ABS ADVISORY ON NOx TIER III COMPLIANCE

ABS

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INTRODUCTION

Nitrogen Oxide (NOx) is one of the gaseous pollutants from ships regulated by the International Convention for the Prevention of Pollution from Ships (MARPOL Annex VI[1]), published by the International Maritime Organization (IMO). Under Regulation 13 of MARPOL Annex VI, three tiers of Nitrogen Oxide (NOx) emission limits are set for diesel engines with a power output higher than 130 kW, i.e., IMO Tier I, Tier II and Tier III. Each Tier limits the NOx emission to a specific value based on the rated engine speed.

Diesel engines for installation on a ship constructed on or after January 1, 2016 are subject to IMO Tier III requirements when the ship is operating in a NOx Tier III emission control area (NOx ECA) designated under Regulation 13 of MARPOL Annex VI.

The North American area and the United States Caribbean Sea area are currently designated as a NOx ECA. The Baltic Sea area and the North Sea are designated as a NOx ECA under MEPC. 286 (71)[2], to which the IMO NOx Tier III requirements will be applicable from January 1, 2021.

The air emission requirements are driving the development of primary engine technologies and secondary exhaust emissions abatement systems to reduce exhaust emissions from ships. As a result, a number of techniques and design features are utilized by internal combustion engine manufacturers to reduce NOx emissions. The predominant technologies used to achieve compliance with the IMO Tier III limit include reduction of NOx emission at the source and the treatment of the exhaust gas after combustion.

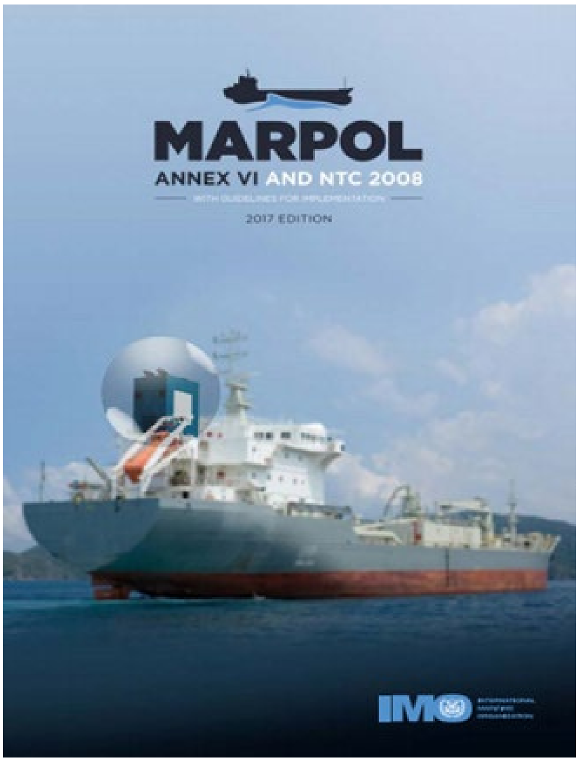
This ABS Advisory is developed to provide some of the best practices for IMO Tier III compliance for new builds as well as existing ships (retrofitted), including an overview of available technologies, consideration for the selection of compliance options, process for statutory and class approval, practice for installation and integration, and challenges during operation.

Some regional, national and local air emission requirements legislations impose limitations on the NOx emissions from ships in addition to the MARPOL regulations. This Advisory also provides information on the respective NOx emission limits, the geographic boundaries, and the compliance criteria set by various authorities.

SECTION 1 - EMISSION REQUIREMENTS

IMO REGULATION

The International Convention for the Prevention of Pollution from Ships, known universally as MARPOL, was adopted by IMO in 1973. In 1997, an IMO international conference of parties to MARPOL adopted the 1997 Protocol to the MARPOL Convention which added a new Annex VI – Regulations for the Prevention of Air Pollution from Ships, based on the regulatory text developed by the IMO Marine Environment Protection Committee (MEPC). This Annex entered into force on May 19, 2005. The conference also adopted the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NOx Technical Code – NTC)[3].



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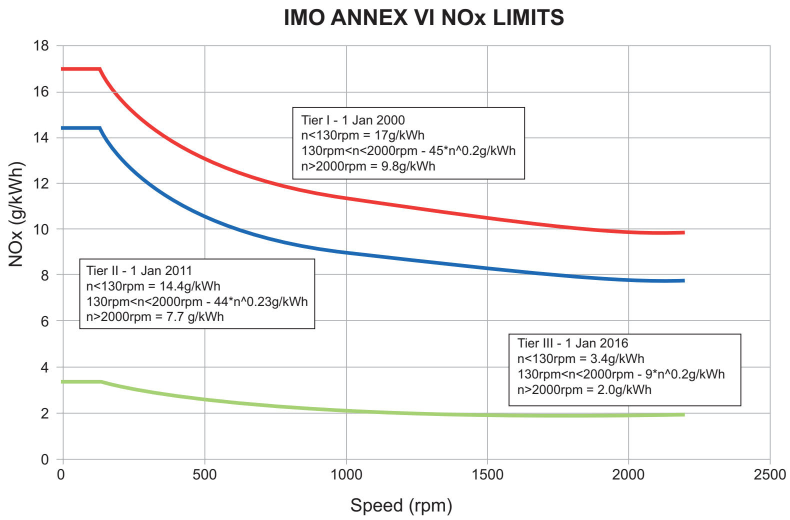
The new Annex VI introduced the first international shipping air pollution controls for Ozone Depleting Substances, Nitrogen Oxides, Sulfur Oxides, Volatile Organic Compounds and shipboard incineration. The Annex sets the general regulatory framework and limits for prevention of air pollution from ships with detailed requirements for survey, certification and means of control. The NTC provides the mandatory procedures for the testing, survey and certification of marine diesel engines to Regulation 13 that enables engine designers/ manufacturers, shipowner and operators to demonstrate and verify that all applicable marine diesel engines comply with the relevant NOx emission value limits. The NTC is in part based on the ISO 8178[4]~[9] series of standards for exhaust emissions measurement including test fuels, test cycles, measurement, reporting, and engine family or engine group definitions.

To reduce the harmful effects of NOx emissions on human health and the environment, Regulation 13 of the MARPOL Annex detailed the limits for NOx emissions from diesel engines. Regulation 13 mandates that all marine diesel engines over 130kW installed on a vessels subject to MARPOL Annex VI are to comply with the applicable emission limit except engines solely used for emergency application such as engines for emergency generators, emergency fire pumps and engines installed in lifeboats. However, diesel engines used to drive external fire monitor pumps on firefighting vessels are not eligible for exemption unless advised otherwise by the Administration. Diesel engines installed in ships not engaged in international voyages may also be exempted provided such engines are subject to an alternative NOx control measure established by the Administration in whose waters the vessel is intended operate.

Marine diesel engines are defined by IMO as any reciprocating internal combustion engine operating on liquid or gaseous or dual fuels, operating on Diesel combustion, or Otto combustion cycle, including gas fueled engines where gas/air mixture can be ignited by the combustion of a certain amount of fuel (pilot injection) or by extraneous ignition (spark plug). The NOx emission limits are therefore also applicable to pure gas spark ignited engines. NOx formation is linked to peak combustion temperatures, and with inherently lower temperatures the natural gas burning engines that use the Otto combustion process in gas mode can meet the Tier III NOx limits of Regulation 13 without exhaust emissions aftertreatment equipment. For more information on gas and dual fuel engines, and the differences between Diesel and Otto combustion cycles see the prime mover section of the ABS *Advisory on Gas and Other Low Flashpoint Fuels*.



RPM	NOx calculated as total weighted emission of NO_2 (g/kWh)			Relative Reduction from Tier I
	< 130	130 ≤ n < 2000	≥ 2000	
Tier I	17.0	$45*n^{(-0.2)}$	9.8	0%
Tier II	14.4	$44*n^{(-0.23)}$	7.7	15.5% - 21.8%
Tier III	3.4	$9*n^{(-0.2)}$	2.0	80%

Figure 1: IMO MARPOL ANNEX VI Regulation 13 NOx Limits

The IMO engine NOx limits are based on engine rated speed (see Figure 1), with the lowest limits applicable to medium and high-speed engines. The application date of the Regulation 13 NOx emission limits is tied to the ship construction date.

The 58th IMO MEPC session in October 2008 adopted further significant changes to Annex VI and the NTC under Resolutions MEPC.176(58)[10] and MEPC.177(58)[11] respectively. These changes entered into force on July 1, 2010.

The Tier I NOx limit was retrospectively applicable to engines fitted to ships with keels laid on or after January 1, 2000 once Annex VI entered into force on May 19, 2005. The 2008 amendments progressively reduced the NOx limits, with the Tier II limit entering into force on January 1, 2011. The amendments also introduced the Tier III limit, which is only applicable in ECAs, and represents a NOx reduction of approximately 80% from the Tier I limit. Where an SCR unit is installed to comply with the IMO Tier III NOx limits it is to be approved in accordance with the additional requirements of the IMO SCR guidelines, currently as amended by MEPC.291(71)[12] and MEPC.313(74).

IMO TIER III EXCEPTION

Regulation 13.5.2.3 of MARPOL Annex VI, as adopted by Resolution MEPC.251(66)[13], allows a five-year delay in the application of the Tier III limits until January 1, 2021 for ships (generally applicable to large yachts) of less than 500 gross tonnage, with a length of 24m or over, that are specifically designed and used solely for recreational purposes.

The proposal to pursue further delay of application of the Tier III NOx requirements for such vessels beyond January 1,2021 was considered at the MEPC 74th session meeting. The committee concluded that there was insufficient support for the proposal, as detailed in paragraphs 5.68 through 5.72 of the MEPC 74/18 Report. Therefore, marine engines installed on such yachts constructed on or after January 1, 2021 are to comply with the Tier III emission requirement.

The IMO NOx Tier application dates are given in Table 1, with the Tier III exemption provisions for engines of less than 750kW and small vessels designed and used for recreational purposes.

Emission Limit	Application of Requirements	Ship Constructed (≥ January 1)	Operation Areas
Tier I	Engine > 130 kW (#)	2000 ≤ x < 2011	Operating outside and inside of ECA
Tier II		2011 ≤ x < 2016	
		≥ 2016	Operating outside of ECA
Tier III		≥ 2016 3 exceptions (*)	North American ECA and the U.S. Caribbean Sea ECA
		≥ 2021 3 exceptions (*)	Baltic Sea and North Sea ECAs

#except engines solely for emergencies, or to power any devices/equipment for emergencies, or installed on lifeboat solely for emergencies
*L<24m if used for recreational purposes; or
total propulsion <750kW if unable to achieve due to design limitations; or
purely recreational ships constructed prior to January 1, 2021 less than 500 GT and L>24m.

Table 1: Application of IMO NOx Limits

EMISSION CONTROL AREAS

Currently the only NOx ECAs in force are the North American (see Figure 2) and United States Caribbean Sea ECAs (see Figure 3), which entered into force on January 1, 2016. The existing Baltic and North Sea SOx ECAs (see Figure 4) were designated as NOx ECAs at the 71st MEPC session meeting by Resolution MEPC.286(71), with the application of the Tier III requirements in these ECAs to start from January 1, 2021.

