less flexible regulatory approaches.

Voluntary port dues differentiation is one way mentioned, which could be based on

the Swedish experiences with differentiated port and fairway dues. It would require a system of emission indices and differentiation formulas. Consortia benchmarking is another possible approach, where consortia of shipowners band together to reduce the costs for meeting more stringent limits. The primary difficulty would be to develop rules and procedures applicable. The third approach could be a rigorous credit-based approach which would provide incentives for

shipowners to participate. Implementing this system would require legal and political actions by the Commission.

Emission trading is the approach which is preferred by at least some of the actors on the shipping market, a.o. Ship Emission Abatement Techniques SEAT. It is understood that all the recommended approaches would be based on existing regulatory structures and provide incremental shifts.

Example - Environmentally differentiated fairway due in Sweden

Initiatives have been taken to promote the introduction of emissions control in Swedish waters by using a system with environmentally differentiated fairway dues. Most Swedish ports have a discount for ships with low emissions. A system with environmentally differentiated fairway dues was introduced by the Swedish Maritime Administration in 1998. It was revised in 2005. The system involves that fairway dues are paid in relation to ship-generated emissions of nitrogen oxides and sulphur. (www.sjofartsverket.se).

For sulphur the dues is 0 SEK/GRT if the fuel contains max. 0.2 % S (by weight). With a sulphur content in fuel higher than 1 %, the dues is 0.6 SEK/GRT. There is a slight difference between passenger vessels and other vessels.

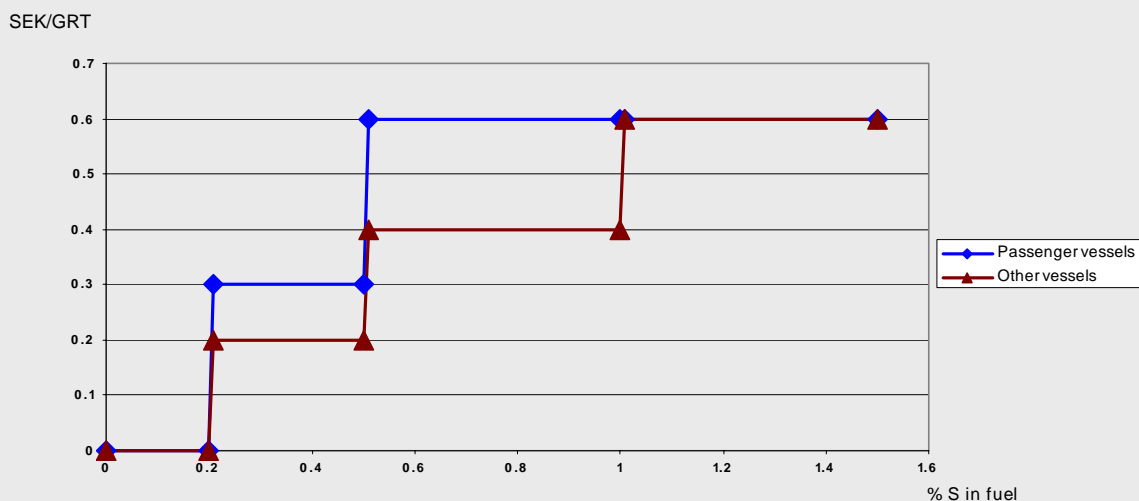


Figure 2: Fairway dues in Sweden in relation to sulphur in the fuel used for different types of vessels

For nitrogen oxides emissions the discount starts at an emission of 10 g/kWh. The discount increases in steps down to 0.5 g/kWh. There are slightly different dues for different types of vessels, where oil tankers have the highest fairway dues and cruise vessels have the lowest. The highest due is 2.20 SEK/GRT.

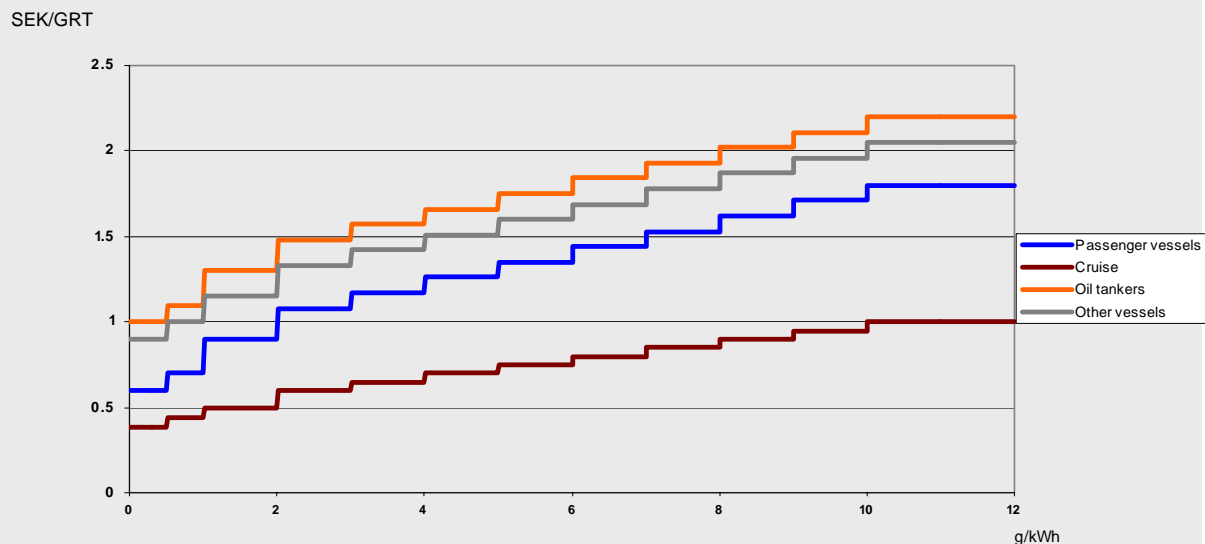


Figure 3: Fairway dues in Sweden in relation to NO_x emissions for different types of vessels

At present 43 ships have a low-NO_x certificate for reduced fairway dues in Sweden www.sjofartsverket.se. The Swedish Maritime Administration estimates that, in total, more emissions of more than 40 000 tonnes of NO_x per year are avoided due to NO_x control.

3. Sea transport and long range trans-boundary air pollution

Transports of goods are presently increasing and the need for transports within the next decade is estimated to increase further also within the next 10 to 15 years. Projections indicate that transport of goods by ships is expected to increase between 1.5 and 3 % yearly (IMO, 2000; Entec, 2002). Under such projections, emissions of air pollutants from ships are expected to increase considerably. Consequently, the sulphur dioxide emissions from ships can be estimated to

increase by more than 40 % between 2000 and 2020 and the nitrogen oxides emissions to increase by 65-70 %, unless actions are taken to reduce emissions. These emission projections have assumed full implementation of MARPOL Annex VI and the EU directive on sulphur in marine fuels.

