ESTABLISHMENT OF NO_x MEASUREMENT AND CERTIFICATION SYSTEM FOR SMALL SHIPS

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SUMMARY

Measurement of NO_x emissions from small ship diesel engines is technically quite complex and at most times it is very difficult or impossible to perform on board. Hence, there is need to build and model an applicable measurement and certification system compliant with NO_x measurement rules of NO_x Technical Code. The system needs to perform efficiently, economically and also need to have adequate elasticity for ships that cannot meet NO_x criteria in order to fulfil the requirements of the Code. The aim of this study is the formation of a technical and legislative infrastructure about safe and efficient measurement and certification of NO_x emissions of main and auxiliary engine in the Merchant ships, in accordance with Regulation 13 and NO_x Technical Code related to the control of nitrogen oxides (NO_x) and which takes place in Annex VI appendix about prevention of air pollution caused by ships in MARPOL 73/78 Convention.

NOMENCLATURE

CO_2	Carbon dioxide (kg)
HCs	Hydro carbons (kg)
NO_x	Nitrogen oxides (kg)
NO	Nitric oxide (kg)
NO_2	Nitrogen dioxide (kg)
O_3	Ozone (kg)
PM	Particulate matter (kg)
SO_2	Sulphur dioxide (kg)
VOCs	Volatile organic compounds (kg)

1. INTRODUCTION

Nitrogen oxides (NO_x) is a generic term for the mono-nitrogen oxides, nitric oxide (NO) and nitrogen dioxide NO_2). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. Nitrogen oxide may refer to a binary compound of oxygen and nitrogen, or a mixture of such compounds.

Environmental impact categories can be defined as follows: depletion of abiotic resources, impacts of land use, climate change, stratospheric ozone depletion, human toxicity, ecotoxicity, photo-oxidant formation, acidification, eutrophication, ionizing radiation, odour, noise, waste heat, depletion of biotic resources and desiccation [7]. NO_x emission has acidification, eutrophication and photochemical oxidant creation potentials [2].

NO_x, along with volatile organic compounds (VOCs), play a crucial role in controlling the distribution and variability of tropospheric ozone (O_3), which is a key trace gas in context of the air quality, atmospheric chemistry and climate change [8]. Formation of O_3 involves oxidation of VOCs by NO_x in the presence of sunlight. It is a highly nonlinear process that in part depends on the ratio of NO_x and VOC concentrations, which can vary greatly over time and space [19]. Warmer air temperature could also enhance the formation of tropospheric O_3 and other pollutants by changing the amounts and the distributions of anthropogenic and biogenic emissions, as well as mixing heights and winds which affect pollutant transport [20]. Abatement measures for the reduction of anthropogenic NO_x emissions will reduce ozone, in general, offsetting ozone increase in higher temperatures but may increase ozone levels, locally, enhancing ozone increase in higher temperatures [22].

Climate change-induced increases in surface temperatures could influence human health in several ways, for instance by increased heat-related deaths during heat waves [6]. World Health Organization (WHO) reports that in 2012 around 7 million people died - one in eight of total global deaths – as a result of air pollution exposure. This finding more than doubles previous estimates and confirms that air pollution is now the world's largest single environmental health risk [24].

Short sea shipping (SSS), is a special mode of sea transport. SSS produces less carbon dioxide (CO_2) than other modes of transport, however, improvements need to be made to the NO_x and sulphur dioxide (SO_2) emission levels though these are still lower per tonne kilometre than those from the other modes of transport [15]. Sustainability in the fishing fleet may be characterized by seven attributes: accident risk, employment, profitability, quality of the fish meat, catch capacity, greenhouse gas emissions/acidification, and bycatch/selection-measured by performance indicators [23]. The introduction of NO_x emission limits will lead to a number of innovations in fishing vessel design and operation. The reduction of engine load and retardation of fuel injection can reduce NO_x emissions [13].

