International Association for Catalytic Control of Ship Emissions to Air

The Technical and Operational Capabilities of Marine Selective Catalytic Reduction

Since its inception in January 2011, IACCSEA (see Appendix II) has recognised a number of concerns/misunderstandings relating to the application of Selective Catalytic Reduction technology (SCR) on marine vessels. This paper offers a response to the most frequently cited challenges. A second order response is given in Appendix I.

Technical/operational issues

1) The high sulphur content of heavy fuel oil (HFO) causes significant catalyst deterioration, which can decrease SCR efficiency by 50-60% (and which is irreversible).

   Industry response:

   - Sulphur is not a poison to vanadium SCR catalysts (each of the 500+ vessels with marine SCR use vanadium catalysts)
   - High sulphur fuels do however require specific operating temperatures
   - IMO Tier III only applies to new build vessels – in the design phase SCR providers/engine OEMs ensure that appropriate temperatures will be met when in operation

2) An SCR system is only reliable within a narrow temperature range (250-400°C). There are problems maintaining this operational window under variable or low loads, for example when ships are in port.

   Industry response:

   - Operational features which ensure that appropriate exhaust gas temperatures are met at low load have been introduced by engine OEMs
   - Hitachi Zosen have demonstrated that SCR meets Tier III even at 10% load with only a very small fuel penalty

3) When diesel engines are operating under variable load regimes, catalyst inertia leads to the release of ammonia, the toxicity of which is at least equal to NOx in a marine exhaust stream

   Industry response:

   - It has been demonstrated that ammonia slip is not a significant problem at NOx conversions required by Tier III.
   - Ammonia concentrations are maintained at <10ppm whilst an SCR is in operation – even at low loads – so long as the appropriate engine temperatures are reached
   - Catalyst suppliers/engine OEMs work together to ensure that ammonia slip is mitigated
   - Continuous monitoring is one way of ensuring that ammonia slip is monitored

4) When neutralising NOx with SCR, urea used in the process releases greenhouse gas (CO_2) in proportional quantities to the neutralised NOx. SCR technology may therefore seriously contribute to GHG emissions from shipping

   Industry response:

   - Moving from a Tier II compliant engine to a fuel efficient/optimised Tier III compliant engine fitted with SCR reduces both CO_2 and NOx emissions simultaneously

5) Vessels installing SCR in conjunction with SOx scrubbers (to comply with regulation 14 of MARPOL Annex VI in an ECA) could find a lack of space for the two technologies

Industry response:

- SCR can be used in conjunction with a SOx scrubber
- As long as it is factored in during the design phase of a vessel space is not inhibitive

6) Oil and fuel spills on the catalyst during operation of the SCR will result in catalyst deterioration and replacement at a high cost. It can also lead to a decrease in process efficiency of 20-40%

Industry response:

- The use of well-considered standards (e.g. of fuel, lubricant and urea) ensures that the engine/SCR functions adequately for thousands of hours of operation
- If, on a rare occasion, fuel were to get onto the catalyst, it would flare off with no long-term damage

7) The safety implications of using SCR have not been fully considered

Industry response:

- Safety has been fully considered
- Tier III compliant SCR systems are certified and classified by classification societies before installation
- Urea is classified as non-toxic

8) There has been no attention drawn to the problem of how to make catalysts available or how to dispose of them at the end of their operational life

Industry response:

- Even with a 2016 implementation date, marine demand for catalysts will have a minor impact on total SCR demand (less than 1% of global demand and growing only slowly since Tier III is a new build requirement)
- Industry is carrying out life cycle analysis for marine catalysts and is developing systems to recycle

9) Ship-owners and manufacturers have gained experience with SCR systems over the last 10 to 15 years. These figures cause the greatest concern as the drawbacks with the technology have not been rectified within such a long period

Industry response:

- Marine SCR is a proven technology applied to over 500 vessels
- There is clear evidence that any early operational difficulties have been resolved through time

10) SCR technology has not been discussed in detail and further discussion is required, as well as research into potential consequences of its application on board ships at sea

Industry response:

- The IMOs NOx Review Correspondence Group explored the efficacy of SCR, in detail, and concluded that SCR can meet Tier III NOx Limits

Concerns about SCR costs

11) For a ship of 20,000 deadweight tonnes the shipowner will have to spend 6 million Euros to purchase and install the SCR system with the pay-off period of not less than 8 to 10 years (and this does not take into account, any emergencies involving the catalyst replacement or operational costs/urea)

Industry response:

- A calculation tool has been developed by IACCSEA
- The tool was pulled together to grant some insight into the true costs and benefits of SCR technology on-board vessels, in order to meet IMO Tier III NOx limits
- Using the example of a 10MW engine, powering a vessel of 20,000 DWT using HFO that spends 1500 hours p.a. in a NOx ECA for a period of 25 years - the total lifetime SCR cost is $2.25m. A total fuel benefit of $425k can also be expected.
- This equates to a total cost of ownership in the order of $1.8m over the lifetime of the vessel, or about $75k p.a.