Generally comparisons between modes of transport depend on the conditions for the calculations made and data presented can

always be questioned. When studying transport alternatives available, sea transports appear advantageous from several environmental aspects. One of the main aspects is that carbon dioxide emissions in many cases are lower for ships than for road transports calculated in relation to amount of goods transported (per tonnes km). See for example the comparison made by EEB (2004) table 3 using data from www.ntm.a.se. However, the emissions from sulphur dioxide are

presently considerably larger than from road transports and the nitrogen oxides emissions are about twice the emissions from road transports in relation to amount of good transported (per tonnes km).

Fuel consumption of ships may vary from the lowest to the highest level of all transport modes. Sea transports are mainly energy effective in relation to speed, as can be illustrated by Figure 4.

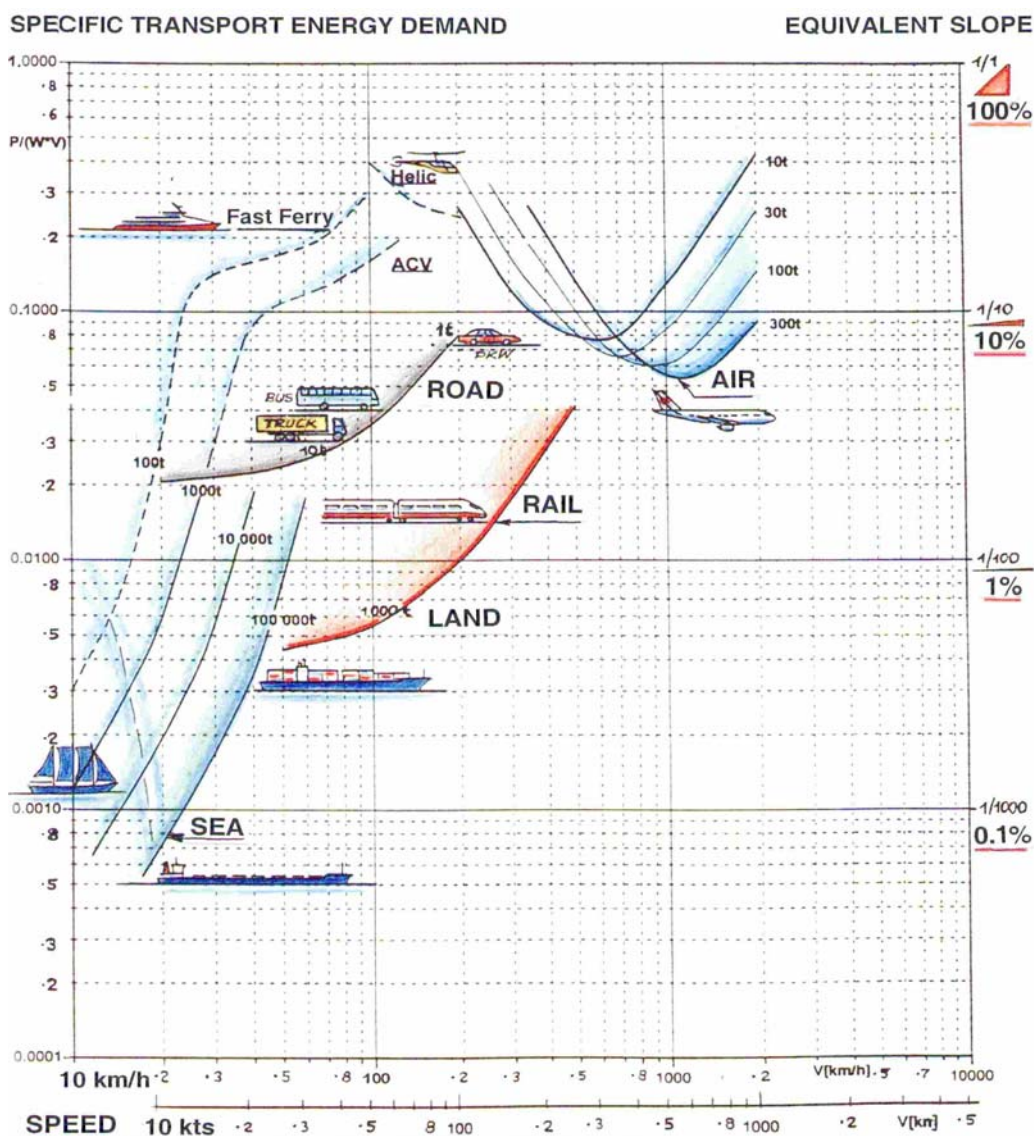
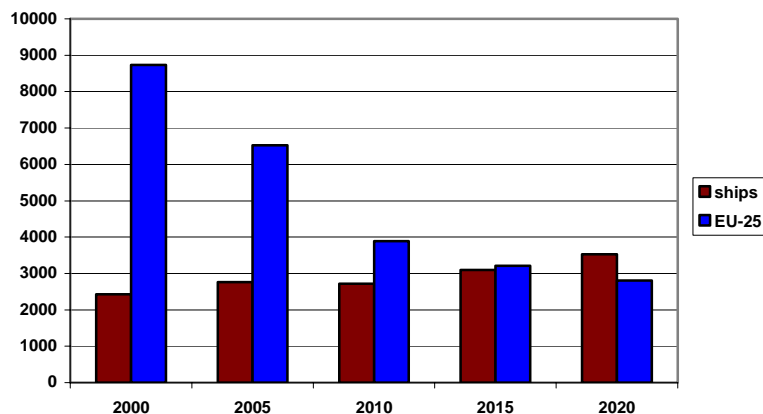


Figure 4: Karman-Gabrielli Diagram improved by Peter Schenzle, Hamburg Ship Model Basin HSVA, presented by Jürgen Isensee (2005)

In its thematic strategy on air pollution from September 2005, the European Commission concludes that unless actions are taken, ships are fast becoming the biggest source of the air pollutants SO₂ and NO_x within the EU-25. Under the EU's Clean Air for Europe (CAFE) programme, scenarios showing future levels of air pollutant emissions have been elaborated. The so-called baseline scenario describe emissions in the EU between 2000 and 2020 based on projections of future levels of activity in the energy, transport, industry and other sectors. It also assumes full

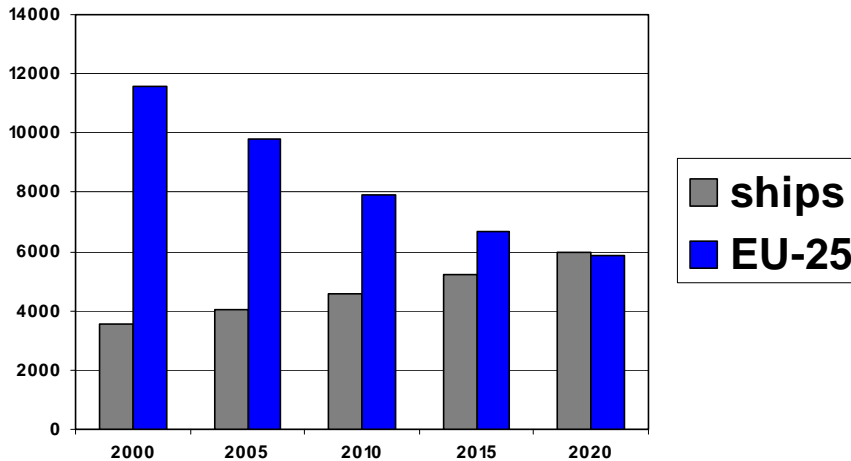
implementation of existing legislation, i.e. the scenarios imply that all decided abatement actions are to be fulfilled in accordance with current legislation. The CAFE scenarios will form the starting point for the negotiations on future air pollutant abatement strategies, including the revision of the EU directive on national emissions ceilings for the EU member states.

