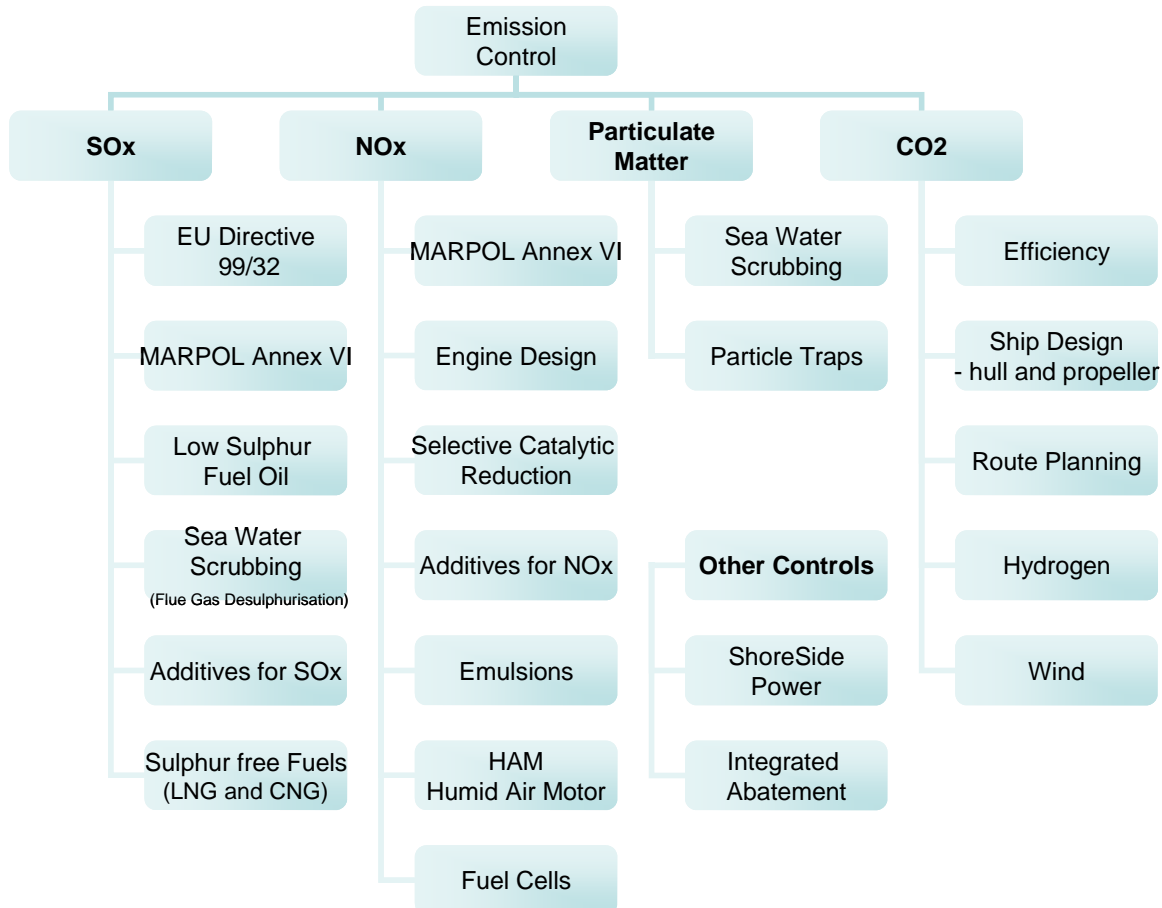


Emission Control

An Overview of the Technologies

Background

This paper parallels the Emission Control pages of the SEAAAT web site. Each section aims to be self contained, but the document can be read from start to finish.



Emission Control

SEAaT advocates competitive markets to achieve environmental objectives. This will create innovation and lower cost in the abatement technologies, and give ship owners and operators opportunities to choose the mixture of technologies that best suits their trading.

Here we give a flavour of the technologies available and possible, but emphasise that this is just a beginning. There is scope for lots more new ideas and technologies.

Abatement in its broadest sense is a reduction in harmfulness. Sometimes this is best done by removal of matter from the exhaust, sometimes by its transformation onto harmless substances, and sometimes by avoiding materials in the fuels.

We give examples of all these.

SOx Abatement

SOx are various Oxides of Sulphur in particular SO₂ and SO₃ derived from the burning of sulphur embedded in fuel. SOx emissions have been shown to affect human health and acidification of groundwater

Since there is a direct relationship between the sulphur content of the fuel and the sulphur content within untreated exhaust gas, legislation has generally been framed around limiting the sulphur content of fuel.

International legislation (IMO MARPOL Annex VI) and regional legislation (EU Directive 1999/32) limits the SOx that ships may emit, and abatement technologies may be used by ships to achieve these required emissions reductions.

