EMISSIONS FROM MARINE ENGINES VERSUS IMO CERTIFICATION AND REQUIREMENTS OF TIER 3

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Abstract

The emission of noxious substances from combustion of marine fuels is restricted in respect of the atmosphere protection and International Maritime Organization (IMO) regulations. The IMO requirements were determined by time of being in force. The first tier started in 2000 year, the second in 2011, the third will be valid from 2016 and it will be a necessity to comply those last requirements. In case of NO_x – between the first and second tier the emission was limited 20%, while the next step will be limited 80% of the first. This is a very great challenge; because in nowadays marine diesel engines and marine heavy and diesel oils generally applied, it would seem impossible comply those requirements. It was formed environmental controlled areas of NO_x emission (ECA) and they will extend. It was determined controlled areas of SO_x (SECA). Governments of some countries (USA, Norway) were introduced on own territorial waters the requirements of NO_x and SO_x emission. In case of exceeding the limits (or a lack of the proper certificate) it was imposed an ecological charge (a form of tax). In Norway from this charge it was created a fund. It is possible to receive a subvention for some actions like an exchange of marine equipment for new one with proper certificate. In the paper it was given an attention to the waiting new challenges for engine producers and ship-owners of fulfilling tier 3 standards or search new substitute solutions.

Keywords: *emission, marine engines, IMO requirements, tier 3*

1. Initial remarks

The emission of noxious substances from combustion of marine fuels is restricted in respect of the atmosphere protection and International Maritime Organization (IMO) regulations [1]. The IMO requirements of Marpol Convention Annex VI were determined by time of being in force. The first tier started in 2000 year, the second in 2011, the third will be valid from 2016 and it will be a necessity to comply those last requirements (Fig. 1). In case of NO_x – between the first and second tier the emission was limited 20%, while the next step will be limited 80% of the first (Fig. 2). This is a very great challenge because in nowadays marine diesel engines and marine heavy and diesel oils generally applied, it would seem impossible comply those requirements.

The emission levels have been lowered largely by reducing the maximum combustion temperatures. This has involved a combination of measures:
- early inlet valve closing (Miller timing),
- optimization of the combustion chamber,
- optimization of the fuel injection equipment [6].

This has reduced NO_x emissions about 20-40% with only a marginal decrease in efficiency or none at all but it has to fulfil only the tier 2. The fulfilment of tier 3 needs the cleaning combustion gas process. The next problem is SO_x emissions (Fig. 3).

The simplest way is decreasing the sulphur content in the fuel. So from 2012 it will reduce the sulphur content in HFO (heavy fuel oils) to 3.5% (on SECAs areas to 1%) and consequently from 2015 on SECAs areas to below 0.1% and from 2020 global to below 0.5% of sulphur. Now in

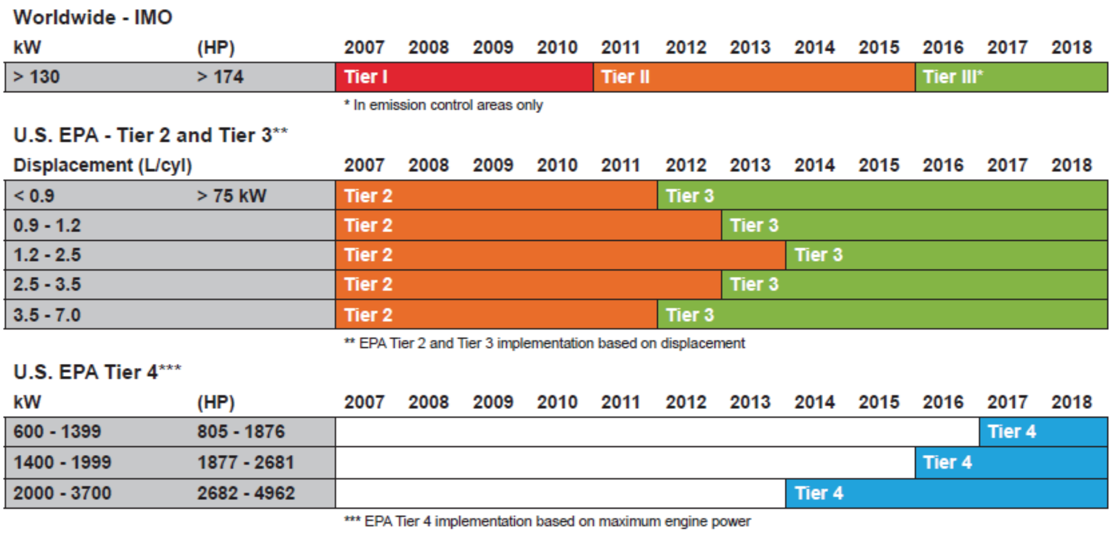


Fig. 1. Timetable of limited emissions depends on the world region [3]