Under the CAFE baseline scenario (Figure 5) by 2020 ships are set to emit more SO₂ and NO_x than all land-based sources in EU25 together.



5a:
Estimated emissions of sulphur dioxide to the atmosphere from land based sources within EU25 and from ship transport in European sea areas for 2005 - 2020 (1000 tonnes per year).

Figure 5: Baseline scenarios for the emissions of sulphur dioxide and nitrogen oxides in EU. Data from the RAINS model www.iiasa.ac.at Scenario CP-CLE(Nov04)



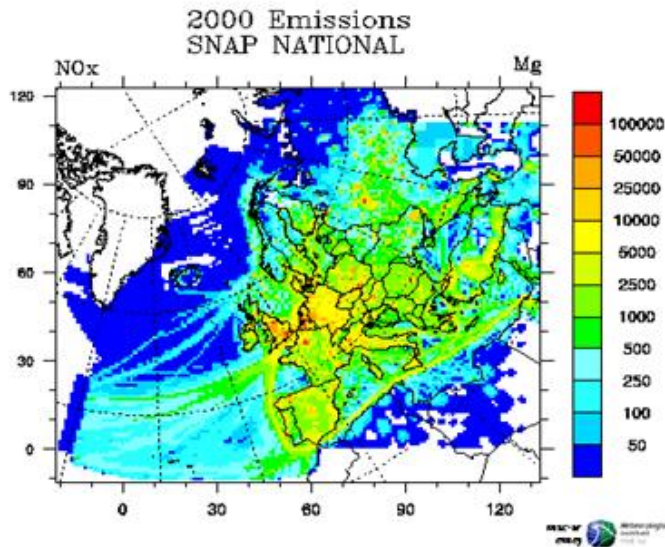
5b:
 Estimated emissions of nitrogen oxides to the atmosphere from land based sources within EU25 and from ship transport in European sea areas for 2005 - 2020 (in 1000 tonnes per year).

- See also Clean Air For Europe, (<http://europa.eu.int/comm/environment/air/cafe/index.htm>).

Ship transports will - in addition to other sources of emissions such as road transports, energy production and industrial processes – be subject to proposals for control measures. The aim of the national emissions ceilings directive is to reduce air pollution damage to health and ecosystems by cost-effective EU-wide emission reduction strategies.

The emissions from ships of mainly sulphur, nitrogen oxides and particles will add to the levels of pollution from other sources over the European continent. Particles as well as sulphur and nitrogen oxides from ship emissions contribute to particle levels in air over Europe, see Fagerli and Tarrasón (2001).

The main part of emissions from ships in the seas around Europe is estimated to occur along specific routes (Figure 6), near the coast through the English Channel, along the northern coast of the European continent, in the western part of the Bay of Biscay, through the Strait of Gibraltar and along the route through the Mediterranean to the Suez Channel. The estimate of emissions over the seas has shown that the emissions per km² on these navigation routes are equal to or even larger than in many polluted land areas. The largest influence is observed in coastal areas with intensive traffic.



From EMEP MSC-W,
www.emep.int
 for the year 2000

Figure 6: Emissions of nitrogen dioxide in Europe in 50 km times 50 km grid squares (tonnes of NO₂ per year and grid square) show that the emission density in many of the navigation routes are equal to or even larger than in moderately polluted parts of Europe.

<http://europa.eu.int/comm/environment/air/transport.htm>).

The additional cases of hospital admission by increased air pollution due to emissions from ships was estimated to 0.64 per 1000 tonnes emitted SO₂ and 0.69 per 1000 tonnes emitted particles. The years of life lost within the EU countries due to shipping pollution was estimated to nearly 4 per 1000 tonnes of emitted SO₂ and 14 per 1000 tonnes of emitted particles. The costs connected with human health effects due to shipping emissions in the EU harbours were estimated to € 8 200 per 1000 tonnes of SO₂ emitted and € 30 500 per 1000 tonnes of particles. So, there are obvious health benefits possible in the reduction of ship pollution.

Reducing emissions will also benefit the ecosystems. Sulphur and nitrogen deposition contribute to ecosystem effects

such as acidification (mainly sulphur but partly also nitrogen deposition) and eutrophication (nitrogen deposition), see e.g. Jonson, m.fl. (2000). The deposition contribution and its effects have been quantified using air pollution models. In contrast to sulphur, nitrogen deposition on the sea surface may at least in coastal areas contribute to eutrophication. In addition, nitrogen deposited over land is partly brought out to the marine ecosystems via run-off from forest land and rivers, and will also be of importance for the coastal water eutrophication. Nitrogen oxides emissions also take part in the photochemical reactions forming ground-level ozone. The ozone concentrations in Europe may damage human health, forest trees, agricultural crops and interact with the climate.

4. Technical measures to reduce nitrogen oxides emissions

NO_x reduction techniques were installed on the first ships in the beginning of the 1990s. Many of the installations were made for demonstration purposes before the technique was finally developed. Initially, there were problems connected to the use onboard ships but much of the problems have been overcome. Today, most of the techniques described below are mature and more or less commercial and the experiences by operation on ships are extensive.

The techniques are based on different principles, see for example Entec (2005a). Engines and combustion conditions can be modified by a range of methods to reduce NO_x emissions. The aim can be either optimised combustion, improved air charge characteristics or altered fuel injection system. There are two categories of techniques of internal engine modifications (IEM); basic IEM (mainly installation of slide valves) and more advanced IEM. The NO_x reduction efficiency of these techniques is typically in the area 20 – 30 %. The more advanced internal engine modifications includes a number of actions such as retard injection, higher compression ratio, increased turbo efficiency, etc. The techniques are still under development, but are expected to reduce NO_x emissions with around 30 % in relation to the IMO NO_x standard.