Marpol Annex VI

Summary

This international legislation covering all shipping activity establishes Sulphur Emissions Control Areas (SECAs) which are geographically defined areas where ships must limit their SOx emissions

The first of these, the Baltic Sea, will come into effect on May 20, 2006, with the North Sea and English Channel becoming SECAs in 2007

For further information and the detailed text of legislation, visit www.imo.org where the book is sold

Detail

The relevant MARPOL Annex VI clause on SOx abatement is:

While ships are within SO_x emission control areas, at least one-of the following conditions shall be fulfilled:

- (a) the sulphur content of fuel oil used on board ships in a SO_x emission control area does not exceed 1.5% m/m;
- (b) an exhaust gas cleaning system, approved by the Administration taking into account guidelines to be developed by the Organization, is applied to reduce the total emission of sulphur oxides from ships, including both auxiliary and main propulsion engines, to 6.0 g SO_x/kW h or less calculated as the total weight of sulphur dioxide emission. Waste streams from the use of such equipment shall not be discharged into enclosed ports, harbours and estuaries unless it can be thoroughly documented by the ship that such waste streams have no adverse impact on the ecosystems of such enclosed ports, harbours and estuaries, based upon criteria communicated by the authorities of the port State to the Organization. The Organization shall circulate the criteria to all Parties to the Convention; or
- (c) any other technological method that is verifiable and enforceable to limit SO₂ emissions to a level equivalent to that described in sub-paragraph (b) is applied. These methods shall be approved by the Administration taking into account guidelines to be developed by the Organization.

EU Directive 99/32 Amendments

Summary

- While the EU Legislative process has not yet completed debate and agreement as to the precise nature and wording of the new Directive, the current draft includes allows ships using approved abatement technology as an alternative to Low Sulphur fuel use while sailing in a SECA
- In general, the requirements of the Directive and the approval process for abatement technologies mirror IMO MARPOL Annex VI
- For the full DRAFT text of the proposed Directive 1999/32, see the [SEAaT Library](#)

Detail

The following texts are extracted from the latest draft of the proposed legislation, and approved by the EU Council, and may be further amended.

“Member States shall take all necessary measures to ensure that marine fuels are not used in the areas of their territorial seas, exclusive economic zones and pollution control zones falling within SOx Emission Control Areas if the sulphur content of those fuels exceeds 1.5% by mass. This shall apply to all vessels of all flags, including vessels whose journey began outside the Community.”

“Member States shall take all necessary measures to ensure that, from the date referred to in paragraph 2(a), marine fuels are not used in their territorial seas, exclusive economic zones and pollution control zones by passenger ships operating on regular services to or from any Community port if the sulphur content of those fuels exceeds 1.5% by mass. Member States shall be responsible for the enforcement of this requirement at least in respect of vessels flying their flags and vessels of all flags while in their ports.”

“With effect from 1 January 2010, Member States shall take all necessary steps to ensure that the following vessels do not use marine fuels with a sulphur content exceeding 0.1% by mass:

- (a) inland waterway vessels; and
- (b) ships at berth in Community ports, allowing sufficient time for the crew to complete any necessary switch from or to other fuels as soon as possible after arrival at berth and as late as possible before departure.

Member States shall require the time of any fuel-changeover operation to be recorded in ships' logbooks.”

“As an alternative to using low sulphur marine fuels meeting the requirements of Articles 4a and 4b, Member States may allow ships to use an approved abatement technology, provided that these ships:

- achieve emissions reductions which are at least equivalent to those which would be achieved through the fuel sulphur limits specified in this Directive; and
- document thoroughly that any waste streams discharged into enclosed ports, harbours and estuaries have no impact on ecosystems, based on criteria communicated by authorities of port States to the International Maritime Organization.”.

Low Sulphur Fuel

Summary

- Ships use of low sulphur fuel, typically with a sulphur content of 1.5%, is the primary abatement approach considered by the current international and regional legislation
- Fuel with a sulphur content of 1.5% or lower is currently only 1% of all the fuel used by ships around the world
- The availability and price of low sulphur fuel is a source of much debate and discussion in both the shipping and oil industries ahead of the implementation of legislation
- For more information about estimated availability and cost of low sulphur fuel for ships, see [SEAaT Library](#)
- Detail below gives a better understanding of the chemistry and production of low sulphur fuel.

Detail

Virtually all fossil fuels include sulphur in what can be extracted from the planet's endowment of such fuels. It is not a desirable addition. Indeed, the word for elemental sulphur – brimstone – has overtones of Hades and hellish origins. Oil, the fuel of choice for ships, is no exception.

In refineries, the crude oil is separated into various useful components, such as petrol, diesel and kerosene. The process is largely one of distillation, so the products can be described as “distillates” and “residuals”. Technological development and investment in refineries has increased the proportion of the more valuable distillates and reduced the volumes of residuals. Marine fuels are generally blends of residuals. They are difficult to use, and so cheaper, but have slightly lower energy densities. The content of sulphur also reduces the energy as combustion of sulphur produces less energy than the combustion of carbon.

The sulphur that remains in distillates can be separated – “desulphurised” – down to very low levels (10 ppm is now considered to be equivalent to “zero sulphur”). There are several ways to do this, all of which consume energy. The sulphur extracted may become elemental sulphur (a yellow crystal, or, more usually, a hot yellow liquid) or sulphuric acid (H₂SO₄) – an important industrial chemical. It has a role as a fertiliser, for “pickling” or cleaning surfaces, and in vulcanising rubber. The bulk of this sulphur, after use, finds its way harmlessly into our rivers and other run-off into the oceans and seas.