Figure 2: North American ECA

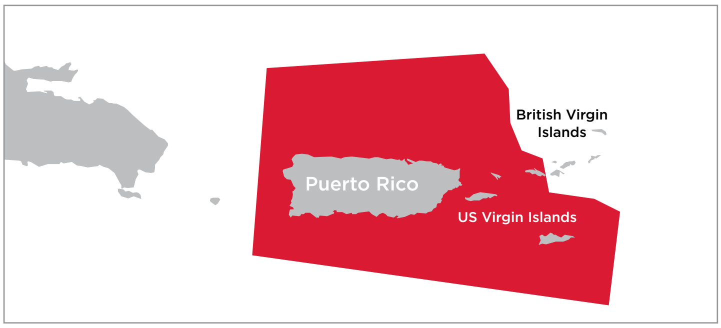


Figure 3: United States Caribbean Sea ECA

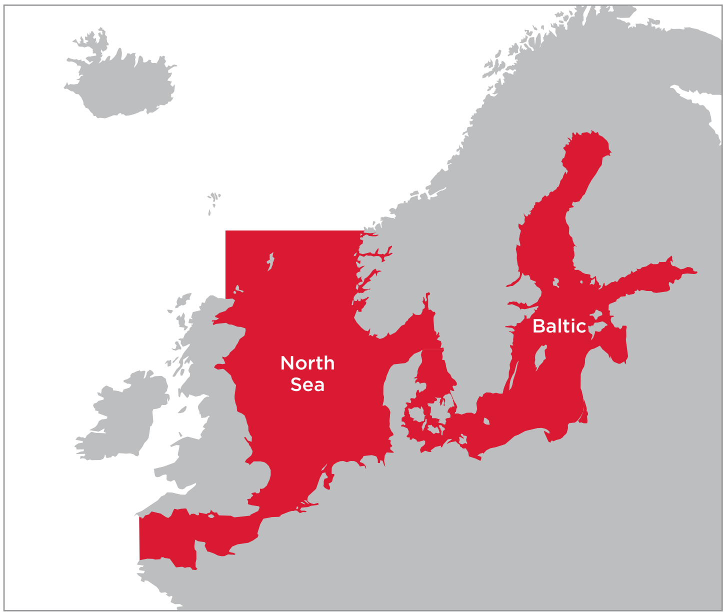


Figure 4: Baltic and North Sea ECA

REGIONAL EMISSION REGULATIONS

Some regional, national and local authorities have taken a different approach or introduced additional measures to limit NOx. The following paragraphs provide information on the different approaches taken by those authorities, including the U.S. Environmental Protection Agency (EPA), California Air Resource Board (CARB), and Norwegian Maritime Authority.

The briefing of the regional emission regulation are based on ABS understanding. Users of this document should contact the respective authority for interpretation and implementation of their regulation.

UNITED STATES REGULATION

The U.S. Environmental Protection Agency (EPA) and U.S. Coast Guard are authorized to administer MARPOL Annex VI by the Act to Prevent Pollution from Ships. U.S. EPA regulations implementing Annex VI are codified at 40 CFR Part 1043. The NOx emission limits in Regulation 13 of MARPOL Annex VI are applicable to U.S. flagged ships trading in international waters and foreign flag ships while operating in the U.S. ECA areas. US flagged vessels are also subject to engine requirements under the Clean Air Act. The U.S. EPA categorizes marine engines as follows under Clean Air Act regulations in 40 CFR part 1042:

- Category 1: Displacement < 7.0 liter/cylinder
- Category 2: Displacement from 7.0 and above but < 30 liter/cylinder
- Category 3: Displacement ≥ 30 liter/cylinder

Engines intended to be installed onboard U.S. flagged vessels are to comply with the emission requirements laid down in 40 CFR Part 1042[14] and 40 CFR Part 1043[15]. Category 1 and 2 engines are to comply with the emission Tiers in accordance with Tables 1, 2, 3, 4 of 40 CFR Part 1042.101. Category 3 engines are to comply with Table 1 of 40 CFR Part 1042.104, which is equivalent to the IMO NOx emission levels, except that the CFR also sets a HC limit of 2.0g/kWh and a CO limit of 5.0 g/kWh under Tier 2/II and Tier 3/III.

Such engines needing an Engine International Air Pollution Prevention (EIAPP) Certificate must be covered by an EIAPP Certificate that is issued by the U.S. EPA. Engines on U.S. flagged vessels that do not operate in waters subject to the jurisdiction of another country may comply with the EPA's domestic emission standards in lieu of compliance with Annex VI.

Note: The EPA has four NOx emission Tiers written in Arabic numerals (e.g. Tier 1, 2, 3 & 4) compared to IMO MARPOL, which has three NOx emission Tiers written in Roman numerals (e.g. Tier I, II & III).

On October 17, 2018 the United States Coast Guard (USCG) released a Work Instruction (WI) to clarify how it will enforce Regulation 13.5.1.2 of Annex VI due to the unavailability of Tier III engines of the size required to comply with this regulation. The USCG will defer enforcement of this regulation on qualified vessels and engines;. In lieu of meeting MARPOL Annex VI Tier III performance standards, engines with rating of 130 kW to 600 kW installed on vessels with keel-laying date on or after January 1, 2016 may instead be accepted by the US Government provided they meet the Clean Air Act Tier 3 requirements under 40 CFR part 1042.

Such certified engines are available and will be accepted in the short-term if available engines of the required size certified to meet MARPOL Annex VI Tier III are demonstrated to be unsuitable . This WI is applicable to U.S.-flagged and foreign-flagged vessels.

For further information on EPA emission standards for nonroad engines and vehicles please refer to:
https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-nonroad-engines-and-vehicles

EPA Policy and Guidance Documents

EPA also provides guidance on particular topics for compliance issues for the North American and U.S. Caribbean Sea ECA . Please refer to the following web pages for the relevant EPA policy and guidance documents.

- https://iaspub.epa.gov/otaqpub/
- https://www.epa.gov/regulations-emissions-vehicles-and-engines/guidance-documents-related-annex-vi-standards-marine
- https://www.epa.gov/ve-certification/certification-marine-compression-ignition-ci-engines

CALIFORNIA AIR RESOURCE BOARD REGULATIONS

In addition to U.S. EPA requirements, the California Air Resource Board (CARB) implements California Code of Regulation (CCR) to control NOx and Particulate Matter emission from the operation of auxiliary engines on ocean going vessels while docked at berth at a California port.

The current applicable California Code of Regulation is title 17 Section 93118.3, "Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-berth in a California Port"[16]. This CCR is applicable to U.S. or foreign-flagged container vessels, passenger vessels, and refrigerated cargo vessels when they visit California ports, including the Port of Los Angeles, Long Beach, Oakland, San Diego, Hueneme and San Francisco.

Exemption of the CCR requirements apply to the following:

- Ocean-going vessel voyages that consist of continuous and expeditious navigation through any of the Regulated California Waters for the purpose of traversing such bodies of water without entering California internal or estuarine waters or calling at a port, roadstead, or terminal facility
- Steamships
- Auxiliary engines operating primarily on liquefied natural gas (LNG) or compressed natural gas (CNG)

The emission/power reduction percentages phase in from 10% in 2010 to 80% in 2020. The CCR accepts the following two pathways for the reduction of emissions:

- Reduced on-board power generation
- Equivalent emission reduction

The first pathway option limits the hours of operation of auxiliary generator engines and the power generated on-board while docked at the berth.

The CCR set operation time limits for the specified percentage of visits by the fleet during a defined calendar year. The time limit is either 3 hours or 5 hours, depending on power transfer process to change from vessel-based power to shore-based power. For example, beginning January 1, 2020, the CCR require that at least 80% of a fleet's total number of visits to the port (e.g., for container vessels, if total time of visits by a fleet is 30, then 24 out of the 30 visits) shall operate auxiliary engines no more than 3 hours per visit to a berth if the visiting vessel uses a synchronous power transfer process. If synchronous power transfer process is not used, the time limit for each visit is 5 hours. The 3- or 5-hour limit applies to the combined operating time for all auxiliary diesel engines used in a vessel visit, rather than on a per-engine basis.

For reduction of on-board power generation, taking the 2020 requirements as example, the fleet's onboard auxiliary-diesel-engine power generation while docked at berth shall be reduced by at least 80% from the fleet baseline power generation. Baseline fleet power generation is the product of berthing time and power requirement of a fleet during docked at berth.

The other option is through the application of equivalent emission reduction to reduce the emissions of the fleet, i.e., using one or more control techniques including electric power from the utility grid, electrical power from sources that are not part of an utility's electrical grid (distributed generation), or alternative control technologies e.g. SCR, so that the emission on a fleet basis is reduced to the required percentage of baseline fleet emissions. For example, for the quarter beginning on January 1, 2020, and each subsequent quarter thereafter, the NOx and Particulate Matter emissions from the fleet's auxiliary engines when the vessels in the fleet are docked at the berth must be reduced by 80 percent from the baseline fleet emissions. The baseline fleet emission is the product of emission rate, average berthing time, power required and number of visits of a fleet.

Demonstration of compliance is through the provision of relevant report and record to the CARB authority.

CARB has developed new sections of the CCR (Sections 93130-93130.22), "Control Measure for Ocean-Going Vessels Operating at Berth". The Control Measure is designed to supersede section 93118.3 of title 17 and section 2299.3 of title 13 of the California Code of Regulations on January 1, 2023. However, on January 1, 2021, certain provisions in this Control Measure shall become operative alongside the requirements of section 93118.3 of title 17 and sections 2299.3 of title 13 of the California Code of Regulations.

Compared to the current 17 CCR Section 93118.3, the noticeable changes in the new sections include:

- Compliance based on actions during a single visit (each vessel is to comply with the requirements at each visit vs the previous requirements that limit the total auxiliary generator operating hours based on percentage of total number of visits by a fleet, as per d (1) of 17 CCR 93118.3.)
- Expended scope of regulated vessel types
- Extended the application of the regulation to all ports in California receiving an ocean-going vessel
- Shared responsibilities among all crucial parties, including vessel owners, vessel operators, terminal operators, port authorities and technology suppliers

Based on the new regulations, shore power is the preferred method for compliance if the ocean-going vessel is provided with commissioned shore power equipment. Other emission control strategies may be acceptable, subject to approval by CARB. Both NOx and PM emissions are limited. The NOx limitation applies not only to auxiliary engines, but also to boilers on tankers. The limitation for auxiliary engines is more stringent than IMO Tier III limit.

CHINA

Notice of China Ministry of Transport for the Implementation of Air Pollution Prevention in Emission Control Area, Document No. JHF [2018] 168[17] dated November 30, 2018, specifies the requirements for limiting air emission from ships including NOx emission control and use of shore power (cold ironing). The requirements are applicable only to Chinese flag ships operating in domestic water.

NORWEGIAN MARITIME AUTHORITY REGULATIONS

In the March 2019 Circular 02-2019 the Norwegian Maritime Authority (NMA) provided background and details to the amendments to Regulation No. 488[18] on environmental safety for ships and mobile offshore units. Under the amendments, the NMA included a new provision in section 14c on special rules regarding NOx emissions from ships of 1000 gross tonnage and above operating in the Norwegian world heritage fjords.

The new provision is based on the Tiers set out in MARPOL Annex VI regulation 13, with the requirements be phased in as follows, regardless of year of construction:

- Tier I requirements to be satisfied by January 1, 2020

- Tier II requirements to be satisfied by January 1, 2022
- Tier III requirements to be satisfied by January 1, 2025

These Regulations apply to Norwegian ships, including recreational craft and mobile offshore units. Subject to limitations from international law, these Regulations apply to foreign ships and mobile offshore units:

a) In Norwegian territorial waters, including waters near Svalbard and Jan Mayen;

b) In the Norwegian economic zone;

c) On the Norwegian Continental Shelf.

NORWEGIAN NOx FUND

In 1999 the United Nations Economic Commission for Europe (UNECE) adopted the Gothenburg Protocol to the 1979 convention on long-range transboundary air pollution. The Protocol set out maximum national NOx emissions for the Parties to the Protocol, that include Norway, European Union members and the United States. Norway is obligated to reduce its annual NOx emission under the Protocol.

In order to encourage industries to take diligent action for the reduction of NOx emissions, Norway started to impose a NOx tax from 2008. For shipping, the tax covers emissions from vessels within Norwegian territorial waters and Norwegian flagged ships. As a response to the NOx tax, the NOx fund was created by industry in the same year. Enterprises joining the fund have the option of not paying the tax but to pay the fund at a lower rate than the NOx tax with a commitment for a certain amount of NOx reduction. As a member of the fund, members can apply for funding to support their NOx emission reduction measures and technology. The fund is to ensure sufficient NOx reduction measures are implemented to meet the agreed reductions. The NOx fund has played a part in stimulating the use of LNG as fuel in Norwegian ferries and OSVs.

As reported in the NOx Fund website, Norwegian NOx emissions have decreased by 39,000 tonnes since the creation of the NOx fund in 2008 until the end of 2019 (refer to below website).

Detailed and latest information for the Norwegian NOx Fund is available on the website of the Confederation of Norwegian Enterprise (NGO): https://www.nho.no/samarbeid/nox-fondet/the-nox-fund/

IACS

Members of the International Association of Classification Societies (IACS) verify compliance with the IMO MARPOL Annex VI requirements, acting as Recognized Organizations (RO) for the flag Administration of the ship.