Exhaust gas recirculation (EGR) is a technique under development for cooling the combustion and for reducing the oxygen supply to the combustion in order to reduce the NO_x formation. A fraction of the exhaust gas from combustion is filtered, cooled and re-routed back and mixed into the engine charge air. The process results in a reduced combustion temperature, somewhat lower oxygen

supply and, as a consequence, less NO_x formation. It is of special importance to remove pollutants especially particles and corrosive components such as sulphur before mixing the exhaust gas into the hot charge air. Particle deposition in the combustion chamber will pollute the lubrication oil leading to increase wear of the combustion chamber. Sulphur in the exhaust gas will lead to risk of corrosion. It is not yet commercial, but the recirculation is expected to reduce nitrogen oxides emissions by 30-40 %. It is assumed that the practical application of EGR will be limited to ships using marine diesel oils with low (<0.2 %) sulphur content. EGR is not expected to impact on fuel consumption and will therefore not have any influence on CO₂ emissions. The technique may – as several other techniques used to lower the combustion temperature – result in slightly increased emissions of VOC, particles and CO.

Water can be used to cool the combustion and reduce the amount of NO_x formed. One technique is the direct water injection (DWI) resulting in a NO_x reduction of around 50-60 %. Water can also be introduced as vapour as in the Humid Air Motor (HAM) and similar techniques. HAM is a little more advanced and requires a little more encroachments. It is also more effective (70 - 85 %) than DWI since it utilise thermal losses from the jacket cooling and turbo charger to evaporate the sea water in the process. There is a variety of similar techniques developed or under development, such as the Saturated Air Motor, SAM technique and the Wärtsilä WetPac method. However, these two techniques utilise technically pure water, while HAM uses sea water.

Finally, there is a technique where the formed NO_x reacts with a reducing agent (usually urea solution) which is pyrolysed in a catalytic converter and reacts with NO_x to form nitrogen (N_2) and water. The SCR-technique is now used relatively frequently in order to effectively reduce NO_x emissions from ships. Most comments have been achieved from shipowners using SCR. Most of them have been satisfied with the operation. One or two have had serious problems with the catalyst if it was not maintained thoroughly. It is obvious that use of gas oil with low sulphur content is an advantage when using both SCR as well as several other NO_x reduction techniques.

There are some also other operational possibilities to lower the emissions of sulphur dioxide and nitrogen oxides. Fuel savings and slow steaming will have an effect on the emitted amounts. Fuel is at present a major cost for the ship transport

and savings is highly prioritised by the ship owners. Effective hull paint will decrease the fuel consumption. Work is going on e.g. in Sweden (Mistra project Marine Paint) to develop effective but environmentally non-toxic paint to reduce fouling.

Det Norske Veritas (2005) has studied the change of fuel from liquid oils to gas. Gas has so far mainly been used as ship fuel for ships transporting liquid gas or for transport to and from the oil and gas fields in Norway. There are two main drawbacks, the availability of gas and the associated risks. The reduction potential is estimated to be significant. NO_x emissions lower than 1.5 g/kWh are reached, equal to approximately 90 % lower emissions than for a traditional medium speed diesel engine. In addition the SO_2 and particle emissions will be reduced to nearly zero.

A summary of basic characteristics of some of the different techniques is made below:

Basic internal engine modification technique – slide valves

Technique:

The most wide-spread internal engine modification technique involves the exchange of conventional fuel valves with low- NO_x slide valves. Slide valves can only be delivered for MAN B&W 2-stroke engines, but the modification of the spray pattern can be implemented on any injection nozzle. Slide valves are designed to optimise spray distribution in the combustion chamber, which results in somewhat lower heat release than the conventional fuel valves, which gives a considerable reduction of NO_x -emissions. The main purpose of these valves, however, was initially to reduce engine fouling.

Status of the technique:

Use of slide valves is the most common type of NO_x reduction measure. From the year 2000 slide valves are used as standard on most new engines. Since 1998 more than 500 commercial installations are made world-wide. Cost estimates are therefore relatively certain.

Reduction efficiency:

The slide valves will reduce the NO_x emissions by 20 %. On a longer time perspective higher reduction may be possible.

Impact on fuel consumption

The fuel consumption is not affected.

Impact on emissions of other pollutants

Slide valves may in addition to reducing NO_x-emissions, also provide considerable reductions in VOC and PM emission (Aabo 2003, Kubel 2004). Wallenius Marine reports that measurements on MS Aida indicated 50 % reduction of particle emission. This is believed to be due to the fact that slide valves provide a better control of the combustion process. However, like the techniques based on affecting the combustion temperature for the reduction of NO_x, slide valves may increase the CO emissions.

It is important, however, to keep the temperature sufficiently high for a complete combustion. If the fuel enters the combustion zone when the temperature is too low there is a risk for fouling of the engine and increased soot and VOC emissions.

Impact on consumption of lubricating oil

No data are available.

Life time:

The expected life span is around 5 years. Once installed the life time of the valves will be the same as for conventional valves. During their life time they will be effective.

Ships using slide valves:

The slide valves are applicable for slow-speed 2-strokes engines. Virtually all new engines of this type are equipped with these valves as standard. Retrofitting of slide valves is technically possible for the main part of the 2 strokes engines.

Required space for installation:

No extra space is required. The slide valves replace conventional fuel valves.

Installation

Retrofitting of slide valves is considered easy since it only includes removing the old valves and enlarging the fuel injector holes in the cylinder covers. However, the modification of the fuel injection valves is considered a major modification according to IMO. The change is simple and could be comparably inexpensive, but since the effect has to be demonstrated, it can be expensive depending on the number of installations made on the same type of engine. Usually it is possible to enlarge the fuel injector holes in the cylinder cover.

Sources of information:

Data from Entec (2005), Wallenius Marine Quality Safety and Environment Report 2004,

Contact with Lena Ekbohm, Wallenius Marine, Britt-Mari Kullas-Nyman and Rolf Andersson, Wärtsilä. David Cooper (formerly IVL), Stefan Lemieszewski, Swedish Maritime Administration.

Direct Water Injection (DWI)

Technique:

Freshwater is injected into the combustion chamber in order to lower the combustion temperature. The injection of water is made just before the fuel is injected. In some cases the water is mixed with the fuel. The lowering of the combustion temperature will reduce the NO_x formation during combustion. According to Entec 2005, so far only Wärtsilä has developed the DWI method to apply to their ship engines. In the Wärtsilä case the water system is separated from the fuel system as a safety precaution.

Status of the technique

The technique has been in operation for a large number of hours since 1998. It has been proven to be effective, but the experience is limited to a small number of manufacturers, such as Wärtsilä. In 2005 direct water injection was commercially installed on 23 ships. Cost estimates for new build ships are relatively certain.

All water injection techniques are said to be associated with risks for disturbed lubrication films inside the cylinders, which may increase the cylinder wear. However Wärtsilä states that no effect is expected on the engine components.

A number of new ships delivered within the near future will have DWI systems installed.

Reduction efficiency:

The NO_x reduction efficiency has been showed to be 50 – 60 %. MAN B&W has achieved 20 – 30 % while there are reports on lower reductions for other systems.

Availability:

More or less 100 % availability is normally achieved. No start-up time is necessary and the system may operate directly when the engines are started.

Use of fuel

It is recommended to be used in combination with fuels having a sulphur content lower than 1.5 %.

Use of water:

Fresh water must be used for the Wärtsilä DWI method. Sea water cannot be used. The typical water to fuel ratio used is 40-70 % to achieve 50-60 % NO_x emission reductions.