The use of low sulphur distillates clearly avoids the emissions of sulphur compounds when it is used. However, its greatest importance arises because exhaust gas treatments for other emissions – NOx and hydrocarbon particulates

– can be more efficient and cheaper, as many catalysts are poisoned by sulphur. These benefits may offset the extra energy costs incurred in the refinery.

Desulphurisation of residuals is harder and rarely done. Residuals tend to be long chain molecules with the sulphur deeply incorporated. So to remove the sulphur, the molecules need to be broken open, and this is an energy intensive process, invariably involving the addition of hydrogen. The output tends to be lighter products, which are suitable for blending with the higher value distillates rather than for use as heavy fuels.

An alternative and cheaper process is “coking”, by which higher value distillates are extracted from the residuals to leave a carbon dust – petroleum coke. If pure, there is a limited market for graphite made from the coke, but most is used as a low value additive to coal in plants with flue gas desulphurisation.

In the USA all refineries are fitted with Cokers. This results in complete residue conversion and the import of bunker fuels for local supply from abroad. However US refineries do from time to time supply residue fuel for the bunker markets. This arises when;

- Refineries undergo maintenance and the cokers may not be working
- Upset conditions in the refinery with certain processes shutdown
- Exceedances of regulatory permits
- Refinery equipment breakdown

So, in general, desulphurising marine fuels will result in a different, more expensive product, whose formation needs more energy (and so creates greater emissions). The benefits may justify these costs, but only if no cheaper ways are possible.

Flue Gas Desulphurisation

Exhaust gases can be treated to remove sulphur before the gasses are emitted. The basic chemical process is generally to mix the gases with a compound containing calcium, so the SO_x is converted to Calcium Sulphate. Calcium sulphate – gypsum – is recovered and disposed of (in landfill) or used in building materials. It is a significant component of plasterboard and plays a role in cement manufacture.

On-land, the calcium often comes from limestone or chalk. After mining and transport it is made into a slurry, and mixed with the exhaust gasses. The mixing technology varies, and may comprise a “spray curtain” or “bubble bath” through which the exhaust gasses pass. This is generally known as a scrubbing process. The reactions to form sulphates from SO_x are very fast and efficient, and can often be achieved in compact single pass equipment. 95% reduction of SO_x is readily achieved, so scrubbing the exhaust from 4% S fuel is equivalent to using 0.2%S fuel. Further processing is often required to remove the water that may have joined the gas-stream.

In plants near coasts, the consumable material can be sea water – hence the technology became known as SeaWater Scrubbing or SWS. Seawater already includes high levels of sulphates so the additional sulphur, once diluted, has negligible impact, generally too small to detect.

Ships clearly have the advantage of plenty of seawater, but face special challenges:

- High gas speeds and limited space for the scrubber. However, current technology can replace the conventional silencers – hence EcoSilencer – and so can fit within current space constraints. Clearly, the equipment needs to cope with the movement of the ship. On land, space is rarely such a significant constraint and the platform does not rock about.
- Acidity and high temperatures. The acidity of the scrubbing water is increased, so the materials used must be particularly resistant to acid. Mild steel, for example, is quite inappropriate, and titanium is the preferred material. On land, lower temperatures are possible, so a wider range of resistant materials can be used.
- Cleaning the scrubbing water. A significant benefit of the scrubbing process is that it also removes many other materials from the flue gas, in particular particulates. However, these materials cannot safely be discharged so the scrubbing water has to be treated. Ships normally carry treatment equipment to prevent oily water discharges, but, with current designs, this will normally need to be extended, and will take up more space in equipment rooms.

These challenges do not present difficult obstacles, but, in the absence of commercial incentives and a secured market, only a very few people have so far tried.

Fuel Additives for SO_x

Summary

- Additives cannot remove sulphur in fuel, but they can convert it to less harmful forms
- The changed form may be easier to capture than SO_x gases

- SEAAAT does not advocate fuel additives for SO_x reduction unless this is associated with a capture system. SEAAAT is not aware of any currently available technologies

Detail

Fuel additives bring many benefits – see elsewhere on this web site – but cannot get rid of the sulphur in fuel.

What it can do is enable the sulphur to convert to another form. If an appropriate material is added to the fuel – calcium is the normal element to be suggested – sulphates can form during the combustion process. Many sulphates are widespread in nature and often nearly inert. Calcium sulphate – gypsum – is a benign material, and can be formed during combustion.

While calcium sulphate is not acidic, and so is much less harmful than SO_x, its impact when emitted is not well understood, so its emissions remain inappropriate.

Sulphates may be amenable to sophisticated post combustion treatment that can remove it from the exhaust stream more easily than SO_x can be removed. Very small particles are hard to remove, so one approach is to encourage particles to agglomerate to become large enough to be easily captured.

For ships there is currently no proven and acceptable SO_x reduction approach based solely on fuel additives.