Concerns about Modal Shift

12) Shipowners striving to ensure compliance will have to incur serious expenses to equip their ships, or they will have to avoid calling at ports in NOx emission control areas. This will result in cargoes being redistributed on land, which will lead to much higher air pollution

Industry response:

- Independent analysis have found that the implementation of Tier III NOx limits will not lead to modal shift

APPENDIX I

Detailed IACCSEA Response

Technical/operational issues	
High sulphur fuels and SCR	
1) The high sulphur content of HFO causes significant catalyst deterioration, which can decrease SCR efficiency by 50-60% and which is irreversible	• Sulphur is not a poison to conventional marine SCR catalysts (which are vanadium, not platinum based, as has been incorrectly stated). However, the high sulphur content of marine fuels (the global average sulphur content of HFO is currently around 2.4%) presents a challenge to the efficacy of SCR, because at low temperatures, ammonia and sulphuric acid condense as liquid ammonium bisulphate (ABS) which can block/foul the catalyst • If vessels use low sulphur fuels in ECAs with fuel sulphur content of 0.1%, this should be sufficiently low to reduce the sensitivity of systems to ABS deposition. For HFO, care must be taken to design system operating temperatures which are high enough to prevent ABS formation. For typical heavy fuel oils, the exhaust temperature would need to be over 300°C to prevent ABS • Exhaust gas temperature will vary with engine type and with engine load. New engines will be made to meet Tier III regulations in combination with SCR. In the design phase, SCR providers will work closely with engine OEMs to tune/integrate systems that meet the required temperatures for SCR to operate without generating ABS. These methods include the specific positioning of the SCR catalyst and the use of burners • If an SCR system is not operated correctly and ABS does form, ABS formation is reversible i.e. the ABS deposits may be removed and returned to the gas phase by increasing the temperature
Low engine load and associated temperature	
2) An SCR system is only reliable within a narrow temperature range (250-400ºC). There are problems maintaining this operational window under variable or low loads, for example when ships are in port	• Due to the fact that exhaust gas temperatures are correlated with the operating load placed on the engine, it has historically been a challenge to maintain sufficiently high temperatures when engines are operating at low engine loads (<25%) for extended periods of time • However - as per the above response relating to sulphur, in order to achieve the suitable temperature window, special features to increase exhaust gas temperature have already been introduced by some engine manufacturers. A variety of strategies are being developed by manufacturers for low load performance. It is a question of addressing the issue as an "Engine/SCR system" • Tuning of the engine/SCR system has meant that the required SCR temperature window can now be achieved even at very low loads of 5% • In general, 2 stroke engines are more of an issue because they are designed for high efficiency low temperature operation. However, Hitachi Zosen has an example of a 2-stroke SCR engine, which can work even at 10% load with a very small fuel penalty
3) When diesel engines are operating under variable load regimes, catalyst inertia leads to the release of ammonia, the toxicity of which is at least equal to NOx in a marine exhaust stream	• During the design phase of an engine/SCR system, catalyst suppliers/engine OEMs ensure that the catalyst is properly sized for the exhaust stream and that there is the correct urea dosage. As long as the SCR catalyst is properly sized for the application, there should be no initial issue with overdosing of urea and subsequent ammonia slip should be maintained below 10ppm • As covered above, irrespective of engine load, as long as the SCR temperature window is maintained, overdosing of urea will not occur • However, ammonia slip can potentially take place over time as the SCR catalyst degrades. This can be caused by plugging of the catalysts by poisons contained within engine lubricants and the ash component of non-distillate fuels. • Plugging due to these components has to be mitigated by an effective soot blower • A small part of the ash components do accumulate on the SCR catalyst over time. However, the net effect is that the SCR activity is kept at a high level throughout the catalyst lifetime • Based on experience, catalyst suppliers can estimate the accumulation rate of poisons on the catalyst. Manufacturers factor deactivating mechanisms into their sizing programmes, which means that deterioration can be considered at the design phase. There are also other technical mechanisms that can be used to prolong catalyst life and prevent ammonia slip • There is a growing consensus that continuous monitoring of exhaust emissions and the active management of the injection rate of the reductant represents the best means to guard against ammonia slip
Linking SCR with greenhouse gas emissions	