Impact on fuel consumption:

Earlier studies, e.g. Kågeson (1999), reported that NO_x reduction using DWI is made at the cost of increased fuel consumption. However, more recent data indicates that the losses may be insignificant. The Wärtsilä system for example is said not to impose any power losses, and no change in fuel consumption. All sources reported to Entec indicates very small changes, increased fuel consumption with 1-2 %, while Det Norske Veritas (2005) reports constant or slightly reduced fuel consumption.

Impact on other pollutants

Impact on other emissions is reported to be negligible. DWI is not known to produce any additional noise.

Required space for installation:

For using this technique it is necessary with storage and bunkering of freshwater.

Installation:

Installation can be carried out while the ship is in normal operation.

Ships used to demonstrate the method:

MS Silja Symphony has used the method since 1999. The emission of NO_x has been reduced from 14 to 5.5 g NO_x/kWh.

Sources of information:

Data from Entec (2005), Silja 2004 Hållbarhetsredovisning, Silja 2004 Årsöversikt, Det Norske Veritas (2005).

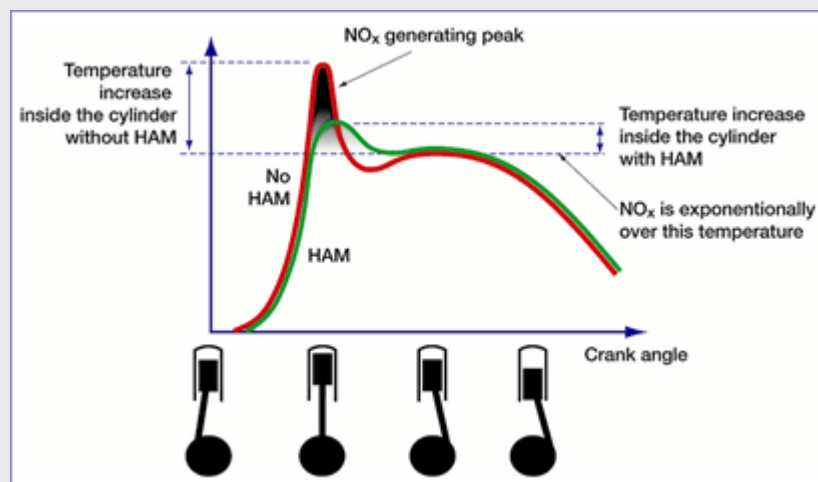
Contacts with Lena Ekbohm Wallenius Marine. Britt-Mari Kullas-Nyman and Rolf Andersson, Wärtsilä. David Cooper (formerly IVL)



Humid Air Motors (HAM), SAM and WetPac

Technique:

The Humid Air Motor technique uses hot charge air to which water vapour is added to cool down and reduce the NO_x formation during the combustion process.



All water injection techniques are said to be associated with risks for disturbed lubrication films inside the cylinders, which may increase cylinder wear.

The SAM system from Man B&W and the WetPac from Wärtsiä are in principle the same techniques as HAM. The SAM system reduces NO_x emissions by spraying sea and fresh water into the hot scavenging air for cooling and humification of it. The water injection takes place in three stages. First sea water is used for humification and cooling and then two fresh water stages for removal of any salt from the scavenging. The scavenging air will be fully saturated. From each of the stages, surplus water will be drained back into three different tanks.

Status of the technique

So far only one ship have used the HAM method in daily operation; Viking Line's MS Mariella. Their experience with the method is long. HAM has been in use since 1997. SAM and Wetpac are similar techniques. The difference is in the use of water. WetPac is presently being installed in a number of new ships. SAM is so far only a test system, not commercially available.

Reduction efficiency:

The reduction efficiency of HAM is reported to be 70 – 85 %. The latest measurements on Mariellas four engines have shown emissions on the main engines to be reduced from 17 to between 2.2 and 2.6 g/kWh. For the Wetpac method the reduction efficiency is reported to be equal to 50 % below the present IMO NO_x curve, equal to 7 g/kWh. For SAM 30-40 % reduction is expected, but since it is still under testing, these levels may be somewhat uncertain.

Availability:

The HAM method works very well on MS Mariella, independent on load. More or less 100 % availability is normally achieved. MS Mariella has had the HAM installed during >27000 hours on engine 1 and >15000 and >17000 on engines 2 and 3. HAM requires no warm-up time and NO_x -reduction begins more or less once the engine is engaged. The HAM system is shut down about 15 minutes before stopping the main engine. This is made in order to dry up the engine to avoid corrosion.

Initially there were some problems, e.g. with CaCO₃ deposits in the evaporator vessel, but these could be overcome by treatment. During the latest years there have not been many operation problems.

The SAM method is expected to have low availability at low load due to low temperature of the scavenging air and consequently limited possibilities to humidify it.

Use of water:

The HAM on Mariella uses water from the Baltic Sea (brackish), which is economically advantageous. Roughly, about three times as much water vapour as fuel is introduced into the engine to achieve 70-80 % NO_x reduction. The water amount necessary for the voyage between Stockholm and Helsinki is around 60 tons. The incoming water is filtered in order to separate algae and other solid water pollution. Filter cleaning is an additional part of the maintenance, which may cause some work during periods of algae pollution. Mariella uses two parallel filters with an alarm system for cleaning. Test to use salt sea water (in France) have been successful, even if there are some reports that sodium content of the water may be a problem (Det Norske Veritas, 2005). Almost saturated salt solution was tested in lab. 95 % of the water is recirculated, 5 % is bled off to the sea in order to control the content of salt in the process.

The SAM technique and the Wet Pack method uses “technically pure” water; equal to deionised or evaporated water.

Impact on fuel consumption:

Low sulphur residual oil (>380 cst) is used in combination with HAM. The HAM installation has been estimated to decrease fuel consumption slightly, 2-3 % according to Mariella’s experience, due to the fact that waste heat is recovered and used for the evaporation of sea water.

Impact on other pollutants

HAM may like other techniques based on decrease of combustion temperature, slightly increase VOC and CO emissions. Also increases in particle emissions have been indicated, but not quantified (Entec, 2005; Det Norske Veritas, 2005).

Impact on lubricating oil and maintenance:

The HAM installation is estimated to decrease the lubrication oil consumption with around 40 %. Also, the required need for maintenance of the valves is decreased and can be made at longer intervals. DNV reports on the risk for disturbed lubrication films.

Required space for installation:

HAM was originally installed as retrofit on Mariella. The system needs space, which is usually possible to find. The HAM system can be considered as an integrated part of the engine since it replaces the conventional engine air inter-cooler. Since waste heat from the engine is also used for generation of hot water for other onboard uses, installation of HAM could lead to capacity problems calling for additional boiler capacity. A central part of the HAM system is a humidification tower and its insulation, which require space close to the engine.

Installation considerations:

Installation of HAM on the first engine was made during day-time stops of the ferry. The installation on the three other engines was made during one week in dry dock.