By the 1997 Protocol, Annex VI entitled Regulations for the Prevention of Air Pollution from Ships is added to the International Convention for the Prevention of Pollution from Ships (MARPOL) and entered into force on 19 May 2005. Regulation 13 of MARPOL Annex VI which makes the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NO_x Technical Code) mandatory under that Annex. NO_x Technical Code applies to all marine diesel engines with a power output of more than 130 kW which are installed, or are designed and intended for installation, on board ships that built 1 January 2000 or later.

Besides enabling the execution of the application in accordance with national and international legislation, with the purpose of minimizing adverse effects about the costs of measurement, improvement precautions, registry and inventory of ships in merchant marine fleet in our country and maritime sector; a common commission was formed by The Chamber of Marine Engineers (GEMIMO) and The Chamber of Naval Architects (GMO), with the aim of the application of Rule 13 taking place in MARPOL Appendix VI titled “Nitrogen Oxides” for Turkish flagged ships.

Our technical and legal studies, which were prepared by using our professional, academic and technical accumulation about NO_x measurement, control and survey, were prepared to be presented for the service of the Administration and the sector. Contributions and support of Istanbul & Marmara, Aegean, Mediterranean and Black Sea Regions Chamber of Shipping (DTO) and Turkish Lloyd (TL) Foundation were assured for the established program through meetings, interviews and commission studies.

As a result of the conducted measurements, organizing a “Conformity Report for the Prevention of Air Pollution for Marine Engines” is aimed to be completed by monitoring the conformity of prepared test report and technical files with national and international legislation. Administration cooperation and making collective works are targeted on the topics of training, documentation, registry and archive system and legislative improvement about the topic.

Various regulations exist in Turkey currently about the measurement of emissions arising from the chimneys of industrial facilities or vehicle exhausts. However marine vessels are out of the context of these regulations. Some of these regulations are Regulation Concerning the Monitoring of Greenhouse Gas Emissions (17.05.2014, RG: 29003), Type Approval Regulation about the Emissions of Heavy-Duty Vehicles and Engines (Euro IV and Euro V) (24.10.2007, RG: 26680), Exhaust Emission Testers Inspection Regulation (19.07.2013, RG: 28712), Exhaust Gas Emission Control and Fuel and Diesel Quality Regulation (30.11.2013, RG: 28837, Type Approval Regulation regarding the Precautions to be Taken against Pollutant Emissions in the State of Gas and Particle, Coming out of Internal Combustion Engines Attached to Live Parts Used out of Highway (20.06.2007, RG: 26558). An adequate legislation infrastructure does not exist yet about the measurement and certification of marine vessels in the Turkish Law System.

The aim of this study is to form a technical infrastructure for necessary legal regulations by modelling a necessary and adequate system, in order for all elements of NO_x Technical Code to be implemented. Formation of the legal and technical infrastructure of NO_x measurement and certification studies originating from ships is not only a national scaled study; a model that will be robust in terms of procedure would also be a good example with regards to other countries. This study is the formation of a legislation structure of an applicable NO_x measurement and certification system with minimum cost for marine diesel motors at 130 and higher kW within the framework of NO_x Technical Code and by considering 400 grt limit for vessels such as fishing vessel cruising cabotage and internationally, private and commercial yachts and service ships.

2. PURPOSE OF SHIP NO_X MEASUREMENT AND CERTIFICATION SYSTEM FORMATION

Ships are very important resource of air pollution because they emit a great amounts and types of emissions, from their high power diesel engines. Some of the important emissions in terms of environment and human health are SO_2, NO_x, hydrocarbons (HCs), particulate matter (PM) and VOC.

In order to limit the NO_x emission amount occurring in ships diesel engines, NO_x limits are given according to engine speed number in MARPOL Annex VI Regulation 13. NO_x limits are changed as Tier I, Tier II and Tier III based on years. Dramatic changes are in question especially between Tier II and Tier III limits. Because of this reason, radical revisions or modifications need to be done in marine engines, in order to meet Tier III standards.