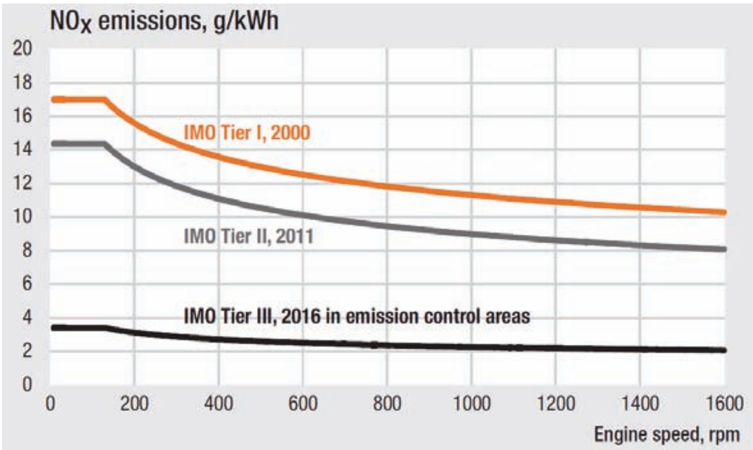


Fig. 2. NO_x emissions according to Marpol Annex VI requirements [1, 6]

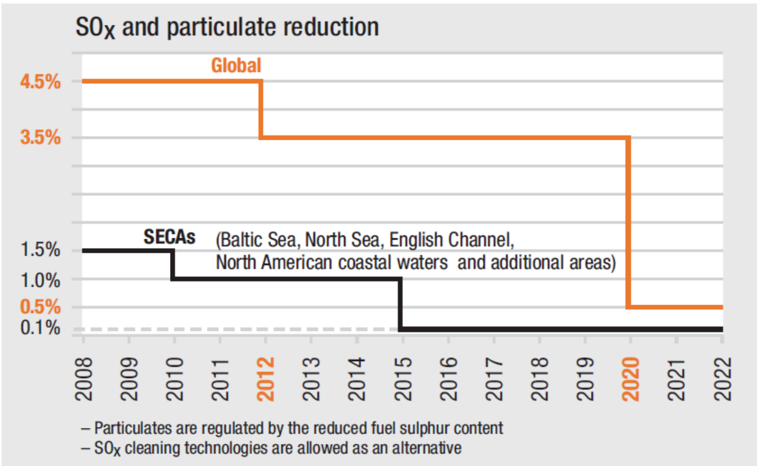


Fig. 3. The requirements of SO_x and particulate reduction [1, 6]

2011 we have a few types of fuel on board and use this type of fuel depending on the sea area where the ship is. It complicates the fuel system because each type fuel installation must be independent from bunkering installation through storage tanks, transport installation, settling and daily tanks. In time advance it must be remembered to change the fuel type on supplying installation to the engines.

2. Nowadays situation and practice on SECA's areas

It was determined controlled areas of SO_x and NO_x (SECA area). Governments of some countries (USA, Norway) were introduced on own territorial waters the requirements of NO_x and SO_x emission. In case of exceeding the limits (or a lack of the proper certificate) it was imposed an ecological charge (a form of tax). In Norway NO_x emissions fee was in force since January 1st, 1997. Initially the fee was set to 15 NOK/kg NO_x (for engines over 750 kW), most likely to increase up to 50 NOK/kg towards year 2010. The geographical area is limited to "Norwegian waters" as describes in Gothenburg protocol in 1997. The fee will have to be paid monthly to marine administration (Toll-og avgiftsdirektoratet). The fuel consumption and NO_x factor are the basis of the fee calculation. For vessels without documentation of emission level (either an EIAPP certificate or an approved emission measurement) a standard NO_x factor will be used. From this charge it was created a fund. It is possible to receive a subvention for some actions like an exchange of marine equipment for new one with proper certificate.