Sulphur free fuels

Some bulk trades, such as Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG), are carrying as cargo fuels that are free of sulphur. The economics will vary according to the specific trade, and it may be appropriate to use the cargo as fuel, so achieving very low emissions of sulphur.

Diesel Engines using LNG or CNG need complex modifications to change from normal fuel oils, and it is hard to make such vessels able to use both fuels efficiently. The key complexity is the need to vary the engine compression ratio.

As steam raising boilers can change between fuels relatively easily, steam turbines continue to play a role in LNG shipping.

There have been occasions when ships have been modified to use crude oil cargos as fuel. This is invariably illegal and dangerous, as crudes have many volatile components unsuited to normal marine fuel use. It is illegal to use fuel in an enclosed machinery space on board ship with a flash point below 60degC

NO_x Abatement

Summary

- NO_x are the various possible oxides of nitrogen, NO, NO₂, NO₃ and NO₄, of which NO₂ is the main emission of concern
- There are two general approaches to NO_x abatement: prevent NO_x forming; and post combustion conversion back to N₂ and O₂. Most NO_x abatement technologies have some aspects of both
- The key NO_x regulation is MARPOL Annex VI, which is backdated to ships built from 2000
- The EU has announced a strategy for NO_x from marine sources, but has published no proposals. They hope to achieve more stringent Annex VI regulation

Detail

NO_x are formed from elements present in all air, the nitrogen N₂ that makes up about 79% of our atmosphere, and the O₂, which makes up the bulk of the rest. It arises when these two elements are made hot together, so all combustion processes create NO_x. The longer and the hotter the combustion processes the more NO_x that are formed. Since higher combustion temperatures can lead to greater thermal efficiencies some trade-offs between high efficiencies or low NO_x are possible.

Some fuels have nitrogen embodied within their molecules – Nitrogen is an essential constituent of all life, including that which formed the oil – but has not been a significant contributor to the NO_x. As engines get better at avoiding NO_x formation, the contribution of NO_x from fuel will become more evident.

Over time NO_x in the atmosphere revert to their constituents, becoming again O₂ and N₂.

MARPOL Annex VI – NO_x Clause

Summary

- The relevant clause of MARPOL Annex VI was designed to ensure that engine design for low NO_x can achieve the standards
- Large, efficient slow speed engines face the biggest challenges, and so are permitted greater emissions

- New NO_x emissions standards come into effect on May 20 2006
- For further information and the detailed text of legislation, visit www.imo.org where the book is sold

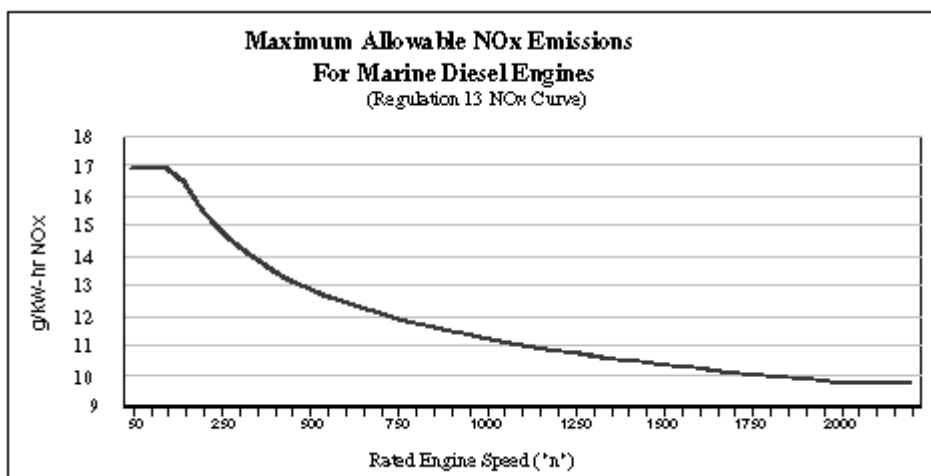
Detail

“(3) (a) Subject to the provision of regulation 3 of this Annex, the operation of each diesel engine to which this regulation applies is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO₂) from the engine is within the following limits:

- (i) 17.0 g/kW h when n is less than 130 rpm
- (ii) $45.0 \times n^{(-0.2)}$ g/kW h when n is 130 or more but less than 2000 rpm
- (iii) 9.8 g/kW h when n is 2000 rpm or more

where n = rated engine speed (crankshaft revolutions per minute).

This translates into the IMO NO_x curve shown below (diagram from EPA)



When using fuel composed of blends from hydrocarbons derived from petroleum refining, test procedure and measurement methods shall be in accordance with the NO_x Technical Code, taking into consideration the test cycles and weighting factors outlined in appendix II to this Annex.

(b) Notwithstanding the provisions of sub-paragraph (a) of this paragraph, the operation of a diesel engine is permitted when:

- (i) an exhaust gas cleaning system, approved by the Administration in accordance with the NO_x Technical Code, is applied to the engine to reduce onboard NO_x emissions at least to the limits specified in sub-paragraph (a), or
- (ii) any other equivalent method, approved by the Administration taking into account relevant guidelines to be developed by the Organization, is applied to reduce onboard NO_x emissions at least to the limit specified in sub-paragraph (a) of this paragraph.”