Ships using the method in daily operation:

In contrast to some other techniques, it is possible to obtain a good NO_x reduction linked with a good fuel economy. There is an economic incentive to keep the technique in operation since there is no cost for a reduction media, the engine is kept cleaner, the consumption of lubrication oil is lowered and the service interval increases. HAM has been appreciated in these aspects by several contacts. Further, there are possibilities to use the increased mass flow through the engine for additional power production, if so desired.

Sources of information:

Data from Entec (2005), Munters (www.munters.com) Environmentally friendly diesels with HAM

Contacts with Ulf Hagström, Viking Line and Christer Mattson, Viking Mariella. David Cooper, Britt-Mari Kullas-Nyman and Rolf Andersson Wärtsilä, Stefan Lemieszewski, Swedish Maritime Administration, Peter Skjoldager, MAN B&W.

Selective catalytic reduction SCR

Technique:

SCR is based on a reaction between urea - decomposed to ammonia (NH₃) - and NO_x in the flue gas over a catalyst. NO_x is then reduced to nitrogen (N₂). Urea solution is injected into the hot flue gas after the combustion. SCR can be installed in or after any type of motor, as long as the flue gas temperature is in the specified temperature interval, from 270 °C up to 500 °C, usually around 320 °C. The urea injection is automatically tuned to power changes in the engine.

The catalyst is made from titanium oxide and vanadium oxide and consists of small exchangeable units (monoliths of extruded ceramics).

Status of the technique

SCR is presently the most common method to reduce NO_x emission from ships. SCR is now estimated to be commercially installed on more than 300 engines world-wide. It

has been in commercial use since 1989. Cost estimates can consequently be made by a high degree of certainty.

Reduction efficiency for NO_x :

Technically it is possible to reach 95 % or even higher reduction. However, the NO_x reduction efficiency of the SCR is often operated to reach around 90 %. The efficiency is dependent on the urea flow. To achieve 90 % NO_x reduction approximately 15 g urea is needed per kWh energy from the engine. The engine may be fuel-optimised, so that the fuel consumption is minimised to the cost of somewhat higher NO_x emission. In this way lower fuel consumption can be combined with low NO_x emissions.

Life time of catalyst:

The life time of the catalyst is usually relatively long. The longest operating SCR-system has been in operation for 14 years (using marine diesel fuel) and the catalyst is still efficient. However, low sulphur (max 0.2 %) diesel oil has been used in this case. Other ships has reached 40 000 hours of operation using heavy fuel oil. The life time of the catalyst depends on the fuel. Pollutants in the exhaust gases may deactivate the catalyst. Clean fuel will prolong the life of the catalyst and decrease the maintenance necessary. Using a fuel with ≤ 1.5 % sulphur, the reactor may have to be rebuilt every five years. Using average fuel containing 2.7 % sulphur the reactors may have to be rebuilt every 3 years. Ships using diesel fuel will most likely have a lifetime of the reactors of 15-20 years. A soot-blower may be necessary to keep the pores of the catalyst open, especially when operating on heavy fuel oil and oil with high sulphur content. Usually more than 20 000 hours of operation are guaranteed.

Calcium sulphate (gypsum) and other particles from the combustion will deposit on the front of the catalyst and may cause soiling problems if it is not removed regularly by a soot-blowing system. Some ship owners have recommended improvements to be made by introducing pre-switched soot-filters. Soot sedimentation - from the soot-blowing - will negatively influence the system.

Availability:

Once installed the SCR is in most cases operating nearly 100 % of the time.

A consequence of the need for relatively high exhaust gas temperatures (above 270 °C) for an effective NO_x reduction is that a warm-up time of around 20-30 minutes is required after a cold-start. After the warm-up, the urea injection will start.

Seen over a longer time period a certification is made every 3rd year. Usually there is only a slightly decreased efficiency in the NO_x reduction.

Use of urea:

The consumption of urea is generally within 5-8 % (by weight) of the fuel consumption to achieve effective NO_x reduction. However, there are variations between 2 -10 %. Urea in a 40 % water solution is delivered to the ship by a tank truck. Urea is a common chemical, non-poisonous and relatively safe to transport. Urea should be possible to be delivered in most harbours. At present, there are experiences from urea deliveries in Sweden, Norway, Finland, Germany and the Netherlands. It is

expected to be possible to have a deliverance of urea in any European harbour. Urea is delivered (40 tonnes) with a road tanker directly to the ship. The volume of the urea tank on board is usually 40-50 m³. The transport costs are significant, so the volume of a full tanker should be possible to fill into the urea tank.

40 % urea solution must be stored above 0 °C in order to minimise the risk for crystallisation. More diluted solutions (35 %) may be stored at some minus degrees. This can be solved by storing below the water line. At present around 20 000 tonnes of urea solution is sold in Sweden annually. In this way 12 000 tonnes of NO_x is reduced every year. In Sweden two independent companies now deliver urea in Swedish ports. Due to increased competition, the prices have decreased.

For longer voyages, it is possible to mix the urea solution onboard. Urea pellets can be delivered in big bags and stored onboard until needed. Pellets and water can be mixed in a mixing tank

Fuel used:

SCR may be used with diesel fuelled engines and with engines operating with residual oil. However, use of a cleaner fuel will as mentioned prolong the life of the catalyst. There is an optimum, where the costs for a more expensive fuel will be counteracted by the costs for decreased maintenance need. There are also indications that use of heavy fuel oil may severely increase the need for maintenance on some ships, while the catalysts on other ships seem to operate quite well using heavy fuel oil. This increased need is mainly due to slow speed navigation by large bore engines during longer periods with low exhaust gas temperature.

Impact on fuel consumption:

No significant change in fuel consumption is reported to occur from using SCR.

Impact on other pollutants

Particle emissions may be reduced using the SCR technique. However, this is not well documented. VOC emissions are also reduced, and if SCR is used in combination with an oxidation catalyst, VOC and CO emissions are reduced considerably.

With a poorly trimmed reaction between exhaust NO_x and urea or a suboptimised catalytic reactor, there is a risk for excessive NH₃ emissions. Ammonia slip may occur when the amount of urea/ammonia injected into the exhausts are larger than necessary for the complete reaction of NO_x to nitrogen and water. The additional ammonia is then emitted to the atmosphere. The slip is usually kept below 10 ppm in SCR installations. Ammonia emissions from ships are usually well below 0.1 g/kWh (a mean for 7 engines on 5 ships was 0.003 g/kWh) (Cooper 2004). If used in combination with an oxidation catalyst, VOC emissions can be reduced by 75-90% and CO emissions by 50-90 %.

There is sometimes a feedback loop in order to avoid ammonia slip at rapid changes in load for example during manoeuvring in harbour.

The catalyst will improve noise reduction. Consequently, engine noise may be reduced by using SCR system with up to 10 – 35 dB(A).

Impact on lubricating oil:

No data are available.