4) When neutralising NOx with SCR, urea used in the process releases greenhouse gas (CO_2) in proportional quantities to the neutralised NOx. SCR technology may therefore seriously contribute to GHG emissions from shipping	• It is possible to reduce both CO_2 and NOx emissions simultaneously from a marine engine, through the application of SCR technology. • Although Tier II requirements do not significantly constrain combustion conditions, increased fuel efficiencies can be gained when moving to Tier III compliance • The expectation is for fuel savings from engine optimisation to be up to 4%. Such fuel-optimisation will increase thermal NOx from the engine, but this is captured by the SCR • See the below calculation provided by Hitachi Zosen: - In the case of low speed 2-stroke diesel engines, their typical specific fuel oil consumption (SFOC) is 170 g/kWh. In general, when SFOC is reduced (improved) by 1 g/kWh, NOx increases by about 1 g/kWh (this is the so-called diesel dilemma) - Assuming that NOx is to be reduced by 11 g/kWh from Tier II to Tier III, of which limits are 14.4 g/kWh and 3.4 g/kWh respectively for low speed 2-strokes, necessary urea is 11/46/2 = 0.1196 mol, where the molecular weight of NOx (counted as NO_2) is 46 g/mol. - 1 mol of urea produces 1 mol of CO_2. - CO_2 generated through the urea decomposition is 0.1196*44 = 5.3 g/kWh, where the molecular weight of CO_2 is 44 g/mol. - This CO_2 increase can be cancelled by reducing SFOC by 1% (= 5.3/530), where 530 g/kWh of CO_2 is generated when 170 g/kWh of fuel containing 85%wt carbon is combusted. - However, if SFOC is reduced by 1%, thermal NOx will increase by 170 [g/kW] * 1% = 1.7 g/kWh due to the diesel dilemma. This should be also cancelled by SCR. - This additional cancellation process generates CO_2 of 1.7/11*5.3 = 0.8 g/kWh due to urea decomposition. The 0.8 g/kWh of CO_2 corresponds to only 0.15% of the 530 g/kW of CO_2 generated by the fuel combustion. This takes place only in ECAs. - The above discussion is a case of SFOC reduction by 1%. If the SFOC is reduced by 2%, then, the total CO_2 emission from the engine fitted with SCR will decrease even taking the urea decomposition into account. Today, 2% of SFOC improvement is easy on the basis of Tier I or Tier II engines
Compatibility with SOx scrubbers	
5) Vessels installing SCR in conjunction with SOx scrubbers (to comply with regulation 14 of MARPOL Annex VI in an ECA) could find a lack of space for the two technologies	• SCR can be used in conjunction with a scrubber and there are examples of vessels with both technologies • Given the temperature range within which SCR operates efficiently, the common view is that the SCR system should be positioned upstream of the scrubber. If the SCR is located downstream of the scrubber, it is necessary to reheat the gas to approximately 200°C (due to the low sulphur content) which carries an inherent carbon cost associated with reheating. • Some dry SOx scrubbers do not lower the temperature, meaning that in these instances the SCR system can be placed downstream of the scrubber
Catalyst deterioration caused by soot and oil	
6) Oil and fuel spills on the catalyst during operation of the SCR will result in catalyst deterioration and replacement at a high cost (and a decrease in process efficiency of 20-40%)	(see also answer to #3)**:** • Manufacturers guarantee the useful lifetime of the catalyst depending upon operating conditions, fuel quality etc. A useful life value for SCR catalysts is often given as 16,000 hours of operation • SCR catalysts have a honeycomb structure, large surface area and a dense network of active sites upon which the catalyst facilitates the reduction of NOx • If these active sites are blocked then the ability of the catalyst to reduce NOx is diminished • Physical blocking with dust etc from the fuel may be minimized through the correct choice of catalyst pitch and/or mechanisms to dislodge weakly bound material, e.g. with the use of dust blowers. • When chemical components in the exhaust bind tightly to the active sites, they are more difficult to dislodge and are said to poison the catalyst. These poisons are generally traceable to either the combustion products of the fuel/lubricant or the thermolysis of urea/ammonia solution • Their deleterious impact on SCR performance is so significant that the industry recommends the use of standards. Slow deactivation of the catalyst is expected over time, but the use of well-considered standards (e.g. of fuel, lubricant and urea) generally ensures that the engine/SCR functions adequately for many years • Catalyst experts' understanding of the mechanism and rate of poisoning allows them to offer warranty periods, with the caveat that the operator complies with the use of standard/certified consumables that do not accelerate poisoning
Safety	