To assist uniform application of requirements that may be outside the scope of the IMO regulations, or fall within traditional Classification requirements, IACS members work together to develop Unified Requirements (UR). All IACS members can then apply these requirements in a consistent manner. The URs are publicly available on the IACS website and cover a wide range of ship and machinery topics. Of particular relevance to the application of NOx Tier III exhaust emissions aftertreatment are the IACS requirements for the storage and use of SCR reductants given in UR M77(19).

IACS are also active at IMO in the support of further development and application of MARPOL Annex VI and the NOx Technical Code under the IMO PPR sub-committee.

To support harmonized application of MARPOL Annex VI and the NOx Technical Code, IACS also develops Unified Interpretations (UI). These are submitted to IMO for agreement before being incorporated as IACS UIs and available from the publicly available publications section of the IACS website. IACS publishes these interpretations to individual Annex or Code requirements as "MPC" UIs on the IACS website: http://www.iacs.org.uk/publications/unified-interpretations/ui-mpc/

ABS RULES

ABS published the ABS Guide for Exhaust Emission Abatement (ABS EEA Guide)(20) in 2013. This guide covers the additional safety and reliability aspects of exhaust emission control equipment that are outside of the statutory environmental regulations and fall within the scope of traditional Classification requirements. The guide provides guidance, requirements and notations for the design and construction of exhaust emission abatement systems, focusing on SOx scrubbers, SCR systems, EGR arrangements, emissions monitoring systems, and may be applied to all vessel types. An exhaust emission abatement system is considered approved upon verification of compliance with both the ABS requirements and the applicable IMO Regulations and Guidelines.

All ABS Rules, Guides and Guidance Notes can be downloaded free of charge at www.eagle.org

Appendix I provides a list of frequently asked questions for typical air emissions regulatory and rule inquiries.

SECTION 2 - APPROVAL AND CERTIFICATION PROCESS

GENERAL

Each marine engine over 130 kW intended to be installed on vessels subject to MARPOL Annex VI, and not used solely for emergency purposes, must be certified as meeting the NOx emission limits of Regulation 13 of MARPOL Annex VI in accordance with the NOx Technical Code and any applicable IMO guidelines. This mandatory approval process is typically undertaken by a class society in its role as a Recognized Organization (RO) on behalf of the flag Administration of the ship and is demonstrated by the issue of an Engine International Air Pollution Prevention (EIAPP) Certificate for each engine and approval of the associated member engine Technical File. This statutory process is outlined in this section and highlights that this process incorporates review and approval of the particular engine design, the manufacturers Conformity of Production arrangements, witnessed exhaust emissions testing of the Parent Engine and a pre-certification survey (at the place of engine manufacture) of each installed engine and subsequent verification of that installed engine at the ships initial survey prior to issue of the ships International Air Pollution Prevention Certificate (IAPPC).

Flag Administration may have specific policy for the certification process and may implement additional requirements. It is advisable that the relevant Flag Administration is to be contacted for instruction, particularly when a RO is not authorized to act on behalf of a flag, e.g., any U.S. EPA-certified engine on a US vessel.

In addition to this validation of the engine's environmental performance with respect to MARPOL Annex VI Regulation 13, each engine installed on an ABS classed vessel must be design approved and surveyed as meeting the general rule requirements for internal combustion engines (ABS Marine Vessel Rules 4-2-1) but also any mandatory, or optional, requirements for the exhaust emission abatement equipment detailed in the ABS Exhaust Emission Abatement Guide (EEA Guide) that includes a review of the equipment, as well as the approval of the onboard installation.

STATUTORY APPROVAL

GENERAL:

Engine to which NOx emission limits in Regulation 13 of MARPOL Annex VI apply is subject to the following survey for the compliance:

- **Pre-certification survey** is to verify compliance of NOx emission limit. Confirmation of compliance leads to issuance of Engine International Air Pollution Prevention (EIAPP) Certification by the Administration or its recognized organization (RO) such as Class.
- **Initial certification survey** is carried out on board after installation but before being placed in service; which may lead to issuance of an International Air Pollution Prevention (IAPP) Certification or amend the valid IAPP Certification reflecting the installation of a new engine by the Administration or the RO will issue
- **Annual, intermediate and renewal survey** as part of ship's survey are to verify engine continue to fully comply with the NOx Technical Code (NTC).
- **Onboard engines undergone major conversion** are subject to an initial engine certification survey onboard a ship to ensure that the engine comply with the NOx emission limit, resulting in the issue of an EIAPP certificate and the amendment of the IAPP certificate.

ENGINE PRE-CERTIFICATION

Marine diesel engines are to be pre-certified for NOx emission for compliance with NOx emission limit through one of the following options:

- Pre-certified through test-bed test as an individual engine
- Engine family or engine group concept is applied. Test-bed test is to be conducted for the parent engine
- For engines which cannot be pre-certified on a test bed, as per 2.1.2.2 of the Code, if agreed by the Administration, onboard initial certification test in accordance with the full test-bed test requirements of Chapter 5 of NTC 2008 may serve as the pre-certification test. This option can only be applied for an individual engine or for an engine group represented by the parent engine, but not for an engine family certification as per 2.2.4.2 of NTC 2008

Engine family and engine group concept have been defined per NTC 2008 as follows:

- Engine family concept may be applied to any series-produced engines that, through their design, are proven to have similar NOx emission characteristics, are used as produced and, during installation on board, require no adjustments or modifications that could adversely affect the NOx emissions.
- Engine group concept may be applied to a smaller series of engines produced for similar engine application and that require minor adjustments and modifications during installation or in service on board.

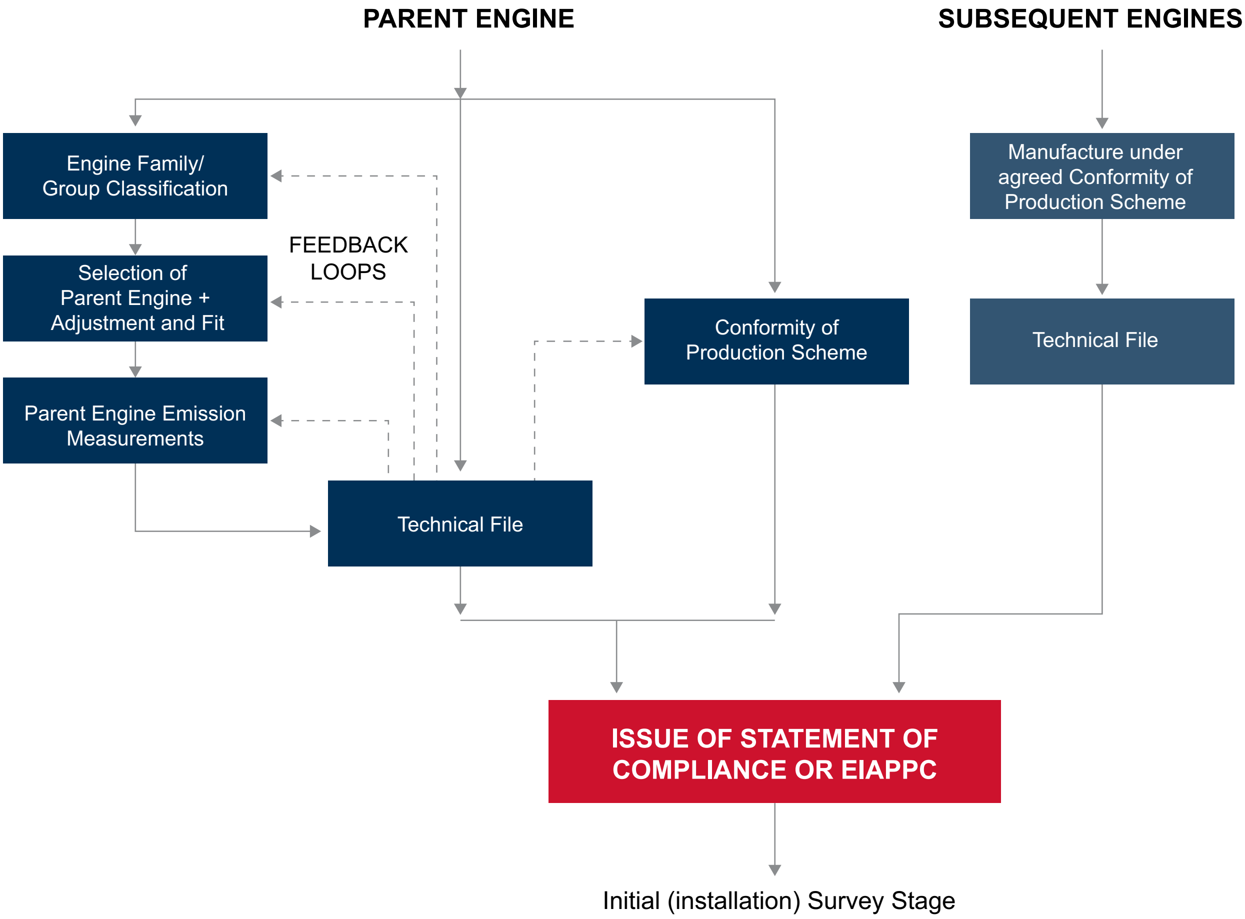


Figure 5: process for engine pre-certification

The certification procedure includes an initial approval of the engine Technical File for every parent engine of each engine family or engine group and will include, but may not be limited to:

1. A review and acceptance of the range of engine models to be included in an engine family or engine group and the choice of parent engine to represent that family or group,
2. Approval, in principle, of a preliminary copy of the Technical File (the contents of which are set out at paragraph 2.4.1 of the NTC) which would include everything except the copy of the test report; and,
3. Pre-certification test-bed test is to be carried out in accordance with Chapter 5 of NTC 2008 as required in 2.1.2.1 of the Code. Alternatively, onboard initial certification test in lieu of test-bed test as previously mentioned,
4. Approval of the final copy of the Technical File, based on the report of the test bed results, which may include observations and/or recommendations regarding one or more of the items contained in the Technical File, and which may also involve checking the final emissions figure,
5. The above process will also establish the conformity of production scheme as per 4.3.7 of NTC that will be used as the "agreed conformity of production scheme" by the manufacturer and RO for the certification of the subsequent engines under the certified engine family or engine group.

Chapter 2 of NTC 2008 specifies the detailed requirements for the aforementioned survey and certification.

ENGINE WITH SCR FOR NOx TIER III COMPLIANCE:

SCR as a NOx reduction device is typically manufactured and supplied separately from the engine. When SCR is fitted for meeting NOx emission limit, the SCR must be considered as a component of the engine it serves for the purpose of EIAPP certification.

Pre-certification of engine systems fitted with SCR is to be in accordance with the procedures provided by certification Scheme A or Scheme B of IMO Guidelines MEPC. 291(71) as amended by MEPC. 313(74)[21].

Regardless of Scheme A or Scheme B, there should be only one applicant for the Tier III certification, who is the entity for the complete engine system fitted with SCR, as summarized below:

- One owner of "engine + SCR"
- One applicant owning the "engine + SCR" for the EIAPP certification
- One technical file for "engine + SCR", and
- One EIAPP certificate for "engine + SCR"

The engine family and group concepts in chapter 4 of the NTC 2008 apply equally to engine system fitted with SCR. The parent engine is to be the engine system fitted with SCR with the highest NOx emission value of the group/family. In cases where there is more than one combined engine/SCR system with the same highest NOx emission value given to two decimal places (cycle value in g/kWh) within an engine family or an engine group, the parent engine is the system with the highest raw NOx value emitted from the engine.

The process can be applied to Tier II as well. When an engine is to be certified to both Tier II and Tier III, the EIAPP Certificate should be completed for both Tier II and Tier III with a single Technical File covering both Tier modes. The parent engine for Tier II compliance is not necessarily the same parent of the combined engine/SCR system for Tier III compliance.

It needs to be noted that the Technical File for engine system with SCR should include additional parameters as specified in Section 3.2 of MEPC. 291(71) as amended by MEPC. 313(74).

Scheme A:

In this process. the combined engine and SCR system, as one unit, is to be subject to pre-certification test-bed test for verification of compliance with NOx emission limit. Upon satisfactory verification of the test result and review of the technical files, EIAPP certificate is issued to the engine with SCR.

This scheme follows the procedure stated in chapter 5 of NTC 2008 and Section 5 of IMO Guidelines MEPC. 291(71) as amended by MEPC. 313(74).

Scheme B:

In cases where the combined engine/SCR systems cannot be tested on a test bed owing to technical and practical reasons nor an on board test can be performed fully complying with the requirements of chapter 5 of the NTC 2008, the procedures provided by Scheme B of the IMO Guidelines MEPC. 291(71) as amended by MEPC. 313(74) should be applied.