Required space for installation:

Installation of the equipment needs space for the catalyst reactor – in the engine room casing - and for the urea storage tank (usually 50 – 100 m³). The catalyst may replace the noise reduction unit. The easiest is of course to install the SCR when building the ship. But retrofits are possible. The tank may be located in the ship hull or a ballast tank on board could be used. In almost all cases it is possible to find the necessary space using a special design. Any stability problems of the ship due to installation of heavy equipment at some height must be considered but can usually be solved.

Time of installation – for a retrofit in a shipyard – may vary between 1 and 3 weeks.

Need for maintenance:

The crew on some SCR equipped ships indicates that maintenance work is generally required especially for cleaning the urea injection nozzles. The crew may also have to be trained in the operation and maintenance of the SCR system. However, other states that the complete system is very reliable and disturbances are rare. The system has in many cases been running without major problems and been in service 95-98 % of the time.

It is an essential part of the maintenance to ensure that the urea injectors are not blocked.

Ships using the technique in daily operation:

There seem to be no restriction on which type of ship that can use SCR, as long as the temperature of the exhaust gas can reach the temperature 270 °C or preferably around 320 °C. SCR is an add-on exhaust treatment system, working with almost any type of engine. Most experience is gained using SCR on 4-stroke medium and high speed diesel engines. On the 4-stroke engines the SCR is normally placed in engine room casing. SCR-systems have also been fitted on slow speed 2-stroke engines. In this case, the SCR is positioned in the exhaust channel before the turbocharger in the engine room.

Munters reference list of ships with catalysts contain around 50 ships and 200 engines www.munters.com/home.nsf/ByKey/CKIL-5ZE9ML .

Sources of information:

Entec (2005), Cooper (2004).

Viking Lines

Munters (www.munters.com) Munters SCR Converter™ System

Ulf Hagström, Viking Line, Scand Line, Agnar Milde Teekay Marine Services. Soenke Dittmer Reederei Roerd Braren, David Cooper (formerly IVL). Vincent Lundström, Holmberg & Co AB, Stefan Lemieszewski, Swedish Maritime Administration.

5. Costs for reducing nitrogen oxides emissions from ships

Data on costs for using NO_x emission reduction technique are mainly based on data presented in Entec 2005. In this way the costs are believed to be more comparable. Many of the contacts made in this report could not present any detailed estimate on costs. The reduction equipment was in many cases installed for testing purposes and the economy was not the first priority.

The costs are summarised below in a way to show comparable data. As can be seen here is a large variation between the cheapest and the most expensive technique. Generally, it is more expensive to install reduction technique on existing ships, compared with installation at ship building. The costs for emission reduction onboard ships are in general significantly lower than those for further reducing the emissions from land-based sources.



Table 1: Costs involved with NO_x emission reductions from ships

NO _x control technique cost	Capital cost	Operating cost	Life span
Basic internal engine modification – new and retrofit of slide valves in young engines is estimated to € 9-12/ton NO _x depending on the ship size.	Additional cost in relation to conventional valves is around € 200. There are two valves per cylinder in the engine	No. Engine may require less lubrication oil. No good estimate is available.	Fuel valves life span is around 5 years
Advanced IEM technique. Total cost equal to capital cost for new engines is 19 – 98 €/ton NO _x for 30 % reduction below IMO standard	Costs are not possible to estimate, they vary from one ship to another.	No operating costs. Service benefits may be possible, such as decreased lubricating oil.	Life span is the life of the engine
Direct Water Injection DWI installed on new ships is estimated to cost € 345-411 per tonne NO _x	Cost of retrofitting is described as relatively high, due to expected need of new cylinder heads which is around ¼ of the cost of a new engine (around € 50/kW)	High water quality is necessary, 90 g/kWh (45% water injection rate). Entec calculated with a distilled water cost estimated € 15/m ³ . In many cases, drinking water is used - to a lower cost.	DWI life span is estimated to around 4 years. Rest of the equipment is estimated to have a life time of 25 years.
Humid Air Motor – HAM – installed on new ships is estimated to cost 198 – 268 €/tonne NO _x . As a retrofit 263 – 306 €/tonne NO _x	90-130 €/kW for new built engines and 110-130 €/kW for retrofit.	Maintenance cost is 4 000 €/year for a 5.7 MW engine, around 0.15 €/MWh.	Life span if durable – non-corrosive or galvanised - material is used 25 years.
Selective Catalytic Reduction – SCR For a new ship using MD the cost is estimated to 313-413 € per tonne NO _x and for a new ship using high sulphur residual oil >1,5 % S the estimated cost is 526 -740 €/tonne NO _x	40 – 60 €/kW for new built engines and 60 – 100 for retrofit.	Urea solution €170/tonne. = €2.6/MWh. There are indications of a lowered price-- 120 – 140 €/tonne - due to several companies delivering urea. Transport of the urea may be a considerable part of the urea cost. Maintenance of equipment is required. Entec estimated a need of cleaning equal to € 8 000 per year and ship. The need for maintenance depends on the fuel used. An estimate of operating cost given for one ship (excl. financing) is €10 000 per year.	The catalyst is estimated to require a rebuild every 20 000 hours of operation, when using residual oil.

In addition to the above mentioned techniques, Det Norske Veritas (2005) has provided costs for a gas engine which is estimated to be 20 – 30 % more expensive than a conventional marine engine. If no tanks are necessary (e.g. for a gas transport ship) the technique is economically attractive today. Also the need for maintenance is lower.

Estimated efficiency for reducing nitrogen oxides varies from 20 to over 90 %. In addition some techniques effectively reduce also other pollutants. Data are obtained from Entec (2005). Table 2 gives a summary of the effectiveness of NO_x reduction via different techniques and the possibility of reducing also other pollutants.

Table 2: Summary of the effectiveness of NO_x emission reduction

	Efficiency			
	NO _x	PM	VOC	CO
Basic internal engine modifications – slide valves ¹	-20 %	Assumed ±0, Unconfirmed up to 50 % reduction	Assumed ±0, Unconfirmed up to 50 % reduction	Assumed ±0 some increases are possible
Direct water injection	-50 %	±0	±0	±0
Humid Air Motor HAM and similar methods	-70 - 85 %	±0	±0	±0
Selective Catalytic Reduction SCR ^{2,3}	-90 %	±0	±0 75-90 % if used in comb. with an oxidation catalyst	±0 50-90 % if used in comb. with an oxidation catalyst

¹ Basic internal engine modifications may impact positively with reductions also of PM and VOC emissions dependent on fuel.

² SCR may reduce noise produced by the engine by 20-35 dB(A). Noise is not known to be affected by any other of the techniques.