Low NO_x Engine Design

Summary

- This is currently the primary abatement approach assumed, for example, by MARPOL Annex VI.
- The standards (not considered particularly demanding) are normally achieved by:
 - Careful design of combustion by the shape of the combustion chambers and auxiliary chambers.
 - Careful design of the gas flows into the cylinder to ensure appropriate mixing
 - Careful design of valve timing; and
 - Appropriate timing of fuel injection.

Detail

The optimisation is complex; the general approach is to achieve mixing to avoid high peak combustion temperatures at flame fronts, which is where NO_x forms most easily.

The certification also places constraints on the changes and modifications that can be made to the engine, such as timing of injection or valves.

Certification is done using distillate fuels in a defined and controlled cycle. Once operating, however, different fuels and different operating practices tend to mean that NO_x emissions are higher than the certified limits.

Selective Catalytic Reduction (SCR)

Summary

- The principle of SCR is that flue gas, when mixed with a reagent – ideally Ammonia (NH₃) – and passed over a catalyst will reduce the NO_x components to N₂, water and O₂.
- In ideal circumstances NO_x reductions of up to 95% and beyond can be achieved, but these ideal conditions tend not to apply when manoeuvring close to port, and realistic reductions are significantly lower.
- SCR is the technology of choice for NO_x reductions, and is planned for the next generation of road and off road diesel engined trucks and equipment.
- SCR is being used on a number of ships for NO_x reductions, mainly for auxiliary engines.
- SCR can in principle be integrated with other abatement technologies, with, for example, the exhaust being further scrubbed to remove SO_x.

Detail

There are complexities that make SCR a tricky technology to install and get to work reliably:

- Ammonia is a nasty material to handle, and it is more common to use urea – a readily available industrial chemical – which largely converts to ammonia when injected into the hot exhaust stream.
- Effectiveness of conversion depends on good control of the urea injection. Too much or too little for the exhaust flows damages efficiency and effectiveness.
- The catalysts, often embedded on ceramic substrates, create backpressures with adverse impacts on engine performance. The greater the reduction required, the greater the backpressure.
- The catalysts are poisoned by sulphate salts, and so deteriorate faster the more sulphates are present. This can be countered in two ways: by having no sulphur compounds in the exhaust stream or by operating at temperatures high enough to prevent the sulphate salt formation.
- The catalysts have quite short life and need renewing every few years. It is not yet clear how the spent catalysts can best be disposed of safely.
- Ammonia escaping after SCR processes is dangerous, so rigorous controls are needed.
- Urea (or ammonia) is consumed, so a urea supply chain must exist and be paid for.

Technology Suppliers

Johnson Matthey Catalysts are a leading player in on-shore markets: <http://www.jmcsd.com/se2.html>

The major engine manufacturers: MAN B&W (<http://www.manbw.com/>) and Wärtsilä (see http://www.wartsila.com/wartsila.portal?nfpb=true&pageLabel=shippower_en&jsp_type=0&doc_id=30073876671880364&content_type=product&node_id=601477546020960)

Fuel Additives for NO_x

Summary

- Fuel additives have long promised significant benefits for NO_x reduction, and there are sound theoretical foundations for believing that appropriate additives can modify combustion processes to reduce NO_x formation
- If the additive is water, and this is incorporated and distributed as small droplets within the fuel, these small droplets can “explode” when the fuel gets hot during injection to a cylinder, so ensuring better mixing of fuel and air, and so more controlled combustion
- The water mixed with the fuel oil can also be used to dissolve other additives, and sophisticated modification of combustion processes becomes possible
- So far, there have been few large scale or commercial trials of such technologies in the marine context, but it is reasonable to expect that, with appropriate incentives, good, cost effective technologies will be marketed

Detail

Water and oil do not naturally mix, so to make “emulsion” fuels small quantities of other “emulsifiers” are added. It is the design and management of the additives and the mixing process that is the “black art” of fuel additives.

These fuels are also known as emulsion fuels, with proportions of water up to about 20% of the fuel volume. NO_x performance is good, but there are usually some performance penalties. Many city buses operate on such fuels.

Some fuel additive systems mix the oil and water just before injection. This can reduce the need for emulsifiers, but needs more complex mixing equipment on-board.

The EU has started to address the complex issue of an appropriate tax for land based use of oil water mixtures.

Emulsions

Summary

- Water in oil emulsions are discussed in the section on Fuel Additives
- Water itself appears to modify combustion processes in benign ways that reduce NO_x formation. But the quantities of water needed are quite large, at around 30% of the volume of the fuel water mixture
- Modified engines have been successfully run with such fuels, and have achieved NO_x reductions of some 30%, and research continues to be pursued.

Detail

Emulsions are not easy to make stable, so there is a choice about whether to mix the emulsion at specialised plant, and carry higher volumes of fuel, or to mix the emulsion just before use, when specialist technology and fairly pure water is needed.