Application for Scheme B certification requires justification of inability to test on a test bed or conduct an on-board test. The limitation of the capability of the test facility for the combined engine and SCR in terms of size, weight, and space are some examples for the feasible reasons for this scheme. The fact that the SCR and engine are not manufactured by the same company is not justification for this scheme.

Scheme B may be accepted for individual engine or for an engine group represented by a parent engine. However, this option is not accepted for engine family concept as per section 2.2.4.2 of the NTC 2008.

Under this scheme, the engine and SCR may be tested/validated individually in accordance with Sections 6 and 7 of MEPC. 291(71) as amended by MEPC. 313(74), as summarized below:

1) Engine Test (without SCR):
   - To obtain the NOx emission value (g/kWh)
   - Test-bed test or onboard test
   - NOx emission measurement in accordance with Chapter 5 of NTC 2008
2) SCR NOx Reduction Rate Establishment
   - By calculation model, taking into account of following
   - Geometrical reference conditions, and
   - Chemical NOx conversion models, and
   - Other parameters
3) SCR Chamber Validation Test
   - To validate NOx reduction rate
   - To test for each individual mode point
   - To carry out full scale or scaled test
   - To validate scaling process by Administration or its RO
   - To test with engine exhaust gas or simulated gas
4) Technical Files Completion
   - To calculate NOx emission values after the SCR based on engine emission and validated NOx reduction rate
   - To complete the Technical File combined for engine and SCR, taking into consideration of the requirements Section 3.2 of the Guidelines
   - To enter NOx emission value into the supplement of the EIAPP certificate
5) Onboard Confirmation Test
   - Initial confirmation test for engine with SCR to verify the NOx reduction rate of scaled SCR and model calculation for the full scale application
   - Test to be conducted for parent engine of an engine group
   - Engine with SCR as described in Technical File
   - Operating values and reduction efficiency values corresponding to those in Technical File

Upon completion of the above five steps, the engine will be issued with EIAPP certificate. The process will also establish an engine group if the tested engine with SCR is a representative of the group, and the subsequent engines installed onboard ships will not be required for the confirmation test.

RETROFIT OF SCR TO ONBOARD ENGINE FOR NOX TIER III COMPLIANCE:

Ships constructed on or after January 1, 2016 may not have planned for entering NOx ECA at the time of construction, therefore installation for Tier III compliance is not prepared and not provided. There are cases where such ships need to be Tier III compliance due to the change of operational plan for entering NOx ECA.

There could be several cases associated with such need as outlined below:

a) A parent engine test with SCR was already undertaken in case it would be applied later. In which case the SCR would just be added, the Technical File is to be updated to the SCR specification and an onboard survey to verify installation
b) There is a similar engine group already established, the engine (plus SCR) could be re-approved into that engine group without undertaking emissions measurements
c) Testing could be done at testbed to create a new engine group with the SCR, and then re-approve the existing engine to this engine group
d) The scheme B approach could be applied

For the above case (d), although the scheme B approach does open the door to parties other than the engine manufacturer to supply the SCR, and act as the applicant for Tier III certification, the challenges in such case is that the applicant may not be able to obtain the required engine data and will not be able to amend the engine technical file without the engine manufacturer's permission as the intellectual property (IP) of engine and its technical file lies with the engine manufacturer. Therefore, it will be most practical to engage the engine manufacturer for the retrofitting of SCR and acting as the applicant for the Tier III certification.

Request for Tier III certification submitted by any third party other than the engine manufacturer may be handled on a case-by-case basis and in discussion with the flag Administration or its recognized organization (RO). The potential challenges associated with such approach should be carefully considered.

CLASS APPROVAL

The ABS Guide for Exhaust Emission Abatement details the Class requirements for the principal exhaust emissions abatement technologies used for the reduction of and NOx emissions; namely Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation (EGR).

The guide identifies those requirements that are mandatory in all cases but also the optional class notations for ships with engines adopting exhaust emission abatement technologies. The optional notations will be assigned based upon request and where the arrangements have been verified to be in compliance with the applicable requirements of the ABS EEA Guide.

ABS applies these requirements through the plan review and survey process covering typical Class requirements such as compatibility, system redundancy, material suitability, monitoring, alarm and emergency shutdown system, electrical power and computer-based systems and equipment certification detailed in the guide.

Sections 3 and 4 of the ABS EEA Guide details the Class requirements for SCR and EGR equipment and installation respectively including certification requirements at the manufacturer's facility and which supplement the statutory emissions performance testing, survey, and certification requirements.

For EGR arrangements, the class notation assigned to the ship is intended for EGR systems that incorporate extensive off-engine system that are designed for the purposes of removing the sulfur by-products from the exhaust gases that originate from the fuel and incorporate, for example, water scrubbing and water cleaning systems. The notation for EGR is not intended to be applied to those ships that have installed engines that incorporate all EGR system components within the base engine design and, for example, may be primarily designed for use with low sulfur fuels.

Regardless of the optional class notation, the EGR washwater system needs to be verified for compliance with the minimum safety requirements prescribed under 1/9.11 of the ABS EEA Guide.

As the request for such notations is typically raised by the ship designer or shipyard on behalf of the ship owner, the ship designer or shipyard is to coordinate with the engine designer (and exhaust emission abatement technology provider when it is provided by a third party) to determine the scope of approval required by ABS.

SECTION 3 - NOx REDUCTION TECHNOLOGIES

GENERAL

Nitrogen oxide (NOx) is a collective term of nitric oxide (NO) and nitrogen dioxide (NO_2). There are three primary sources of NOx in the combustion processes, thermal NOx, fuel NOx and prompt NOx, among them the thermal NOx is the main contributor to shipboard NOx emission.

Thermal NOx is formed through high temperature oxidation of nitrogen in the combustion air during the combustion process, typically above 1300°C. The formation rate is primarily related to temperature and the residence time of the combustion gases at high temperature.

NOx reduction may be achieved through methods of lowering the combustion temperature in the cylinders of diesel engine and reducing the residence time of high temperature.

NOx abatement technologies can also be applied to reduce NOx emission.

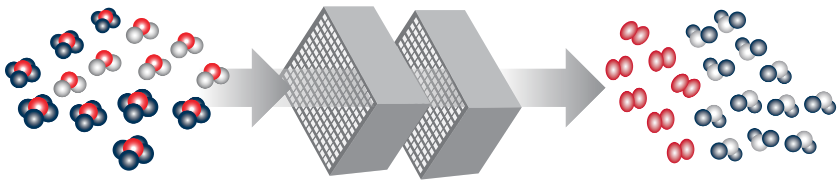
There are three main routes to achieve IMO NOx Tier III compliance, and these involve the use of Selective Catalytic Reduction (SCR), Exhaust Gas Recirculation (EGR) and Otto cycle engines using gas as fuel.

SELECTIVE CATALYTIC REDUCTION (SCR)

PRINCIPLE OF OPERATION

The Selective Catalytic Reduction (SCR) system uses reductant to treat the exhaust gases from diesel engines or dual fuel (DF) engines operating on diesel cycle to reduce the amount of NOx emitted.

- Urea solution, typically 40%. Urea converted to ammonia NH_3
- NOx removed over an SCR catalyst with NH_3
- Typical catalytic reaction temp. 300°C but below 450°C to avoid SO_3 formation
- NOx reduction up to 95% possible



$$(NH_2)_2CO + H_2O \rightarrow 2NH_3 + CO_2$$

Urea + Water > Ammonia + Carbon Dioxide

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

Nitric Oxide + Nitrogen Dioxide +Ammonia > Nitrogen + Water

Figure 6: Selective Catalytic Reduction Process

During the treatment process, the reductant, typically ammonia in the form of urea solution, is injected into the exhaust gas stream and mixed with the exhaust gases prior to entering in the SCR unit. Subsequent chemical reactions take place on the catalyst's elements, where ammonia reacts with the NOx in the exhaust gases, the products of the reaction being nitrogen and water.

Key factors that affect the performance of the SCR include:

- Catalytic reaction temperature in the SCR
- Catalyst specification
- Dosing rate of urea solution
- Sulfur content in the exhaust gas

SCR systems operate within a specific temperature window, and the exhaust gas temperature at the inlet of the SCR unit affects the catalyst's performance. At low exhaust gas temperature, outside the operating window, ammonia reacts with the sulfur oxides in the exhaust gases to form ammonium bisulfate. These ammonium salts (solid particles) stick to the catalytic elements, and reduce the effective area of the catalyst, thereby reducing the NOx conversion efficiency. On the other hand, if the exhaust gas temperature is too high, ammonia will burn leading to increased ammonia consumption and thermal degradation of the catalytic elements.

Overdose of reductant, typically ammonia, will lower further the concentration of NOx emission. However, this may also cause ammonia slip and increase the possibility of formation of ammonium bisulfate deposits.

SCR systems may be used with fuels of low or high sulfur content, subject to the SCR design and location (i.e. before, or after the turbocharger). On two stroke slow speed engines, the exhaust gas temperature before the turbocharger is sufficient to support SCR designs that may operate with high sulfur fuels, where as a SCR unit located after the turbocharger may only operate with fuels of low sulfur content (0.1%S). On four stroke medium speed engines, the exhaust gas temperature after turbocharger is typically high enough to support operation of a SCR with fuels of low or high sulfur content, if needed

SYSTEM CONFIGURATION

Depending on the location of the SCR reactor in relation to the turbocharger, a SCR unit is categorized as high-pressure SCR (hpSCR) or low-pressure SCR (lpSCR).

A SCR system typically consists of the following components:

- Urea solution storage tank
- Dosing unit that transfer urea from storage tank to mixing unit
- Mixing unit where urea solution is injected to the exhaust stream and mixes with exhaust gases
- SCR reacting chamber containing the catalyst
- SCR control system
- Soot cleaning system (compressed air)

For 4-stroke medium speed engines, the SCR reactor is typically located downstream of the turbocharger since exhaust gas temperatures are high enough for catalyst operation, and is therefore considered as a low pressure SCR (lpSCR) installation.

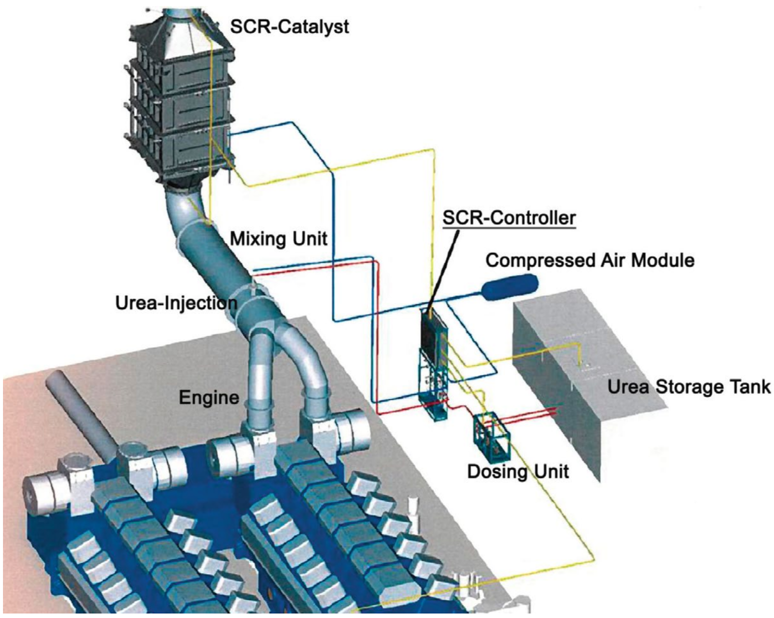


Figure 7: SCR System Configuration (Courtesy IMO, MEPC 66/INF.4)

In 2-stroke slow speed engines the inherently low exhaust gas temperatures require the SCR reactor to be located before the turbocharger, i.e., a high pressure SCR (hpSCR) installation. However, the SCR unit may also be positioned after the turbocharger (i.e. a low-pressure (LP) system), subject to the SCR design and the relevant performance tuning of the engine. During low load operation, the exhaust gas temperature may be too low for catalyst operation (in either HP or LP SCR systems), therefore engine tuning strategies such as cylinder bypass or exhaust gas bypass (wastegate) may be adopted to increase the temperature of the exhaust gases to the required level prior to entering the catalyst.