³ NH₃ emission from SCR low around 0.1 g/kWh

Table 3: Overview of cost estimates for NO_x reduction technique per tonne fuel (Entec 2005 a,b)

Technique used	Installation	Small ship €/tonne fuel	Medium ship €/tonne fuel	Large ship €/tonne fuel
Basic IEM (Two stroke, low speed engine)	New	0.17	0.13	0.12
Basic IEM (Two stroke, low speed), young engines)	Retrofit	0.17	0.13	0.12
Basic IEM (Two stroke, low speed, old engines)	Retrofit	0.90	0.34	0.20
Advanced IEM	New	2	0.7	0.4
Direct Water Injection	New	15	14	13
Humid Air Motors	New	14	12	10
Humid Air Motors	Retrofit	16	15	14
SCR outside SO ₂ ECA ships using 2.7 % S resid. oil	New	50	38	35
SCR outside SO ₂ ships using 2.7 % S resid. oil	Retrofit	55	41	39
SCR inside SO ₂ ECA ships using fuel 1.5 % S	New	37	29	27
SCR inside SO ₂ ECA ships using fuel 1.5 % S	Retrofit	41	32	30
SCR, ships using MD	New	29	23	22
SCR, ships using MD	Retrofit	34	27	25

6. Methods to reduce SO₂ emissions from ships

Change of fuel

The emission of sulphur dioxide is directly proportional to the content of sulphur in fuel. Consequently, the main method to reduce sulphur dioxide emissions from ships is to change the fuel to one with lower sulphur content.

A change in fuel from higher to lower sulphur content will also reduce the emissions of particles. No data are available however, to certify the decrease (Cooper 2004). A number of factors will influence such as the origin of the crude oil and the refinery process used.

Today change of fuel is the method generally chosen to reduce sulphur emissions. However, the demand on low sulphur fuel on the market is expected to cause the fuel prices to increase and the salt water scrubbing may become a competitive technique. The effectiveness of reducing sulphur dioxide emissions from ships and the associated costs according to Entec (2005 b) are summarised in Tables 4 and 5.



Salt water scrubbing

Technique:

Another technique is to use a salt water scrubber. It is considered to be a cost-effective readily available technique. The main principle (e.g. the Eco-Silencer® technique) is that warm exhaust gases are mixed in a cascade of salt water and the SO₂ in the exhaust is caught in the slightly alkaline salt water. The water is re-circulated and particles are separated in a settling tank. The sludge is later disposed. Filtered and used sea water is brought back to the sea. However, there are discussions of the quality of the used water and how it should be treated. Due to formation of sulphuric acid in the scrubber, corrosion problems may arise.

Reduction efficiency:

Using a fuel with 2.5 % sulphur, a reduction of the SO₂ emissions from around 70 to over 90 % is possible. The efficiency depends on contact time between sea water and exhaust gases, but also the salt concentration and the temperature may influence the reduction.

Quality of the waste water discharged:

The quality of waste water allowed to reject back to the sea is determined by environmental legislation. There is not yet sufficient information on the quality of the used water – if it can be returned to the sea or how it should be treated.

Costs for sulphur dioxide emission reduction:

Costs are evaluated from the Pride of Kent test Entec (2005 b). Capital costs include the waste water system and the demisters to reduce the amount of scrubber water in the exhausts. The capital cost for a retrofit on a ship is estimated to €120/kW. Installation on new ships are estimated to be 20-40 % lower than that for retrofits. Life time for a salt water scrubber system is expected to be around 15 years. Costs of operation are estimated to be low. The total cost is estimated to 320 – 576 €/tonne SO₂.

Table 4: Sulphur dioxide emission reduction efficiencies

Method	Change in emission			
	SO ₂	NO _x	PM	VOC
Salt water scrubber	- 75 %	±0 %	- 25 %	±0 %
Change of fuel from 2.7 → 1.5 % S	- 44 %	±0 %	- 18 %	±0 %
Change of fuel from 2.7 → 0.5 % S	- 81 %	±0 %	- 20 %	±0 %

Table 5: Costs estimated for techniques to reduce sulphur dioxide emissions

Method	Installation	Small ship	Medium size ship	Large ship
		€/tonne SO ₂	€/tonne SO ₂	€/tonne SO ₂
Salt water scrubber	New	390	351	320
Salt water scrubber	Retrofit	576	535	504
Change of fuel from 2.7 → 1.5 % sulphur	New/ Retrofit	2053 (1230)	2050 (1230)	2045 (1230)
Change of fuel from 2.7 → 0.5 % sulphur	New/ Retrofit	1439 (1690)	1438 (1690)	1434 (1690)



7. Contacts

Company	Ships	NO _x reduction	Contact persons
SCA Transforest chartering ships from Transatlantic	MS Obbola MS Östrand MS Ortviken	SCR	Peter Eriksson SCA, Lars Holmberg, Transatlantic
Broströms	New ships during 2006	SCR	Peter Stenberg Broströms
Södra Shipping chartering ships from the Braren Shipping Co	MS Cellus MS Timbus MS Forester	SCR	www.sodra.com Jan Gyllén Södra Soenke Dittmer Reederei Roerd Braren
Wallenius Marine	The major part of the fleet have new valves since 2004	Slide valves 20-30 % NO _x reduction	Wallenius Marine Quality, Safety and Environment report 2004
	M/V Manon	Wetpac 10.9 – 6 g/kWh	Lena Ekbohm Wallenius Marine
	M/V Mignon	SAM	
Silja Line	MS Silja Serenade 1995 MS Silja Symphony 1995	SCR on auxillary power engines 14 g/kWh – 0.5 g/kWh	Silja 2004 Årsöversikt (Annual report) Silja 2004 Hållbarhetsredovisning (Sustainability account)
	MS Silja Serenade 1998 MS Silja Symphony 1998	Direct Water Injection on all main engines 17 g/kWh – 5.5 g/kWh	
	MS Silja Europa 2000 MS Silja Festival 2000	SCR on main engines 17 g/kWh – 1 g/kWh	
Viking Line	MS Mariella 1997	Humid Air Motor 17g/kWh – 2.5 g/kWh	Ulf Hagström and Christer Mattsson Viking Line, David Cooper
	MS Cinderella 2003	SCR retrofit 17 – 0.4 g/kWh	Ulf Hagström Viking Line
Preem chartering ships from Tarbit Shipping	Two new tankers are delivered this year with Wetpac	A 50 % reduction of NO _x emissions is expected	Ulf Holmberg Preem
Scand Line	SCR is tested for 15 years on one main engine. All ships will be equipped with SCR.	90 % reduction is achieved. The Scand Line ships will have the fuel optimised version of the SCR.	Bo Ljungbäck, Scand Line

The following persons have provided general information:

Bertil Arvidsson, Swedish Shipowners Association
Anders Björnell and Per Holmström, Munters
David Cooper, formerly at IVL, now at Volvo
Ulf Duus, Consultant, Gothenburg

Jürgen Isensee, Consultant for ship design, optimization and sustainable transport, Hannover
Britt-Mari Kullas-Nyman and Rolf Anderson, Wärtsilä.
Stefan Lemieszewski, Swedish Maritime Administration
Vincent Lundström, Fred Holmbergs & Co AB
Jan Malmstöm, Södra Skogsägarna
Christer Ågren, Swedish NGO Secretariat on Acid Rain

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