7) The safety implications of using SCR have not been fully considered	• There are 500+ vessels with SCR fitted, with no negative safety implications • Tier III compliant SCR systems are certified and classified by classification societies before installation • Urea is the preferred source of ammonia which plays an essential role in reducing NOx • It is classified as *non-toxic non dangerous goods* and is utilised in millions of cars around the globe • The only onboard requirement is to fit a venting device for the urea solution storage tank • As discussed in the above answer to #6, the long-term operation of SCR systems requires the use of standards that do not accelerate catalyst poisoning • Recognising this, the marine SCR industry has established a standard urea solution (AUS40) for application in the shipping sector
Availability and disposal of SCR catalysts	
8) There has been no attention drawn to the problem of how to make catalysts available or how to dispose of them at the end of their operational life	• Even with a 2016 implementation date, marine demand for catalysts (V, Ti, and W) will have a minor impact on total SCR demand (less than 1% of global demand and growing only slowly since Tier III is a new build requirement) • Catalysts are loaded into modules and then put into frames, making them easy to remove • The used catalysts must be handled as hazardous/toxic waste not due to their intrinsic properties but because of contamination from lubrication oil etc • Third-party companies are in operation that regenerate catalysts and reintroduce them into the supply chain. Otherwise, they are currently going into landfill • Vanadium does not present any significant risk such as leeching into the water table • It is envisioned that as demand for V catalysts increases a market for recycled material will develop which will see more spent V catalysts recycled • A recycled catalyst business for land base plant is already established
The technology has not evolved	
9) Ship-owners and manufacturers have gained experience with SCR systems over the last 10 to 15 years. The opinion of the Russian Federation is that these figures cause the greatest concern as the drawbacks with the technology have not been rectified within such a long period	• Selective catalytic reduction of NOx using ammonia as the reducing agent was patented in the United States by the Englehard Corporation in 1957. Since this time millions of systems have been installed on terrestrial applications, from power plants to locomotives to automobiles • SCR is also a proven technology in marine applications. Systems have been installed on over 500 marine vessels over the last 30 years. Some have been in operation for well over 10 years and have accumulated >80,000 hours of experience • Engine manufacturers apply SCR to a wide range of ship types (including ferries, supply ships, RoRos, tankers, container ships, icebreakers, cargo ships, workboats, cruise ships, and foreign navy vessels for both propulsion and auxiliary engines), engine sizes, utilizing different fuels (of differing sulphur content) and operating over a range of engine conditions • Even taking into consideration the significant number of SCR systems that are being successfully utilized on marine vessels, a series of concerns are consistently raised about the applicability of the technology • It is true that issues have been reported, but mainly as part of a learning process where most were quickly resolved thorough holistic thinking and adherence to good practice • SCR technology continues to develop to meet evolving customer and market demands. In the future any issues will be resolved with a more integrated approach involving the engine and its SCR components. As the sector continues to use high sulphur fuels greater effort is required in developing durable, cost effective monitoring mechanisms to ensure safe, efficient and compliant operation