CONSIDERATION FOR SCR APPLICATION

The considerations for the selection of the appropriate SCR systems (hpSCR or lpSCR) include:

- Flexibility in SCR reactor location
- Flexibility in fuel sulfur content
- Fuel consumption penalty
- Additional power and energy consumption
- Urea solution concentration and consumption
- Expected catalyst life

Some key operational parameters of hpSCR and lpSCR systems are summarized as below:

Operational Parameters	hpSCR	lpSCR
Exhaust gas pressure at SCR inlet	1.0 – 4.5 bara	1.0 bara
Exhaust gas temperature at SCR inlet	250-500°C	200-300°C (for 2-stroke engines)
Fuel sulfur content	0.10% S up to 3.5% S	0.10% S for 2 stroke engines
Flexibility in installation location	On engine (no flexibility)	Along the exhaust pipe (flexible location)
Fuel consumption penalty	hpSCR has slightly lower fuel consumption penalty compared to lpSCR	
Urea solution consumption	Similar	
Expected catalyst life	Similar	
Additional power/energy	Lower (SCR auxiliaries)	Higher (SCR auxiliaries, burner and blower)

Flexibility in Installation Location

A hpSCR unit is located between the exhaust manifold and the turbocharger and for this reason does not offer any flexibility in choosing the location of the unit within the machinery space. On the other hand, a lpSCR unit, which is located downstream of turbocharger, may provide some flexibility in the location of the reactor unit in relation to other machinery on board.

Flexibility in Fuel Sulfur Content

In 4-stroke engines, due to the relatively higher exhaust gas temperatures, a lpSCR unit can operate with fuels having either low or high sulfur content.

In 2-stroke engines, due to the lower exhaust gas temperatures, the flexibility in the use of fuels with different sulfur content depends on the location of the SCR unit (ie hpSCR or lpSCR). hpSCR systems may be designed to operate with fuels of low and high sulfur content, whereas lpSCR systems can only operate with fuels of 0.1%S content.

If fuels of high sulfur content are used the hpSCR unit needs to be operated in combination with a SOx Scrubber that reduces the sulfur oxide (SOx) emissions to the required limits.

Impact on Fuel Consumption

The use of an SCR unit introduces a small penalty to the fuel consumption of the engine, mainly due to the engine performance tuning strategies adopted when the engine switches from Tier II to Tier III mode and the SCR unit is engaged in operation. Between the two systems, the lpSCR and the hpSCR, the fuel consumption penalty is comparable, and is slightly less with the hpSCR system.

Space Requirements

The use of an SCR unit requires extra space for the catalyst block, and also additional space for all other auxiliary systems, such as the reducing agent (e.g. urea) storage tank, the dosing equipment, the soot blower equipment and the SCR heating system, if applicable.

Urea Solution Concentration and Consumption

Urea for the SCR system is used in the form of aqueous solution, typically at 40% concentration. The urea storage tank is to be protected from excessively high or low temperatures applicable to the particular urea concentration such as those specified in ISO 18611[22] for AUS 40. High temperature (i.e., greater than 35°C for AUS40) could considerably shorten the shelf life of urea while low temperature (i.e., 1°C for AUS40) may cause the crystallization of the urea solution.

Urea consumption is proportional to the amount of NOx reduction across the SCR catalyst. A typical consumption rate of 40wt% urea solution for NOx reduction from Tier II to Tier III at 100% engine load is around 18g/kWh.

Urea is not defined as a hazardous material but has corrosive effects.

Catalyst Expected Life

Considering the relatively high sulfur content in marine fuels, the SCR catalysts for marine engines are typically vanadium-based due to their resistance to sulfur poisoning and their performance and cost advantage over other catalysts. In the presence of high exhaust temperatures, approximately 550°C and higher (may vary by catalyst and engine), vanadium material can sublimate from the catalyst thereby reducing the NOx conversion efficiency. A test method could be adopted as the industry best-practice for identifying vanadium sublimation temperatures. At the time of certification, engine manufacturers may provide information identifying the vanadium sublimation temperature threshold for the specific catalyst product being used, along with their thermal management strategy for preventing that temperature from being exceeded during normal engine operation and use.

Thermal loading and catalyst poisoning are the main reasons that may reduce the efficiency of the catalyst over time. The volume of the catalyst element, exhaust gas flow velocity, layers of catalysts, fuel type and operating hours in Tier III mode affect the catalysts life.

To maintain the required efficiency of the SCR reactor, the catalyst needs to be replaced periodically according to the suppliers' recommendation, typically after a period of 3 to 5 years

Ammonia Slip

Overdose of reductant may reduce NOx emissions to lower than the expected concentrations, and may also result in ammonia slip, which should be limited to less than 10ppm. Excessive ammonia quantities increase the possibility of formation of ammonium bisulfate, which could clog the catalyst's elements but also deposit on surfaces and components downstream the SCR, along the exhaust duct, such as on the exhaust gas boilers.

RETROFITTING OF SCR FOR TIER III COMPLIANCE

In practice, NOx Tier III compliant technologies are defined and installed during a new construction, for ships keel-laid on or after January 1, 2016. Assessment of suitability and compatibility of the NOx Tier III technology is typically done during the design stage.

However, ships constructed on or after January 1, 2016 may not have planned for entering NOx ECA at the time of design or construction, therefore lacking a Tier III technology installation. If, for example, due to changes of the operating profile a vessel is required to enter NOx ECAs, it will be necessary to be equipped with a Tier III technology through retrofit.

The major challenges in such a case will be the modifications required to the engine and the space needed for accommodating the equipment and auxiliaries required to operate the chosen Tier III technology, as well as the verification process for NOx Tier III emission compliance.

Retrofitting of SCR systems is feasible, but is subjected to several factors of the already existing installation:

- The necessary space in the engine room and exhaust gas duct
- The layout of the turbochargers and auxiliary blowers (and the pressure drop, in case of a lpSCR) need to be evaluated and adjusted for SCR application. The SCR retrofit will most likely require re-matching of the turbocharger
- Verification of Tier III compliance (refer to Retrofit of SCR to Onboard Engine for NOx Tier III Compliance).

EXHAUST GAS RECIRCULATION

PRINCIPLE OF OPERATION

Exhaust gas recirculation (EGR) is the process where portion of the exhaust gases (about 30-40%) is redirected to the intake side of the engine and subsequently re-enters the cylinders. The recirculated exhaust gases reduce the oxygen (O_2) content and increase the concentration of carbon dioxide (CO_2) of the incoming air. As a result, peak combustion temperature reduces significantly due to the reduction of O_2 and the higher specific heat from CO_2 in the combustion air leading to reduced NOx formation. The drawbacks of this process are the reduced combustion efficiency and the increased particulate matter emissions.

The recirculated exhaust gases need to be cleaned and cooled prior to being introduced to the engine's air inlet system in order to prevent corrosion of the combustion chamber components and the EGR system components. The extent of cleaning depends on the sulfur content of the fuel used. EGR systems designed for fuels with maximum 0.10% sulfur content require a relatively simple water scrubbing unit and water handling system. However, engines that use high sulfur fuels (e.g. 3.5%S), a larger scrubber unit is integrated with the EGR system along with a more complex water handling system.

Fresh water is used to clean and cool the recirculated exhaust gas. The water needs to be treated to maintain its capability for cleaning, cooling and neutralizing the exhaust gas. Condensate from the combustion process accumulated in the EGR unit need to be drained and treated. Any water discharged to overboard is referred to as bleed-off water, and is subjected to the IMO Guideline, MEPC. 307(73), 2018 Guidelines for the Discharge of Exhaust Gas Recirculation (EGR) Bleed-Off Water[23].

SYSTEM CONFIGURATION

The typical EGR system applicable to 2-stroke slow-speed engines is the high pressure EGR system where the exhaust gases are taken before the turbocharger (i.e. at high pressure) and are recirculated to the scavenge air receiver.
An EGR system consists of several components integrated on the engine, such as:

- **EGR Scrubber** – to remove sulfur compound in the recirculated gas if EGR is designed for max. 3.5% sulfur fuel
- **EGR Cooler** – to cool the recirculated gas
- **Water Mist Catcher** – to eliminate entrained water droplets
- **EGR Blower** – to increase the pressure of recirculated gases to scavenge air receiver

A water handling system (WHS) is required in order to treat the cleaning (scrubbing), cooling water and the water drained from the EGR unit. Major components of the water handling system are:

- **Caustic soda tank and supply pump** – to add NaOH to cleaning/cooling water for neutralizing sulfur compound in the recirculated gas
- **Receiving tank and circulating pump** – to receive the cleaning/cooling water and condensate from EGR unit, and circulate to a buffer tank
- **Buffer tank and circulating water supply pump** – to temporarily store water coming out of the receiving tank, for further processing and recirculating to the EGR unit
- **Water treatment unit** – to treat the bleed off water from the buffer tank for discharging overboard or diverting the water to the drain tank, depending on the quality of treated water

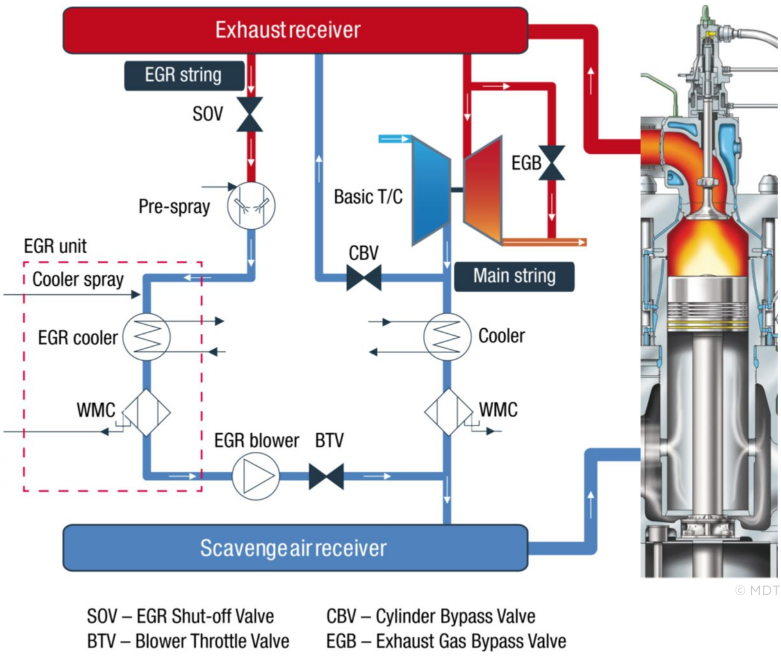


Figure 8: Sample of Exhaust Gas Recirculation System

The operation of an EGR system results in a small fuel penalty, which depends on the EGR configuration and the engine load.

Additional power is required for running the EGR blower and the water handling system. NaOH is consumed for neutralizing the accumulated sulfur in the EGR water.

Specific figures for the relevant consumptions associated with EGR operation, as listed below, need to be determined in consultation with the engine maker, taking into consideration the engine and EGR system installed and the operational parameters.

- Fuel consumption penalty
- Additional power consumption
- NaOH consumption
- Sludge generation
- Bleed-off water amount
- Fresh water consumption
- Additional cooling water for EGR
- Additional lubricating oil for EGR
- Additional compressed air

CONSIDERATION FOR EGR APPLICATION

The operation of EGR requires scrubbing/cleaning of the recirculated gases even when low sulfur fuel is used. However, this cleaning process does not ensure removal of all particulate matter from the recirculated gases with the possibility that some may re-enter the engine

Flexibility in Fuel Sulfur Content

EGR systems for 2-stroke slow-speed engines can be designed to operate on low (0.10%S) and high sulfur fuels (3.5%S), if needed. If fuels with high sulfur content are used the EGR unit needs to be operated in combination with a SOx Scrubber mounted in the exhaust duct further downstream of the turbocharger, in order to reduce sulfur oxide emissions down to the legislated limits.

EGR systems for 4-stroke medium-speed engines are available, but have extremely limited applications.

Impact on Fuel Consumption

The installation of an EGR system reduces the combustion efficiency of an engine and therefore increases fuel consumption.

In general, the fuel consumption penalty introduced by the use of an EGR when operating in Tier III mode is approximately 3% compared to operation in Tier II mode, which is slightly higher, by about 2%, than that introduced by the use of an SCR system.