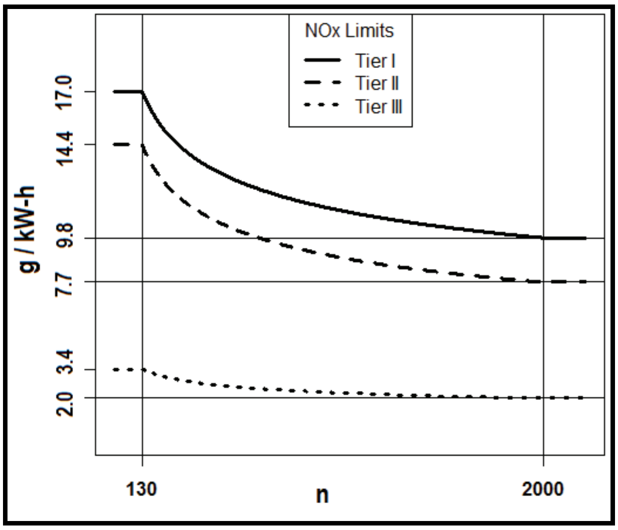

Figure 1: NO_x limits according to years and engine speed.

The purpose of this study to demonstrate how the problems, which may be caused by NO_x surveys related to commercial yachts, gullets, fishing vessels and private yachts sailing in Turkish coasts and cruising to foreign countries, can be solved easily according to NO_x Technical Code rules. With this study, necessary principals and plans are aimed to be regulated by having a co-operation with Union of Chambers of Turkish Engineers and Architects, in order for the NO_x emission values of diesel engines found in Turkish flagged ships, within the context of being measured, controlled and audited, recorded and documented in line with “The Law Regarding the 1978 Protocol and Approval of Our Entrance to 1997 Protocol Changing the International Contract about the Prevention of Sea Pollution by Ships Variously Dated in 1973”, MARPOL Appendix VI and NOx Technical code.

Although NO_x Technical Code states that all the responsibilities related to the topic belongs to the Administration, it also declared that operations under the responsibility of the Administration can be delegated to institutions authorized by itself.

3. CONTEXT OF SHIP NO_X MEASUREMENT AND CERTIFICATION SYSTEM

This study includes the application of Rule 13, which is titled “Nitrogen Oxides” taking place in MARPOL Appendix-VI for diesel engines set on a ship built on 1 January 2000 and later and whose output power is higher than 130kW, and diesel engines that were restored on 1 January 2000 and later and whose output power is higher than 130kW, and NO_x Technical Code.

The initial certification survey to be done after the replacement of the engines to the ship can be done with three different ways: engine parameter check method, simplified measurement method or direct measurement and monitoring method. Engine parameter check method can be used in case the engine owns EIAPP certification and these conditions are continued. If a valid EIAPP certificate does not exist, emissions need to be measured by the simplified method or direct measurement and monitoring method. Since the vessels that constitute the topic of this study are relatively small sized, measurement by simplified method would be more appropriate.

A regulation that will be prepared about the measurement of emissions occurring from marine engine will fill this gap. Since NO_x Technical Code depends on MARPOL contract that is an international agreement, in which Turkey is a signatory, and since the regulation to be prepared will be above national laws in legal hierarchy; it needs to be prepared in a way that will not violate NO_x Technical Code. At the same time, the application of the regulation has to have effective and flexible conditions, which will be adequate technically, and not hinder economic and marine trade as much as possible. Because, time losses during measurements in ships may cause economic losses.

As seen in Figure 1, since transition from Tier II to Tier III causes dramatic changes, this transition cannot be completed without making serious modifications on the marine engines. It cannot be achieved by changing operation conditions of the engines on ships, but by design and manufacturing of engine manufacturers. Because of this reason, the regulation to be formed needs to be prepared with the purpose of marine engines currently being used in the ships to be able to meet Tier II conditions.