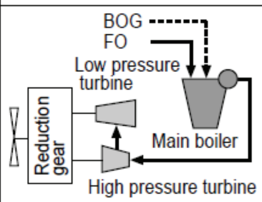
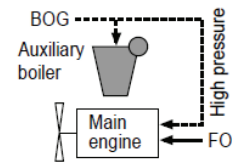
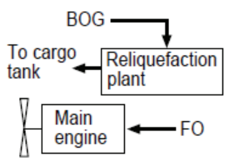
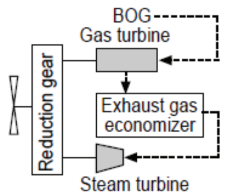
On all SECA areas it is a necessary to use required fuel type with low sulphur quantity (Fig. 3) with problems mentioned above. The other possibility to fulfil the emissions requirements is a use of exhaust gases cleaning systems from NO_x , SO_x and particulates up to fulfil the IMO tier 3 [2]. The systems must have an approved emission measurements. It has been built marine diesel engines with proper cleaning systems (Fig. 4) but the solution to the problem is increasing the investment and operational costs.

3. Possibilities of lowering of exhaust gases emissions

The lowering of exhaust gas emissions is obligatory on ECA and SECA areas according to the Marpol Annex VI requirements (Fig. 1, 2) and in the future worldwide in all sea areas.

The levels of tier 2 and tier 3 may be fulfilled on LNG carriers depending of propulsion plant and use of fuel type (Tab. 1).

Tab. 1. Comparison of propulsion plants for LNG carrier [4]

Propulsion plant		Steam turbine engine	Dual fuel diesel engine	Diesel engine with reliquefaction plant	Gas combined cycle
Plant configuration					
Advantages		•Most LNG ships adopt and reliability is high •100% of BOG can be fired during voyage	•Fuel efficiency is better •BOG can be used as fuel	•Fuel efficiency is better •The cargo part and engine part can be separated	•Fuel cost is better compared with that of the steam turbine engine
Disadvantages		•Fuel efficiency is low	•Exclusive BOG burning is impossible •BOG can not be fired at a low output	•Heavy fuel oil consumption is high •Electric power for driving reliquefaction plant is required	•High quality fuel oil is required •Dual fuel burning is impossible
Economy	Initial investment	100	105	105	104
	Fuel efficiency (fuel)	100 (BOG + HFO)	67 (BOG + HFO)	65 (HFO)	79 (BOG or Gas Oil)
Discharge gases	CO_2	100 (87)	66	77	73
	NOx	4 (3)	100	99	10
	SOx	67 (0)	43	100	0

(Note) Numerals in parentheses are those in the case of BOG exclusive combustion

During burning the BOG (boil-off gas) or vaporized gas from cargo tanks the emissions of CO_2, NO_x and SO_x are decreasing because of gas fuels combustion. In the tab.1 it was presented the propulsion plant configuration, characteristics, economy of each plant. The steam turbine has been adapted to most LNG carriers because it has been burnt all BOG in boilers as a fuel without the reliquefaction plant. Its reliability is high because both BOG and HFO are combustible as fuel for main boilers. In the dual fuel diesel engine the dual fuel burning of BOG and HFO is possible and fuel efficiency is better but the high pressure injection is required when the BOG is introduced to the engine. There is also a disadvantage of needed MDO fuel for pilot burning. Flexibility is inferior because exclusive BOG combustion is impossible and moreover in the diesel engine a large quantity of NO_x is discharged due to the high combustion temperature. In the diesel engine with reliquefaction plant, the propulsion engine and BOG handling are perfectly separated. In this case more emissions are discharged due to the HFO fired diesel engine. In the gas combined cycle the BOG is fired in the gas turbine. The steam turbine is driven by steam generated by the exhaust gas energy from gas turbine. There is needed a high quality fuel MDO or MGO (expensive fuels) so the emission is lowering and is like the same from the steam turbine plant. This system is a proposition with an electric propulsion plant for the largest LNG carriers.