An additional operating mode option that is available for engines equipped with EGR is the use of the Eco-EGR mode. In this mode a small quantity of EGR rate (about 10-15%) is used during operation in Tier II mode, which enables an increase in firing pressure by lowering combustion temperatures, leading to lower fuel consumptions. During Eco-EGR operation the fuel consumption in Tier II mode is improved by about 4% compared to the reference consumption of typical Tier II mode.

Space Requirements

The EGR system is an integral part of the engine which makes the installation compact compared to SCR.

Consideration is also needed for the installation of the NaOH tank, water handling unit, sludge storage and all other auxiliary systems.

Bleed-off Water Discharge and Sludge Handling

The bleed-off water may be retained onboard in holding tanks where zero overboard discharge is required. The bleed-off water from the holding tanks may be discharged overboard later when “en route”, provided all necessary discharge requirements are complied with.

At all times, the discharge of the bleed-off water must comply with the requirements of IMO MEPC 307(73), 2018 Guidelines for the Discharge of Exhaust Gas Recirculation (EGR) bleed-off water, as summarized below.

Bleed-off water when using fuel oil not complying with the relevant limit value in Regulation 14 of MARPOL Annex VI is subject to the same requirements for SOx scrubber wash water discharge as in IMO Guidelines MEPC. 259 (68).

Bleed-off water when using fuel oil complying with the relevant limit value in Regulation 14 of MARPOL Annex VI needs to be monitored for its oil content by a type approved oil content meter when "en route". Oil content of the discharge is not to exceed 15 ppm. When the EGR system (with compliant fuel) is operated in polar waters, ports, harbors or estuaries, the discharge of bleed-off water to the sea should comply with the MEPC.259(68) requirements.

MEPC 307(73) also addresses residues from EGR water treatment systems, and additives used on the bleed-off water.

Attention is also needed to the U.S. EPA Vessel General Permit (VGP[24]) requirements. ABS understand that the 2013 VGP requirements as in 2 .2 .26 for SOx scrubber washwater discharge may also be applicable to the bleed-off water discharge from EGR.

Sludge generated from the treatment of the EGR scrubbing water is to be kept onboard. It cannot be mixed with other sludge generated onboard and is to be disposed to shore reception facilities.

NaOH Consumption

NaOH consumption depends on engine size, engine load, fuel sulfur content, EGR ratio and the concentration of NaOH solution. A 50% NaOH solution is typically used. An estimation of NaOH consumption for a specific EGR application can be obtained from the Engine designer.

DUAL FUEL AND GAS FUELED (OTTO) ENGINES

PRINCIPLE OF OPERATION

In an Otto cycle engine (e.g. Low-Pressure DF engines), air and fuel are premixed during the compression stroke and the mixture is ignited by an energy source when the piston is near top dead center (TDC). The combustion starts by pilot fuel injection (or spark plug aided ignition, in 4-stroke engines) and is characterized by low peak combustion temperatures leading to significantly lower NOx emissions (reduction by approximately 85%) compared to those from a Diesel diffusion combustion process. The Otto cycle combustion process satisfies IMO NOx Tier III limit requirements without the need of any emissions abatement equipment (such as SCR or EGR).

On the other hand, DF engines that utilize the diesel cycle process for combusting the gas (e.g. High-Pressure DF engines) may benefit from some reductions of NOx emissions (about 30%, compared to Diesel) due to the relatively cooler combustion process, as opposed to diesel diffusion combustion, but the reduction is not sufficient to meet NOx Tier III requirements

CONSIDERATION FOR DUAL FUEL AND GAS FUELED ENGINE

The main benefits of gas fueled engines include:

- Due to the negligible content of sulfur in gas SOx emission requirements can be met without the need of SOx abatement systems
- For Otto cycle engines, NOx emission requirements can be satisfied without the use of any NOx abatement technologies
- Fuel consumption is relatively lower compared to that of liquid fuel, due to the higher efficiency involved

For the application of Otto cycle engines, particular attention is drawn to the following:

- Note that Tier III compliance without aftertreatment equipment is for gas mode only. Consideration to installing SCR equipment for compliance on fuel oil should be given. This may save operational problems if gas system repairs are protracted or where local regulations or enforcement require Tier III compliance on all fuels.
- Otto cycle engines currently achieve a relatively lower Brake Mean Effective Pressure – BMEP (17.3 bar) compared to that of Diesel engines (about 21 bar)
- Methane slip is an inherent characteristic of Otto cycle process and although currently unregulated, methane is a Greenhouse Gas (GHG) with significantly higher global warming potential than CO_2
- Pilot diesel fuel is required to start the combustion process, and this involves an additional diesel consumption
- Otto cycle combustion process is sensitive to gas quality, specifically to methane number (MN), which is a measure of the gas resistance to engine knock. A low methane number (< 80) may cause engine knocking
- The Otto cycle is sensitive to ambient conditions. Engine operation in hot and humid climates may cause engine knocking
- Transient response and operation in heavy-sea conditions may affect the stable operation of Otto cycle engines due to offsets from the desired air-fuel ratio

Table 2 provides a brief comparison of the three methods for IMO NOx Tier III compliance, the SCR, EGR and Otto cycle Engines.

	DF/Gas Fueled (Otto Cycle) Engine	SCR	EGR
Emission compliance	Compliance with both, NOx Tier III and SOx limits (gas mode only)	NOx Tier III	NOx Tier III
Space	Larger engine for same power output as Diesel	Requires sufficient space in engine room	Compact
Auxiliaries / Systems	Complicated fuel gas supply system (FGSS)	• Urea solution storage tank • Dosing unit • SCR control system • Soot cleaning system	• NaOH dosing system • Water handling system
Consumables	Pilot Fuel	• Urea • Catalyst replacement	• NaOH
Fuel consumption penalty	Highest penalty compared to SCR and EGR engines during Tier III mode operation	Lowest penalty compared to Otto and EGR engines	Lower penalty than Otto engine and higher than SCR engine

Table 2: Comparison of the different NOx Tier III compliance options

OTHER POTENTIAL OPTIONS

Other potential options for the reduction of NOx emission are possible, but many of the novel aftertreatment technologies are still at research development level only. The introduction of water into the combustion process, by various methods, is a long established NOx reduction technique, but in some cases will not be able to achieve the reduction of NOx emission required to meet IMO Tier III requirements independently, and may be applied in combination with other technologies. The general options for the reduction of NOx formation and emissions are based on the same primary engine combustion technologies, i.e., lowering the combustion temperature, through either the so-called wet method or dry method, or through secondary aftertreatment systems.

The wet method is to add water to the combustion process, using the water's higher heat capacity characteristics compared to air, to lower the combustion temperature thus the reduction of NOx formation and emission. The introduction of water has also been reported as providing direct fuel atomization improvements due to the lower vaporization temperature. The methods for introducing water could include the following:

- **Scavenge Air Moisturizing (Air Humidification)** - Water is introduced to the combustion air, which makes the high temperature air saturated. Water in saturated air reduces the peak temperature in the cylinder as water has higher heat carrying capacity than air. This option has the potential of NOx reduction by 30 to 60%
- **Direct Water Injection** - Water is injected into the cylinder directly. The water added will reduce the peak combustion temperature leading to reduction of NOx formation in cylinder. The NOx reduction potential by this method is between 40% to 50%
- **Fuel Emulsions with Water** - Fuel is blended with water forms fuel/water emulsion. With the added water, the peak combustion temperature is lowered to reduce the formation of NOx, similar as the process in direct water injection option. NOx reduction potential is typically up to 20%

Traditionally, one of the limitations of fuel emulsions achieving lower NOx emissions levels has been the quantity of fuel that can be supplied to the combustion chamber with the standard fuel injection equipment. However, the development of the MAN Energy Solutions dual fuel ME-LGI engine technology (originally developed for methanol and LPG DF applications) has opened the door to utilizing the second fuel injection system to deliver higher quantities of water into the combustion process when burning conventional fuel oils, and while retaining full engine power delivery capability. This opens the door for increasing the water content in the fuel oil emulsion to sufficiently high levels to achieve Tier III NOx emission levels.

The dry method is to alter or optimize the combustion process through one of the following technologies, which when combined with EGR, can meet IMO Tier III:

- Combustion chamber optimization
- Late fuel injection timing
- Variable valve timing,
- Electronic and common rail fuel injection equipment
- Miller cycle
- Turbocharger improvement
- 2-stage turbocharging
- High compression ratio

According to CIMAC document Number 28, 2008, Guide to Diesel Exhaust Emissions Control of NOx, SOx, Particulates, Smoke and CO_2, Seagoing Ships and Large Stationary Diesel Power Plant(25). the dry method could potentially reduce NOx by 15% to 40% compared to IMO Tier I level depending on the engine type and the method used.

SECTION 4 - SHIPBOARD SUITABILITY AND COMPATIBILITY

COMPATIBILITY WITH SULFUR COMPLIANCE OPTIONS

The compatibility concerns the NOx Tier III technology selected and the SOx emission compliance strategy chosen for ships operating in ECA.

Gas fuel or dual fuel engine in gas mode operating in Otto combustion process can meet both NOx Tier III and SOx emission requirements in ECA, therefore, no compatibility concerns for NOx and SOx abatement technology.

Four stroke generator engines for NOx Tier III compliance are typically through the installation and operation of lpSCR (although engines with EGR are available). Such installation may use high sulfur fuel since the temperature at the SCR is high enough to cope with the sulfur content in fuel, therefore is compatible with SOx scrubber installation.

For two stroke slow speed main engine. The possible combination for NOx Tier III and SOx compliance includes the following.

1) Main engine with lpSCR and ultra-low sulfur fuel oil (ULSFO, maximum 0.10% S) for ECA – Practical combination
    - The limited sulfur content in fuel will have less impact on the performance of catalyst
2) Main engine with hpSCR and ultra-low sulfur fuel oil (ULSFO, maximum 0.10% S) for ECA - Practical
    - The limited sulfur content in fuel will have less impact on the performance of catalyst
3) Main engine with hpSCR and high sulfur HFO (HSHFO) with EGCs in ECA - Practical combination.
    - The high temperature at the SCR will help to reduce the formation of ammonium bisulfate at the SCR, therefore reduce the impact on the performance of catalyst
4) Main engine with EGR and ultra-low sulfur fuel oil (ULSFO, maximum 0.10% S) for ECA - Practical combination.
    - The recirculated exhaust gas has less sulfur compound. Gas cleaning is required but need not to incorporate a SOx scrubber for the removal of SOx.
    - Water handling system is needed for the treatment of bleed-off water
5) Main engine with EGR and high sulfur HFO (HSHFO) with EGCs in ECA - Practical with restriction.
    - The EGR has to deal with higher sulfur compound in the recirculated exhaust gas by a built in SOx scrubber.
    - EGCS (SOx scrubber) is needed for SOx emission compliance may increase the back pressure on the engine

MAIN ENGINE NOx MEASUREMENT AND AMENDMENT OF NOx TECHNICAL FILE DUE TO SOx SCRUBBER RETROFIT

The introduction of a SOx scrubber to an exhaust system is expected to increase exhaust back-pressure by about 20 - 60mbar, depending on the scrubber unit design. To overcome the extra backpressure, the engine will need to deliver extra power and thus the increase of combustion temperature, which lead to higher NOx formation.

The increase in NOx depends on the amount of backpressure, engine design and engine tuning, and can be confirmed by NOx measurement or obtained based on engine maker provided data. If NOx needs to be reduced, engine tuning parameters may need to be adjusted, and even some hardware changes may need to take place. The NOx technical file is then to be revised accordingly. This will require a re-approval of the engine NOx certification by the Administration or RO responsible for the original certification.

To avoid the above process, when SOx scrubber is retrofitted, it is important to verify that the certified design and operational exhaust back-pressure limits specified in the engine NOx technical file are not exceeded.

EFFECT OF SCR ON EXHAUST GAS BOILER (EGB)

One issue associated with the operation of SCR is ammonia slip. The excessive ammonia increases the possibility of ammonium bisulfate deposits on the low temperature surface when it combines with sulfuric acid originated from sulfur in the fuel, for example on the downstream exhaust gas boiler.

When ultra-low sulfur fuel (max. 0 .10% s) is used, the formation of ammonium bisulfate deposits in the exhaust boiler is limited due to the low content of sulfur compound in exhaust gas. However, during SCR operation with higher sulfur fuel (>0 .10% S), the ammonium bisulfate deposits in the exhaust gas boiler could be significant when ammonia slip is high, and affect the passage of exhaust gas through the EGB.