10) SCR technology has not been discussed in detail and further discussion is required, as well as research into potential consequences of its application on board ships at sea	• Regulation 13.10 of MARPOL Annex VI called for a review of the status of technological developments to implement the 2016 Tier III NOx emission limits. At MEPC 62, the Committee established a Correspondence Group (CG) to carry out this review over two years to be completed by the end of 2013 • The CG membership covered a broad spectrum of the marine transportation industry, including governmental representatives, shipowners and manufacturers. The CG was coordinated by the United States. • The CG had representation from the following Members of IMO: Canada; Japan; Denmark; Liberia; Estonia; Netherlands; Finland; Norway; France; Sweden; Germany; UK; Ireland; United States • The CG had representation from the European Commission • The CG had observers from the following non-governmental organisations in consultative status: International Chamber of Shipping (ICS); International Association of Ports and Harbours (IAPH); BIMCO; International Association of Classification Societies (IACS); Oil Companies International Marine Forum (OCIMF); International Association of Drilling Contractors (IADC); International Council of Marine Industry Associations (ICOMIA); International Association of Independent Tanker Owners (INTERTANKO); Cruise Liners International Association (CLIA); European Association of Internal Combustion Engine Manufacturers (EUROMOT); Institute of Marine Engineering, Science and Technology (IMaeEST); International Petroleum Industry Environmental Conservation Association (IPIECA); World Shipping Council (WSC); Clean Shipping Coalition (CSC); Integer; International Association for Catalytic Control of Shipping Emissions to Air (IACCSEA) • ***The CG group identified that selective catalytic reduction (SCR), exhaust gas recirculation (EGR) and dual-fuel LNG have the potential to achieve Tier III NOx limits, either alone or in some combination with each other. The group recommended that the effective date of the Tier III NOx standards in regulation 13.5.1.1 of MARPOL Annex VI should be retained***
Concerns about SCR costs	
11) For a ship of 20,000 deadweight tonnes the ship owner will have to spend 6 million Euros to purchase and install the SCR system with the pay-off period of not less than 8 to 10 years (and this does not take into account, any emergencies involving the catalyst replacement or operational costs/urea)	• A calculation tool has been developed by IACCSEA. The tool was pulled together to grant some insight into the true costs and benefits of SCR technology on-board vessels, in order to meet IMO Tier III NOX limits. • It is worth noting that the model incorporates some scaling down of costs over the lifetime of the vessel, as it assumes economies of scale • Using the example of a ***10MW*** engine, powering a vessel of ***20,000 DWT*** using ***HFO*** that spends ***1500 hours p.a***. in a NOx ECA, the capital expenditure cost (including system installation) will be of the order of ***$500k***. • The major operational costs (notably AUS40 urea) required to meet IMO III (from an IMO I baseline NOx level) would be of the order of ***$950k*** over the 25 year lifetime of the vessel. • The catalyst recharge cost during the vessel lifetime of 25 years will be of the order of ***$450k*** with system maintenance cost some ***$150k.*** • Whilst a fuel penalty due to back pressure caused by the SCR equipment may of the order of ***$175k***, an efficiency gain of ***2%*** could lead to fuel savings of the order of ***$425k***. • All this considered means a total lifetime SCR cost of some ***$2.25m*** and a fuel benefit of ***$425k***. • This equates to a total cost of ownership of the order of ***$1.8m*** over the lifetime of the vessel, or about ***$75k p.a.***
Concerns about modal shift	
12) Shipowners striving to ensure compliance will have to incur serious expenses to equip their ships, or they will have to avoid calling at ports in NOx emission control areas. This will result in cargoes being redistributed on land, which will lead to much higher air pollution	• A 2013 report by the North Sea Consultation Group, titled: *The impact on short sea shipping and the risk of modal shift from the establishment of a NOx emission control area* specifically reviewed this issue • The report assessed the potential modal and port shifts following the establishment of a sulphur NOx emission control area (NECA) in the North Sea • The report found a <1% cost increase related to a NECA and a socio-economic cost benefit relationship for a NECA 4.2 which implies that the benefits clearly outweigh the costs • A 2012 paper by the Danish Ministry of the Environment *Economic Impact Assessment of a NOx Emission Control Area in the North Sea*, reached the following conclusions: - "The costs imposed on the ship operators are unlikely to facilitate modal shifts - The increase in freight rates is estimated to be 1%-2% for short-sea shipping - The increase in freight rates is estimated to be 0.2%-0.6% for long distance shipping - A rerouting of the shipping patterns is very unlikely"

APPENDIX II

IACCSEA

The International Association for Catalytic Control of Ship Emissions to Air (IACCSEA) was formed in 2011 with a primary focus of demonstrating the technological and economic viability of Selective Catalytic Reduction (SCR) technology capable of reducing NOx emissions from marine engines. The objective of the Association is chiefly scientific, namely the demonstration of the technological and economic viability of using catalytic emission control technologies on ships. IACCSEA gathers and disseminates objective and factual technical information on marine catalytic emission control technologies (including costs and benefits) and promotes awareness of SCR, including latest developments.

The membership of IACCSEA has been responsible for the vast majority of the 500+ marine SCR systems. Members include: Haldor Topsoe; H+H; Johnson Matthey; Tenneco; Yarwil; Cormetech; Hitachi Zosen; CERAM/IBIDEN; Panasia.