The tier 2 level of exhaust gas emission is obligatory worldwide from ships built after January 1st 2011. From 2016 the tier 3 will be obligatory on ECA areas. From 2012 in the HFO it will be needed the fuel sulphur content reduction to 3.5% and from 2020 to only 0.5% (Fig. 3). From 2015 in the HFO the sulphur content must be below 0.1% on SECA areas. SO_x cleaning technologies are allowed as an alternative. If we know what to do in the future with complying the SO_x emission there is still a problem with NO_x emission to comply the future requirements. It seems that only gas fuels (like LNG) used as marine fuel may fulfil separately the requirements [5]. In that case the next problem will be the access to the LNG as a bunker fuel in ports, especially needed on ECA areas. There are three possibilities of IMO Tier 3 strategy presented on Fig. 4-6 [7] and effects were presented on Fig. 7.

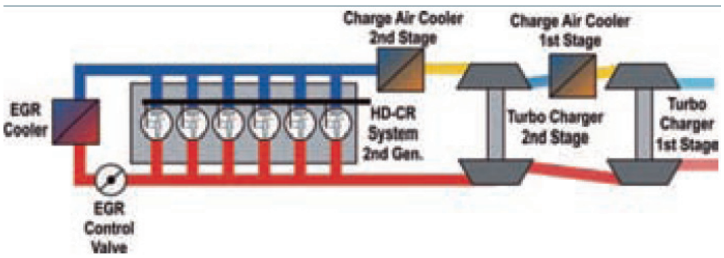


Fig. 4. Basic layout of an EGR-based IMO Tier 3 strategy [7]

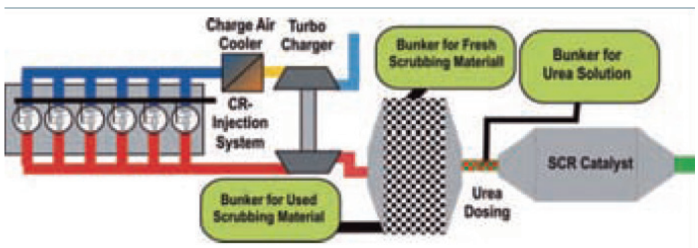


Fig. 5. Basic layout of an IMO Tier 3 strategy based completely on complex exhaust gas after treatment [7]

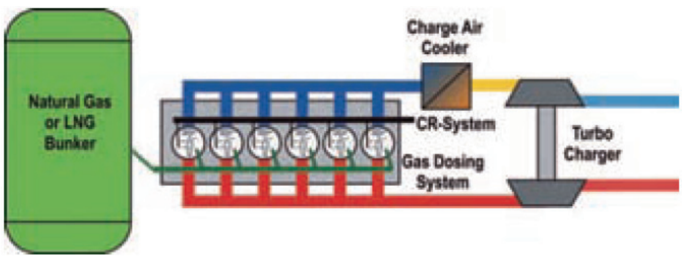


Fig. 6. Basic layout of a gas-operation based IMO Tier 3 strategy [7]

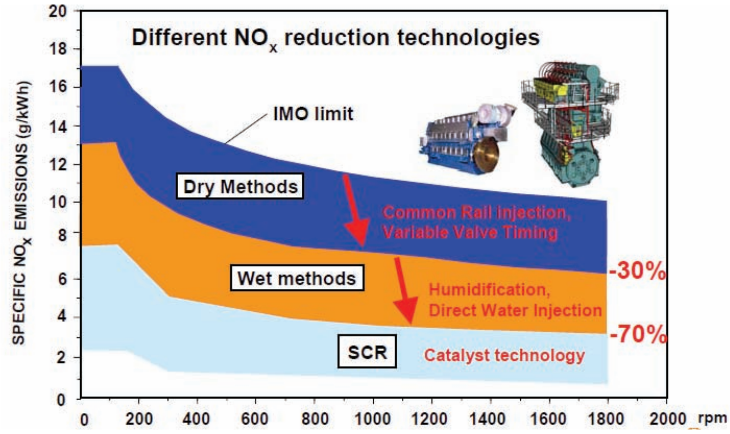


Fig. 7. Possibilities of NO_x reduction due to different technologies [9]

The decision of choose the most convenient IMO Tier 3 strategy belongs to the ship-owners. An example of proposition the after treatment technology was presented on Fig. 8.