FINANCIAL ASPECT

Different options for NOx Tier III compliance will have different impact on financial aspect in terms of CAPEX and OPEX. Among the three practical compliance options, i.e., dual/gas fuel engine operating in Otto combustion process, SCR and EGR, CAPEX for dual fuel/gas fuel option is the highest considering the cost of engine, gas fuel system, fuel containment system, and the cost for design and installation.

The CAPEX for SCR unit tends to increase for higher power installation. In general, for engine of 25,000kW or above, SCR costs more while CAPEX for EGR is typically higher for engine with lower power. hpSCR tends to have higher CAPEX than lpSCR.

SCR or EGR installation including piping and auxiliaries would typically increase the initial cost, i.e., CAPEX by 25% and 30% of the respective cost of SCR and EGR.

According to IMO Document MEPC 66/INF.4, the CAPEX is typically $40 to $135/kW for SCR installation and $55 to $82/kW for EGR installation.

OPEX for SCR is mainly on urea consumption and catalyst replacement. Typical urea consumption is about 7g/kWh. The price of urea varies around the world, ranging from $150/t to $400/t. Catalyst need to be replaced every 12,000 to 24,000 running hours. The replacement cost depend on the size of the SCR chamber and the number of catalytic elements, and can be as much as about $150,000 for each replacement.

For EGR, the OPEX is primarily due to the fuel penalty, additional electrical power demand for running auxiliaries (e.g., EGR blower and water treatment), disposal of sludge generated from recirculated gas cleaning and NaOH consumption. Engine manufacturers will provide the respective figures for each specific installation.

IMO Document MEPC 66/INF.4[26] indicate that the operational cost is typically about 7% to 10% of fuel cost for SCR, and 4% to 6% of fuel cost for EGR.

SECTION 5 - OPERATION CONSIDERATIONS

AUXILIARY CONTROL DEVICE (ACD) AND EPA POLICY

IMO Guidance MEPC.1/Circ.854[27] provides clarifications on the acceptance of auxiliary control devices (ACD) on dual fuel (DF) engine, covering starting and stopping, low load operation and maneuvering and reversing operation. Although the Guidance document targets Dual Fuel engines, the principle is also applicable to SCR installation on liquid fuel engines.

As defined under Regulation 2 of MARPOL Annex VI, an Auxiliary Control Device is a system, function or control strategy installed on a marine diesel engine that is used to protect the engine and/or its ancillary equipment against operating conditions that could result in damage or failure, or that is used to facilitate the starting of the engine.

For engines with SCR installation for NOx Tier III compliance, the Auxiliary Control Device is typically used to control SCR operation under the following situations:

- To disengage SCR or prevent SCR from being activated when engine operate at low load or during startup. At low load condition, exhaust temperature could be lower than minimum operation temperature in SCR reaction chamber. Operation of SCR will result in the formation of ammonium bisulfate that may cause catalyst clogging
- To temporarily reduce urea dosing to prevent ammonia slip during rapid transient load changes when the excessive urea will not be consumed for the catalytic reaction

As per MEPC .1/Circ .854, the Auxiliary Control Device features must be defined and included in the approved NOx technical file. The intent is that all features that limit gas mode operation, whether for engine protection or ancillary equipment protection must be clearly defined within the technical file, even if outside the steady state test points of the particular technical file.

The U.S. Environmental Protection Agency (EPA) have a keen interest in this and have issued guidance addressing the use of Auxiliary Control Device:

> *Any operation of an engine, where that engine deviates from its emission control strategy, is considered an Auxiliary Control Device (ACD) and must be disclosed when applying for engine certification (See Annex VI Regulations 2.4, 2.13, and 13.9). This includes the operation of a dual fuel or gas-fueled engine on liquid fuel during starting, stopping low load operation, and maneuvering and reversing operations (see MPEC.1/Circ.854, July 1, 2015). Consideration of ACDs for approval will be handled on a case-by-case basis during the certificate approval process.*

Please refer to EPA web pages on page 5 of this Advisory for latest information.

For the acceptance of the ACD based on case-by-case examination, it is expected that the operation of ACD/engines abide by the parameters of the EIAPP certificate and Technical files including threshold conditions when the NOx may be at Tier II instead of Tier III inside an ECA. The operational details under ACDs are to be included in Technical files.

In operation, the SCR will typically be disengaged when the Dual Fuel engine load is low, which can be below 25%. Engines tested to the E2 or E3 test cycles are not emissions load tested below 25% for demonstrating NOx Tier III compliance for the issuance of EIAPP certificate in accordance with the NTC. Auxiliary generator engines are emissions tested to the D2 test cycle, and as such are tested at the 10% load point. However the requirement that each node point of the (Tier III) test cycle does not exceed the speed related NOx limit by 50%, is not applicable to the 10% load point. The actual point at which an SCR will need to be disengaged will vary by engine load and by engine design.

Neither the IMO document nor EPA FAQ explicitly specify the conditions for the acceptance of the use of the Auxiliary Control Device.

ANNUAL SPOT CHECK MEASUREMENTS FOR SCR SYSTEMS

For evaluating the installation of SCR for the continued NOx emission compliance during annual survey, the catalyst NOx reduction efficiency needs to be assessed.

Factors related to the deterioration rate of SCR performance, e.g. exchange condition for SCR catalyst blocks and recommended exchange time of SCR catalyst blocks are to be included in Technical Files.

Where a feedback or a feed forward reductant control strategy is incorporated with a NOx measurement device, this is acceptable as a means of monitoring catalyst condition/degradation. The exchange criteria of catalyst blocks against the reading of the NOx measurement device is to be specified in the Technical Files. (3.2.8.1 of MEPC. 291(71)).

Where a feed forward reductant control strategy is adopted without a NOx measurement device, the following details are to be provided in the Technical Files:

- The expected deterioration curve under expected operating conditions or the life of catalyst under expected operating conditions;
- Factors which can influence catalyst NOx reduction efficiency; and
- Guidance on how to assess catalyst NOx reduction efficiency based on periodical spot checks or monitoring as specified by the applicant, if applicable; records are to be kept for inspection during annual, intermediate and renewal surveys. The frequency of periodical spot checks is to be defined considering the expected deterioration of the catalyst. The frequency for spot-checks should be at least after installation and once every 12 months (3.2.8.2 of MEPC. 291(71)).

Other strategies on monitoring the catalyst condition/degradation are subject to the approval of the Administration.

U.S. EPA issued a Guidance for the Certification of Diesel Engines Equipped with Vanadium-based SCR Catalyst. Please refer to the web pages listed on page 5 of this Advisory. EPA recommended the adoption of a test method as the industry best-practice for identifying vanadium sublimation temperatures. At the time of certification, engine manufacturers are expected to provide information identifying the vanadium sublimation temperature threshold for the specific catalyst product being used, along with their thermal management strategy for preventing that temperature from being exceeded during normal engine operation and use.

TIER II/III CHANGEOVER/ON-OFF RECORDING REQUIREMENTS

The marine diesel engines installed onboard a ship subject to NOx Tier III requirements are typically certified to both Tier II and Tier III. If any onboard engines are certified to Tier II only, such engines should not operate in NOx ECA.

The tier status of the engines need to be recorded in a logbook as prescribed by the Administration at entry into or exit from an ECA, or when the on/off status changes within such area, together with the date, time and position of the ship, in accordance with Regulation 13/5.3 of MARPOL Annex VI.

Typical operational conditions for entering and operating within ECA may include:

- Change over from Tier II to Tier III mode
- Starting of additional generator engine for load requirement
- Starting of diesel power pack for cargo operations
- Shutdown of Tier II only certified engines

IMO does not have specific requirements for the format of the logbook for the purpose of recording NOx Tier changeover or on/off status. Hence many operators developed a simple dedicated engine record book to provide a simple survey reference document.

IMO adopted Guidelines for the use of Electronic Record Books under MARPOL (Resolution MEPC. 312(74)) and also accept electronic record books for NOx Technical Code as per MEPC. 317(74). However, they are not applicable to Tier status record. Owner/operator may confirm with Flag for the acceptance of their proposed format since Regulation 13/5.3 state "…logbook as prescribed by the Administration".

ABS SUPPORT

The selection of exhaust emission abatement equipment is intrinsically linked to the prime mover and power generation technologies, fuels and applicable air emissions regulations.

For reaching an informed decision for the selection, ABS can assist owners and operators with reviewing the appropriate compliance options given the specific operating profile for each of their vessels, and support owners and operators with understanding of available technology, life-cycle costs and operational impact.

These services aim to help clients tackle the rapidly changing marketplace, operational, environmental, safety and regulatory dynamics.

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22. ISO 18611 Ships and Marine Technology – Marine NOx Reduction Agent AUS 40
23. MEPC. 307(73), 2018 Guidelines for the Discharge of Exhaust Gas Recirculation (EGR) Bleed-Off Water
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25. CIMAC Guide to Diesel Exhaust Emissions Control of NOx, Sox, Particulates, Smoke and CO_2, Number 28/2008
26. MEPC. 66/INF, Information about the Application Status of Tier III Compliant Technologies
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APPENDIX I: FREQUENTLY ASKED QUESTIONS

CAN ABS APPROVE AND CERTIFY ENGINE AIR EMISSIONS TO MARPOL ANNEX VI AND EPA LIMITS?

ABS undertake the witness of diesel engine emissions test, approves technical files and issues EIAPP (Engine International Air Pollution Prevention) Certificates to MARPOL Annex VI Regulation 13 and the NOx Technical Code in its role as a Recognized Organization on behalf of the majority of the world's flag Administrations.

For US Flagged vessels, only the U.S. EPA can certify diesel engines as meeting the applicable United States Code of Federal Regulations (CFR) emissions limits. Recognized Organization (RO), such as ABS, is not in the position to approve or stamp NOx technical files for engines on US vessels, neither may a RO witness emissions test that is conducted for purposes of EPA engine pre-certification, nor issue statement of voluntary compliance (SOVC) for engines on US vessels.

DO ALL INSTALLED ENGINES NEED TO BE CERTIFIED AS MEETING THE IMO TIER III LIMIT?

All marine diesel engines over 130kW installed on vessels constructed on or after January 1, 2016 operating in North American ECA and the U.S. Caribbean Sea ECA, or ships constructed on or after January 1, 2021 operating in Baltic Sea and North Sea ECAs are to comply with IMO Tier III emission limit except engines solely used for emergency application such as engines for emergency generators, emergency fire pumps and engines installed in lifeboats. However, diesel engines used to drive external fire monitor pumps on firefighting vessels are not eligible for exemption unless advised otherwise by the Administration.

For US Flagged vessels, the USCG defers the enforcement of IMO Tier III on qualified ships and engines under Work Instruction (WI) CVC-WI-014(1) dated October 17, 2018; only engines in the range of 130kW to 1400kW qualify under this Work Instruction. In lieu of meeting IMO Tier III performance standards, engines with rating of 130 kW to 600 kW installed on ships with keel-laying date on or after January 1, 2016 may instead be certified by the EPA as meeting the Clean Air Act Tier 3 requirements under 40 CFR part 1042. Such engines that are not capable of meeting IMO Tier III but certified by EPA as meeting EPA Tier 3 requirements are accepted by EPA till engines within the power range that are capable of meeting IMO Tier III requirements are available.

CAN A DIFFERENT ENTITY TO THE ENGINE BUILDER SUPPLY A SCR SYSTEM?

SCR as a NOx reduction devise is typically manufactured and supplied separately from the engine. When SCR is fitted for meeting NOx emission limit, the SCR must be considered as a component of the engine it serves for the purpose of EIAPP certification.

Pre-certification of engine systems fitted with SCR is to be in accordance with the procedures provided by certification Scheme A or Scheme B of IMO Guidelines MEPC. 291(71) as amended by MEPC. 313(74).

Regardless of Scheme A or Scheme B, there should be only one applicant for the Tier III certification, who is the entity for the complete engine system fitted with SCR, as summarized below:

- One owner of "engine + SCR"
- One applicant owning the "engine + SCR" for the EIAPP certification
- One technical file for "engine + SCR", and
- One EIAPP certificate for "engine + SCR"

IS A NOx EMISSIONS MONITORING SYSTEM REQUIRED TO VERIFY ANNEX VI COMPLIANCE?

The IMO does not require a NOx emission monitoring system to be installed for the verification of NOx emission.