One benefit sought from these technologies is for fuels to flow freely at ambient temperatures, thus avoiding the need for heating throughout the fuel feed processes.

Humid Air Motors

Summary

The benign impact of water on combustion processes raises the possibility of carrying the water into cylinders in the form of humid combustion air, and this is the concept of Humid Air Motors.

They work by putting water vapour into the inlet air stream, and are effective at reducing NO_x.

There are issues to be resolved:

- Quite high volumes of water need to be evaporated to create enough humid air to achieve the reductions sought, and are comparable with the fuel volumes. This requires heat input. The heat input is provided by heat exchange from the hot compressed air after the engine turbocharger. This implies that at low load there may not be sufficient heat in which case the HAM system is not used.
- Under varying loads (when it is most difficult to achieve optimum combustion) it is also hard to control the humidity adequately.

These issues are soluble, but need development and refinement that will only be available if there is a clear market for the technology.

Fuel Cells

Summary

- A good way to avoid NO_x is to avoid combustion, and fuel cells deliver electricity from non combustion reactions moderated by catalysts. There are fuels cells which range from relatively cool to very high temperatures, liquid metal oxides
- The ideal fuel cell configuration is to feed pure Hydrogen (H₂) and pure Oxygen (O₂) to a fuel cell, to obtain electricity and pure water (H₂O). Energy conversion efficiencies of up to 60% can be achieved, and this is now the preferred power source for submarines, as (unlike nuclear reactors) it minimises leakage of heat that might be detectable
- The technology is not yet suitable for commercial use in commercial shipping, but research and development is continuing

Detail

Variations to the technology are possible and promising for shipping.

- Air can be used instead of pure O₂. But with the complication of needing to use 5 times the gas volumes;
- Methanol can be used instead of Hydrogen. But with the complication of needing to reform it first.

- Hydrocarbons can be used instead of methanol, but with the complication of higher temperature reactions and more difficult catalysts,

There may come a time when there are technologies to convert heavy fuels to electricity, water and CO₂, with no other harmful emissions, but there do not yet seem to be grounds for assuming that this will be a viable future technology.

Perhaps more likely, with the appearance of the “hydrogen economy” and the “oil end game” will be hydrogen fuelled ships. Hydrogen is a good energy carrier, with high energy densities for its weight, and it will work with fuel cells as well as internal combustion engines. But it is far from clear how best ships should be equipped to carry hydrogen bunkers, nor what the energy conversion technology should be. So far, we can only speculate.

Particulate Matter

Summary

- Diesel engines on ships produce particulate matter as part of their emission
- Particulate matter has been shown to be related to health issues in humans
- The harm seems related to the numbers of particles involved, as well as their overall weight
- There is significant societal benefit from reduction in the particulates from diesel engines (as well as from other sources). (Petrol engines do not create particles in the same way.)
- Particulates are also implicated in climate change. Because they can act as nucleating points, they can modify cloud formation. Because they change the transmission of sunlight through our atmosphere they can alter the light reaching the surface
- In shipping, particulate reduction has been pursued as a co-benefit of other technologies

Detail

Until the last decade or so governments tended to regard the emissions from diesel engines as relatively benign, and a small price to pay for the greater efficiency of diesel engines. Few acute effects beyond the unpleasantness of the fumes themselves were recognised.

More recently, science has been able to unpick the longer term and more chronic effects of diesel and particulate emissions, and societies and governments now find that the costs, in shortened lives and poor health, justify more stringent controls on these emissions.

Regulation is no simple matter. The particulates in our ambient air come from many sources, some natural and beyond our control. They are made up of many different materials, not all of which are particularly harmful. They come in many different sizes and it is hard to distinguish the effects of these. Particulates and aerosols are also modified by chemical processes in the atmosphere, and are affected by different conditions, such as sunlight, rain and weather. Indeed, individual particles can be quite exotic in their composition, including solid salts, acids, liquids and soot.

Regulation so far has concentrated on particulate emissions from land transport, and has encouraged integrated approaches, incorporating multiple abatement technologies. These technologies have tended also to constrain the fuel specification, requiring, for example, very low sulphur levels, such as <50ppm. It is not yet clear which approach is likely to be most effective for regulating particulates from shipping.

Scrubbing

SeaWater Scrubbing is an effective technology for removal of sulphur from flue gases, as discussed in Flue Gas Desulphurisation. It is also very effective at reducing the particulate load, achieving reductions of 80% or so. This is a significantly greater reduction than is achieved by low sulphur fuel.

This particulate reduction creates sound policy reasons for preferring scrubbing over low sulphur fuel for sulphur reduction.

Particulate Traps

For land transport, particle traps are becoming a mature abatement technology within the integrated emissions control systems of buses and lorries, and is beginning to be seen on some diesel engined cars.

They work in conjunction with NO_x control equipment by having a very fine ceramic filter where the particulates react with other hot exhaust gases to burn up. They work well only with ultra low sulphur fuel.

No products for use with marine engines are under development, as cheaper technologies can meet current and foreseen needs.