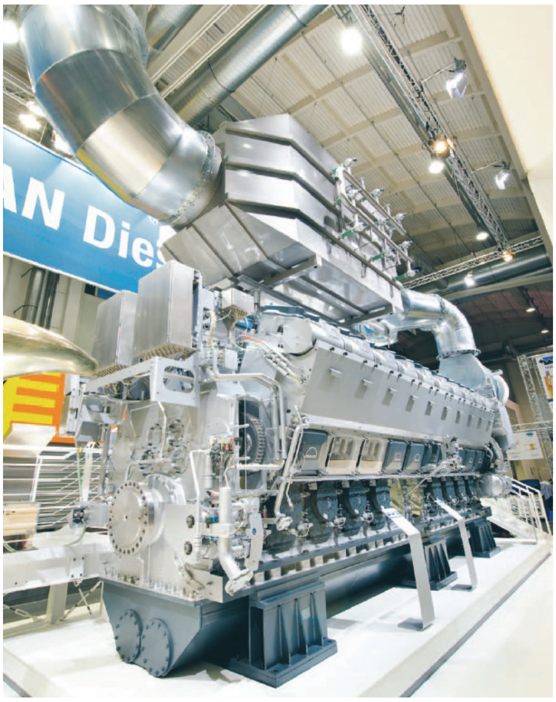


Fig. 8. The 32/44CR engine with SCR pictured at MAN Diesel & Turbo's stand at the SMM Trade exhibition in Hamburg [12]. The engine cracks IMO Tier 3

Depending on the type of ship, the trade route and the strategies of the ship operators, the principle-based advantages and disadvantages of the different strategies may evaluated differently. The future shows the best solution. Maybe different strategies may appear on the marine market.

4. IMO certification of exhaust gas emissions

Annex VI of MARPOL 73/78 "Regulations for the Prevention of Air Pollution from Ships", requires all ships of 400 gross ton or above, and platforms and drilling rigs engaged in voyages, to obtain an International Air Pollution Prevention (IAPP) certificate. The Annex will enter into force 2005-05-19 and will have an immediate effect on ships constructed (keel laid) on or after this date.

Ships constructed (keel laid) before 2005-05-19 are required to comply with Annex VI on the first scheduled dry docking after this date, but in no case later than 2008-05-19.

In order to obtain the IAPP Certificate, Annex VI has requirements to the following:

- Ozone depleting substances from refrigerating plants and fire-fighting equipment,
- Nitrogen Oxides (NO_x) from diesel engines and EIAPP certification,
- Sulphur Oxides (SO_x) from diesel engines,
- Volatile Organic Compound (VOC) Emissions from cargo tanks of oil tankers,
- Shipboard Incineration,
- Fuel oil quality.

The EIAPP certificate is issued for marine diesel engines after demonstrating compliance with NO_x emission limits. The testing shall be carried out in accordance with the NO_x Technical Code issued by IMO [8].

It is envisioned that this supplemental measurement would take place during the sea trial before issuance of the IAPP Certificate (International Air Pollution Prevention Certificate) [10]. The mentioned certificate is mainly issued by classification societies. A simplified calculation for determining compliance would reduce the certification burden on the engine manufacturer by not requiring brake-specific emission calculations. This calculation could be based on the ratio of the NO_x to CO_2 concentration for the composite weighted emissions (certcomp) compared to the ratio of the NO_x to CO_2 concentration for the emissions at the actual test point (act) [8]. The equation for determining compliance would be as follows:

$$[1.5] \cdot NO_{x\,certcomp}\,(ppm)/\,CO_{2\,certcomp}\,(\%) \geq NO_{x\,act}\,(ppm)/\,CO_{2\,act}\,(\%)\,.$$

According to the NO_x Technical Code the engine will only require its Tier3 emission reduction components to be operational when in ECA areas. For many of available technologies, improper operation of the NO_x reduction technology may not affect engine performance, and therefore may not be easily identified [8]. It has been proposed that continuous monitoring be used as an efficient method for ensuring in-use emission control when marine diesel engines are operated in designated ECAs. A continuous monitor system should be design to continuously monitor exhaust emissions, monitor key operating parameters (like: NO_x, CO_2, HC, CO, engine load, exhaust temperature, urea dosing rate for SCR, specific fuel consumption BSFC), record the position of the vessel using the GPS system, and provide notification and alarm if the emission control is not operating properly in ECAs.