For the verification of compliance with the NOx emission limits, it is necessary to confirm that the engine's components, settings and operating values have not deviated from the specifications documented in that engine's Technical File.

For engine family members it will be sufficient to confirm that any maintenance and/or replacement of NOx sensitive components is in compliance with the Technical File specifications

In the case of engine group members any one of the following three methods may be used except that the direct measurement and monitoring method is not permitted for the initial survey.

- Engine Parameter Check Method
- Simplified Measurement Method
- Direct Measurement and Monitoring Method

Chapter 2 of NTC 2008 provide the detailed information on the above options. MEPC. 103(49) provides guidelines for on-board NOx verification procedure for direct measurement and monitoring method.

UNDER THE PARAMETER CHECK METHOD HOW DOES A SURVEYOR OR PORT STATE CONTROL OFFICER VERIFY ANNEX VI COMPLIANCE?

The engine parameter check method shall be carried out in accordance with chapter 6.2 of the NOx Technical Code in order to verify that an engine's components, settings and operating values have not deviated from the specifications in the engine's Technical File.

This method is likely to consist of a visual examination for the initial survey with visual examination and/or document check at subsequent surveys. The document check would consist of a review of the entries in the "Record Book of Engine Parameters" which is the document for recording all parameter changes, including components and engine settings, which may influence the NOx emission of the engine. The "Record Book of Engine Parameters" has no set format and it will be up to individual Administrations to specify the layout (if any) of such a document and how it is to be maintained.

The two procedures for the parameter check method include:

- A documentation check of engine parameters including check of record book of engine parameters, and
- An actual check of engine components and adjustable features as necessary

WHAT DETERMINES IF COMPONENT CHANGES ARE A 'MAJOR CONVERSION/SUBSTANTIAL MODIFICATION', AS DEFINED, UNDER ANNEX VI AND THE NOX TECHNICAL CODE?

Any changes to an engine over 130 kW (not solely used for emergency purpose) relative to components identified in Technical File that could feasibly affect NOx emissions are considered as a major conversion/ substantial modification as defined in the NOx Technical Code.

Examples of such modifications are, but not limited to:

- The maximum continuous rating of the engine is increased by more than 10% compared to the maximum continuous rating of the original certification of the engine
- Engine specification including number of cylinder's, bore size of cylinder liners, stroke
- Fuel injection equipment
- Turbocharger
- Charging air cooler
- Cylinder control unit
- Engine control unit
- Scavenge control unit
- SCR chamber, mixing pipe, nozzle injector, urea dosing and supply unit, SCR control unit and catalyst

NOx CRITICAL COMPONENTS. WHAT IS THE STATUS OF NON-OEM COMPONENTS?

Technical Files include details of the NOx critical component, IMO markings and Conformity of Production arrangements for replacement parts. The approval of this is supported by documentation submitted to the RO when approving the engine family/group and the individual engine. In the case of fitting alternative (i.e. non-OEM) NOx critical component to a certified engine it is ultimately for the shipowner to demonstrate that the fitting of such components does not represent a 'substantial modification' as defined within the NOx Technical Code. In practice this demonstration would normally be provided by the party proposing the introduction of such new design components.

WHAT IS METHANE SLIP?

Methane slip is a general term used for the direct emission of methane to the atmosphere during production of natural gas for energy purposes, but also used to describe the emission of methane to the atmosphere during the operation of natural gas fueled ships. Methane is a potent global warming gas, according to the UN IPCC 5th Assessment Report, methane is categorized with a GWP of 84 times that of CO_2 on a 20-year basis and 28 times that of CO_2 on a 100-year basis. Safety system actions, such as triggering an engine to trip from gas mode operation to oil mode operation, normal changeover operations between fuel modes, fuel tank relief valve operation, fuel supply line purging and bunkering are all sources of operational methane slip for gas fueled ships. However, one of the most significant emissions of methane for gas fueled ships is that direct to the exhaust from the passage of unburned hydrocarbons to the exhaust stream from low pressure Otto process gas and DF engines. This is inherent with Otto cycle gas or Dual Fuel engines and originates from incomplete combustion, valve overlap and combustion chamber crevice volumes. There are scientific studies that indicate using natural gas as a fuel can have an overall lower CO_2 footprint than conventional fuels, but there are also studies that indicate the opposite. At present this emission is not regulated by IMO. However, the IMO initial Green House Gas reduction strategy adopted at MEPC in April 2018 has pushed the issue of marine Green House Gas emissions to the front of the agenda. IMO has indicated that the workplan will consider and analyze measures to address emissions of methane and develop robust lifecycle Green House Gas/carbon intensity guidelines for all types of fuels. Consideration of the full production and use chain, from well-to-funnel, therefore becomes critical to assessing the overall Green House Gas footprint of any fuel to be considered. It is important to note that methane slip to the exhaust is not an issue for High Pressure engines using the Diesel combustion process. Furthermore, other fuels being considered, such as methanol, LPG and ethane are not considered global warming gases.

WHY DO SOME GAS ENGINES MEET TIER III NOx LIMITS WITHOUT AFTERTREATMENT?

NOx formation is linked to peak combustion temperatures.

In Otto cycle engine, air and fuel is compressed on the compression stroke and ignited by an energy source near top dead center (TDC). The combustion commences by spark ignition or pilot injection result inherent lower peak combustion temperature and pressure. This means that Dual Fuel engines using the lean burn Otto process to burn natural gas or alternative fuels such as methanol, ethanol, liquid petrol gas (LPG) or dimethyl ether (DME) have much lower NOx emissions than those using the diesel diffusion combustion process

Therefore, the Otto process gas engines can meet the current IMO NOx limits without emissions abatement equipment.

WHAT ARE THE RECORD BOOK REPORTING REQUIREMENTS FOR TIER III WHEN A SHIP ENTERS AN ECA?

The marine diesel engines installed onboard a ship subject to NOx Tier III requirements are typically certified to both Tier II and Tier III. If any onboard engines are certified to Tier II only, such engines should not operate in NOx ECA.

The tier status of the engines need to be recorded in a logbook as prescribed by the Administration at entry into or exit from an ECA, or when the on/off status changes within such area, together with the date, time and position of the ship in accordance with Regulation 13/5.3 of MARPOL Annex VI.

Typical operational conditions for entering and operating within ECA that need to be record may include:

- Change over from Tier II to Tier III mode
- Starting of additional generator engine for load requirement
- Starting of diesel power pack for cargo operations
- Shutdown of Tier II only certified engines

WHAT IF THE MEANS OF TIER III COMPLIANCE IS OPERATING ON NATURAL GAS AND THERE IS EQUIPMENT FAILURE?

NOx emissions during operation on pure liquid fuel resulting from restricted gas supply in cases of failure under paragraph 1.3.10 of the NOx Technical Code 2008 should be exempted for the voyage to the next appropriate port for the repair of the failure should follow regulation 3.1.2 of MARPOL Annex VI. This would indicate that if such failure prevents operation on gas fuel, the ship should take reasonable precautions to minimize emissions by operating at Tier II NOx levels, if feasible. It should be noted that non-availability of gas fuel under regulation 18 of MARPOL Annex VI is not regarded as a failure in this provision.

According to Regulation 5.6 of MARPOL Annex VI, whenever an accident occurs to a ship or a defect is discovered that substantially affects the efficiency or completeness of its equipment covered by this Annex, the master or owner of the ship shall report at the earliest opportunity to the Administration, or a nominated surveyor or recognized organization responsible for issuing the relevant certificate. Failure of equipment that is vital for complying with MARPOL Annex VI therefore needs to be reported to the flag Administration at the earliest opportunity. This is particularly relevant for application of regulation 13 controlling NOx emissions from internal combustion engines and subject to the Tier III NOx limits and operating in a NOx Emission Control Area.

Note also that not having a means to comply with the Tier III NOx limits with all fuels may also have commercial implications and limit operation in the event that the scheduling of repairs is protracted or where local regulations or enforcement require Tier III compliance on all fuels. Consideration to installing SCR equipment for compliance on fuel oil should therefore be given.

FOR GAS ENGINES IT IS KNOWN THAT THEY MAY NOT BE AS STABLE AS DIESEL ENGINES, PARTICULARLY AT LOW LOAD OR UNDER TRANSIENTS. HOW DOES THIS AFFECT CERTIFICATION AND OPERATION?

On such engines, some exceptions to gas mode operation will occur that require using liquid fuel, such as the following cases:

- Starting and stopping low load operation
- Reversing operations
- Maneuvering in low load operations

The above operation of an engine, where that engine deviates from its emission control strategy, is considered an Auxiliary Control Device (ACD) and must be disclosed when applying for engine certification and denoted in the engine's Technical File.

WHAT ARE AUXILIARY CONTROL DEVICES?

An ACD means a system, function or control strategy installed on a marine diesel engine that is used to protect the engine and/or its ancillary equipment against operating conditions that could result in damage or failure, or that is used to facilitate the starting of the engine. IMO Guidance MEPC.1/Circ.854 provides clarifications on the acceptance of auxiliary control devices (ACD) on dual fuel (DF) engine, covering starting and stopping, low load operation and maneuvering and reversing operation. Although the Guidance document targets Dual Fuel engine, the principle is also applicable to SCR installation on liquid fuel engines.

HOW IS THE CERTIFICATION AND OPERATION IMPACTED WHEN A SCR TAKES A LONG TIME TO REACH OPERATING TEMPERATURE AND THE EXHAUST TEMPERATURES ARE TOO LOW FOR OPERATION AT LOW LOAD OR WHEN MANEUVERING.

For engines with SCR installation for NOx Tier III compliance, the Auxiliary Control Device is typically used to control SCR operation under the mentioned situations:

- To disengage SCR or prevent SCR from being activated when engine operate at low load or during startup. At low load condition, exhaust temperature could be lower than minimum operation temperature in SCR reaction chamber. Operation of SCR will result in the formation of ammonium bisulfate that may cause catalyst clogging
- To temporarily reduce urea dosing to prevent ammonia slip during rapid transient load changes when the excessive urea will not be consumed for the catalytic reaction

As previously mentioned, the ACD must be disclosed when applying for engine certification and denoted in the engine's Technical File. The operation of ACD/engines should abide by the parameters of the EIAPP certificate and Technical files including threshold conditions when the NOx may be at Tier II instead of Tier III inside an ECA. The operational details under ACDs are to be included in Technical files.

LIST OF ACRONYMS

ABS	American Bureau of Shipping
ACD	Auxiliary Control Device
CARB	California Air Resource Board
CAPEX	Capital Expenditures
CCR	California Code of Regulation
CFR	Code of Federal Regulations
CI	Compression-Ignition
CIMAC	International Council on Combustion Engines
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DF	Dual Fuel
DME	DiMethyl Ether
DPF	Diesel Particulate Filter
ECA	Emission Control Area
EEA	Exhaust Emission Abatement
EEDI	Energy Efficiency Design Index
EEZ	Exclusive Economic Zone
EGB	Exhaust Gas Boiler
EGCS	Exhaust Gas Cleaning System
EGR	Exhaust Gas Recirculation
EIAPPC	Engine International Air Pollution Prevention Certificate
EPA	Environmental Protection Agency
EU	European Union
GHG	Green House Gas
GWP	Global Warming Potential
HC	Hydrocarbon
HFO	Heavy Fuel Oil
HSHFO	High Sulfur Heavy Fuel Oil
hpSCR	High Pressure SCR
IACS	International Association of Classification Societies
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Organization for Standardization

LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
lpSCR	Low Pressure SCR
MARPOL	Marine Pollution (IMO)
MCR	Maximum Continuous Rating
MEPC	Marine Environment Protection Committee (IMO)
MVR	Marine Vessel Rules
NGO	Non-Governmental Organization
NMA	Norwegian Maritime Authority
NMHC	Non-methane Hydrocarbon
NRMM	Non-Road Mobile Machinery
NOK	Norwegian Krone
NOx	Nitrogen Oxides
NTC	NOx Technical Code
NTE	Not To Exceed
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditure
PM	Particulate Matter
PPM	Parts Per Million
PPR	Pollution Prevention and Response (IMO sub-committee)
RO	Recognized Organization
SCR	Selective Catalytic Reduction
SOLAS	International Convention for the Safety of Life at Sea, 1974, as amended (IMO)
SOx	Sulfur Oxides
UI	Unified Interpretation
ULSFO	Ultra Low Sulfur Fuel Oil
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UR	Unified Requirement
USCG	United States Coast Guard
WI	Work Instruction

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