Plasma

Plasma technologies have found an effective role in treating flue gases from incineration processes, where particularly complex waste products arise. They work by breaking up complex compounds, and encouraging the resulting elements to combine to form more benign and manageable materials.

This may prove an effective technology for dealing with particulate matter from engines, but any commercial product is, at best, medium term.

CO₂

Summary

- CO₂, Carbon Dioxide, is the principle Green House Gas (GHG) implicated in climate change.
- Although present only in low concentrations, as we add more CO₂ to our air, it is harder for heat absorbed by the sun to be re-radiated to space, so things tend to warm up.
- At present, both international aviation and international shipping fall outside the Kyoto agreement and the EU ETS
- While shipping generates much less CO₂ per tonne of cargo moved than any other form of large scale transport, there are measures shipping can take to reduce greenhouse gas emissions
- For more information on greenhouse gases and ships, visit www.imo.org

Detail

Although only one of many sources of CO₂, our burning of fossil fuels, such as oil and coal, adds to the overall burden that has to be removed from the atmosphere by many natural processes, including the photosynthesis of plants. At present, we are overloading these removal processes, and the concentration of CO₂ in the air is increasing at 2 – 3 parts per million (or ppm) each year. Already we have raised the concentration from a pre-industrial value of 280 ppm to the current 375 ppm. Since it takes about 100 years for CO₂ to be recaptured from the atmosphere, our CO₂ emissions now have an impact long into the future.

This is a global phenomenon, so there are concerted efforts by almost all governments (the US is a notable exception) to reach international agreements to reduce CO₂ emissions, of which the Kyoto treaty is the first outcome. Many consider our emissions to be a threat to civilisation, so demands to reduce CO₂ emissions are certain to grow, and shipping will be no exception.

Emissions from both shipping & aviation sectors are growing, but it is currently faster for aviation. Emissions from aviation also include NO_x and water vapour, which, because of the height at which they are created, cause significantly greater greenhouse effects. The sectors will come under great pressure to participate in the necessary reductions.

There are measures shipping can take, and they are discussed under the headings:

- Efficiency
- Route Planning
- Hull and Propeller Design
- Hydrogen (and LNG, CNG)
- Route Planning
- Wind Assistance
- Nuclear

Efficiency

The most straightforward way to reduce carbon emissions is to use less fuel.

Reductions can be achieved by improving the efficiency of engines, and avoiding waste of energy.

While these may be profitable solely from the reductions in fuel costs, Kyoto and the EU carbon trading scheme permits trading of reductions, so a further profit contribution can be achieved by selling carbon reductions to other players.

However, a legal framework for shipping to do this is not yet established.

Route Planning

Modern weather forecasting and communications capability makes possible worthwhile fuel (and thus emissions) savings by optimal routing of ships, maximising the assistance given by currents, and avoiding the waves and bad weather that can slow ships down. This is particularly helpful when Wind Assistance is used.

Hull & Propeller Design

In the last 30 years, improvements in the shape of hulls, hull coatings and propellers have achieved significant improvements in the efficiency of ships and further improvements continue to be expected.

Hydrogen (and LNG, CNG)

Summary

- At sea level water vapour is harmless, so a way of reducing CO₂ emissions is to burn Hydrogen (so creating H₂O or water) rather than the carbon (which creates CO₂)
- Natural gas has a higher proportion of hydrogen than oil, particularly heavy fuel oil. So using natural gas rather than oil as a fuel reduces the CO₂ emissions created for a unit of energy. (Being free of sulphur, it also reduces SO_x emissions).
- For shipping, the high value of natural gas, whether compressed (CNG) or liquefied (LNG) is likely to be attractive only in special circumstances, but, as the value of carbon reductions increases, the scope will expand

Detail

Ultimately, hydrogen as a fuel creates no CO₂ emissions. It also enables use of fuel cells, which provide a direct chemical conversion from fuel and air to electricity. So this is a very attractive aspiration for the longer term, as several challenges have yet to be overcome.

There are no natural sources of hydrogen as a fuel. It has to be created from other sources.

So one challenge is to develop sources of hydrogen that do not themselves create CO₂. Most energy visionaries see renewable energy, such as wind, wave, tidal and solar as being the likely sources, but most developments will, for some time, be directed at the electricity markets.

Hydrogen is also difficult to store. It is not yet clear how hydrogen as a marine fuel would best be handled and stored.

Wind Assistance

Although still considered visionary, designs for wind assistance continue to be pursued, and shipping may well return to the power source it abandoned a century or so ago.

Three approaches are being pursued.

- **Sail.** Advances in materials, automation and designs (as well as high fuel costs) may open a role for modern sails, particularly on vessels with clear flat decks, such as tankers and bulkers.
- **Wind Turbines.** Various turbine designs may offer ways to capture wind energy in a more flexible way than sails, allowing, for example, sailing directly into the wind.
- **Kites.** Large kites can fly far above a vessel, using the steadier and stronger winds above the boundary layer to pull a ship along.

All these technologies will also gain from optimum route planning, using the winds to maximum effect.