Another option that could be made available for engines utilizing Selective Catalytic Reactor (SCR) system based after treatment is demonstrating SCR efficiency by continuously monitoring NO_x concentrations at the SCR system inlet and outlet [8, 12].

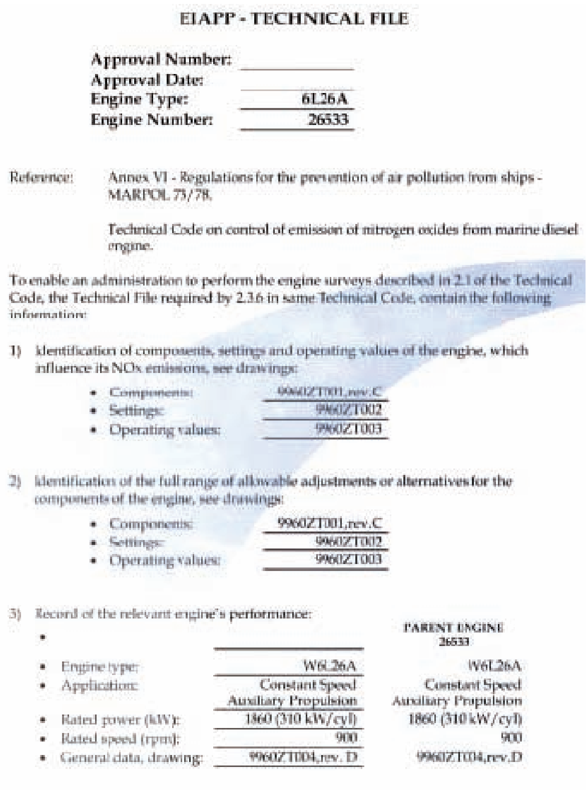
All certified engines are delivered with an individual Technical File that contains the engines specifications for compliance with the NO_x regulation and this is to be kept onboard at all times (Fig. 9). The certification process includes an emission test for compliance with the NO_x requirements on the manufacturer’s test bed in addition to an onboard NO_x verification after installation.

The onboard verification will in general include checking of the IMO markings on the NO_x relevant components and the settings specified in the engine’s Technical File.

The onboard NO_x verification will be performed in most cases at the Initial survey for the IAPP certificate.

5. Final remarks

Marine engines and power plants have to be operated at rather different modes within and outside the ECA areas. It means that the demands for improved engine control will increase sharply. It will also require the development of completely new control systems adapted to the operation of marine engines. There is a risk that the marine diesel engines, this uniquely reliable and efficient source of propulsion and onboard energy has no means reached the end of its development [7]. It has a potential for rigorously reduced emissions (the next Tier 4) at continued high efficiency.



EIAPP - TECHNICAL FILE

Approval Number: ________
Approval Date: ________
Engine Type: 6L26A
Engine Number: 26533

Reference: Annex VI - Regulations for the prevention of air pollution from ships - MARPOL 73/78.

Technical Code on control of emission of nitrogen oxides from marine diesel engine.

To enable an administration to perform the engine surveys described in 2.1 of the Technical Code, the Technical File required by 2.3.6 in same Technical Code, contain the following information:

1) Identification of components, settings and operating values of the engine, which influence its NOx emissions, see drawings:
   - Components: 9960ZT001,rev.C
   - Settings: 9960ZT002
   - Operating values: 9960ZT003

2) Identification of the full range of allowable adjustments or alternatives for the components of the engine, see drawings:
   - Components: 9960ZT001,rev.C
   - Settings: 9960ZT002
   - Operating values: 9960ZT003

3) Record of the relevant engine's performance:

		PARENT ENGINE 26533
Engine type:	W6L26A	W6L26A
Application:	Constant Speed Auxiliary Propulsion	Constant Speed Auxiliary Propulsion
Rated power (kW):	1860 (310 kW/cyl)	1860 (310 kW/cyl)
Rated speed (rpm):	900	900
General data, drawing:	9960ZT004,rev. D	9960ZT04,rev.D

Fig. 9. An example of EIAPP Certificate [11]

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