Nuclear

Navies have found nuclear power attractive for submarines and some other vessels, although fuel cells seem now to be preferred. There have been three civilian experimental cargo vessels. Their major civilian niche has proved to be ice-breakers, and Russia has built and still operates several of them.

Nuclear power for ships offers the same advantages and risks that nuclear power does ashore. There are no emissions at all at the point of use, and their lifetime fuel costs are low. But they are very expensive to build. The designs and quality assurance have to be extreme to manage the risks of escape of radioactivity. They create a long term disposal problem, and may offer terrorism opportunities.

In operation, reactors tend to be inflexible, with a narrow range of power outputs. Indeed the Chernobyl accident was triggered by an attempt to run a reactor at low power outputs. So heat can be an unwanted and potentially harmful emission.

There is no immediate prospect of nuclear power becoming a useful emissions abatement technology for ships, but the concept is undoubtedly being explored, and may yet come up with a workable technology.

Shoreside Power

Summary

- Ships at berth continue to need electrical power, so normally keep their generators running
- Emissions tend to be close to population centres, so regulators are keen to see reductions. The EU is expected to impose fuel sulphur limits of 0.2%S, reducing to 0.1%, to address this issue
- Electricity from shore is seen as a possible alternative, but presents technical and cost issues.

Detail

When at berth, ships continue to need power for many purposes. As well as keeping the ship habitable, many cargoes need refrigeration or heating and some vessels need to operate their loading and unloading gear. Tankers, in particular, have to operate pumps as well as operate the safety equipment, and all vessels need to manage their ballast to keep the ship stable and unstressed.

This power is readily provided by the auxiliary generators and engines that the ship needs for safe operation at sea. However, such engines do create emissions at the ports where they berth, and these are often close to large centres of population.

Regulators are thus keen to see reductions in these emissions, and are able to impose more stringent requirements than at sea. For example, the EU legislation will require that ships at berth use only low sulphur fuel (0.1%) (or clean their exhausts to very high standards).

This can be difficult for ships. Such fuel is expensive, and ships often have only limited capability to store and use different fuel grades. A change of the fuel used by an engine can cause fuel feed problems, and unexpected blackouts create significant risks.

An alternative approach is to feed power from shore, using electricity from the local electricity grid. However, at present, this has significant disadvantages:

- The cost of electricity from shore is invariably greater, often by a factor of two or more. While the ship faces only the marginal cost of the fuel used for generation, shoreside electricity has to cover the costs of the transmission and distribution infrastructure, the generation capacity required for the ship, and, in most cases, profit for the utility.
- The CO₂ emissions arising from shoreside power generation, including transmission and distribution losses, can be greater than those of an efficient on-board diesel generator, particularly if coal plays a significant role in the generator mix.
- The technical standards associated with on-board electricity vary widely. So both the ship and the shore have to adapt the power to match each other. This can be expensive, with no assurance that a ship adaptation for one port is of use at another, or for the port that an adaptation for one ship is of use to another.
- It is surprisingly difficult to make the ship to shore connection. The cables are bulky, safety critical, and need special handling. By their nature berths need to be kept clear of obstructions for their primary activity of moving goods, and have to cope with ships of different lengths and sizes. It is not "plug and play".
- It is hard to make the changeover between ship and shore power supplies without power interruptions, however short. This imposes extra costs and precautions to avoid harm to a great deal of the sensitive electronic equipment upon which modern ships depend.
- The power demands are large in comparison with other port uses. For example, the base consumption of individual ferries can be 2MW, and for Dover to offer shoreside power it would need an extra 10MW of capacity, at both 50Hz and at 60Hz.

Despite these difficulties, there are special cases where the emissions benefits justify the expense, or where regular berthing by specific ships makes the connections easier. Almost invariably, this is subsidised by the port.

It is not yet clear how the balance between effective shipboard abatement and shoreside power connections will evolve as more stringent port emissions constraints are imposed. SEAaT hopes an effective market will emerge, but also recognises that there are many regulatory jurisdictions involved, and many technical options to be explored before this is likely.

Integrated Abatement

Ships will increasingly need to include some combination of the abatement technologies we have described, ideally integrated into complete subsystems offering defined and specified performance tuned to the expected trading of the vessel over its lifetime and the specific needs of the shipowner.

The design will involve complex trade-offs between performance characteristics, costs and risks. These will be more efficient if the future value of different forms of abatement can be assessed and predicted. Is it, for example, better to minimise NO_x emissions, even if this increased CO₂ emissions? The more certain the future value of emissions reductions, the lower the investment risk, and so the easier it is to raise finance for it.

Given this complexity, there is little possibility that technical regulation will lead to optimum, or even efficient, investment in abatement. The traditional form of "command and control" specification of equipment standards and types leads to technical uncertainty, unpredictable outcomes, and high risk investments.

SEAAaT believes that appropriate Emissions Trading, with markets revealing values for each of the harmful emissions, will allow shipowners and designers to optimise their investments for their particular circumstances and patterns of trade. This will also reward innovation in any or all of the abatement technologies, giving sound commercial incentives to develop improved abatement methods and equipment.

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