Authorized administrations of countries have responsibilities on ships, which carry its flag, as flag state. Apart from that, when a ship that carries another flag arrives at its own maritime territory, port state authorities step in. The primary responsibility of Republic of Turkey Ministry of Transport, Maritime Affairs and Communications, General Directorate of Marine and Inland Waters Regulations, which is the authorized administration of Turkey, is to assure the measurement and certification of ships and boats that carry Turkish Flag, according to NO_x Technical Code. Turkey became a party on 4 February 2014, by approving MARPOL Annex VI. Therefore, boats and ships working on cabotage line should be included in this measurement and certification process, only if they are built after this date. Since large ships cruising in international waters are subject to Lloyd rules, they have measurement and certification. The main problem occurs for boats rarely going to neighbouring countries of Turkey. Because, although boats might have been excluded according to national rules in Turkey; they may be arrested during port state controls overseas, within the context of port state control (PSC).

According to Regulation 5, paragraph 1 of Revised MARPOL Annex VI about survey, certification and means of control, five different surveys are defined for the marine diesel type ships 400 grt and over: pre-certification survey, initial certification survey, renewal, annual and intermediate survey. The administration regulates Engine International Air Pollution Prevention (EIAPP) certificate with the pre-certification survey for the engine. International Air Pollution Prevention (IAPP) certificate is regulated for the ship after the engine is placed and before it is started, by conducting an initial survey. On the other hand, renewal, annual and intermediate surveys are done conveniently to the survey system of the ship, and the engine is assured to continue to meet Code rules. Initial survey needs to be conducted, in case any changes that will change NO_x values in the engines are done.

In Regulation 5, paragraph 2 about survey, certification and means of control of Revised MARPOL Annex VI, it is stated that convenient methods can be developed for the rules of Annex VI to be applied by the Authorized Administration for ships smaller than 400 grt. Because, ships that have 400 grt or higher tonnage have to fulfil MARPOL rules. Therefore, primarily in the first phase, the ships need to be separated into two groups as the ones below and above 400 grt. With the aim of the measurements to be done economically, ships under 400 grt would be appropriate to be done with either engine parameter check method or simplified measurement method.

Besides, types of ships to be measured need to be defined in detail. Since large merchant ships carrying cargo and passengers have already passed class approval, they meet all the conditions of NO_x code. However, commercial yacht, fishing vessels, private yachts, service boats and etc. boats that do not have class approval need to be included in the measurement legislation. These boats, either smaller than 400 grt or not, both work on cabotage and cruise to neighbour countries as nearby voyages. No problems exist in boats, whose tonnage is lower than 400 grt, for cabotage and overseas cruises. If the boats over 400 grt on the other hand making only cabotage voyages, they can fulfil the requirements of the code mentioned in this study by the simplified method, since they will be audited by the Flag State that prepared the regulation. However, boats that have tonnage over 400 grt and rarely go out of country with the permission of the Administration are required to be subject to Lloyd rules. If the measurements of such boats that are subject to Lloyd rules, the ship can be assigned to survey board by the Administration.

NO_x Technical Code includes all diesel engines with 130 kW and over power, which are permanently equipped to ships built after 1 January 2000, according to MARPOL Appendix VI Regulation 2.12, except from the ones doing activities of emergency cases or sea bottom minerals. Number of Turkish flagged ships is around 11,000. Nearly 300 ships, which were built after 4 February 2014 and in need of measurement and certification, have been identified.

4. ESTABLISHMENT OF SHIP NO_X MEASUREMENT AND CERTIFICATION SYSTEM

The primary purpose of the measurement and certification of NO_x emission caused by ships is not to perform an R&D project in order to increase the performances or improve the emissions of engines by testing them in test-bed conditions on laboratory environment, but to determine whether they are below a given limit value for specific conditions. Since the measurements will be done on the ship instead of laboratory conditions, the measurements need to be as simple and functional as possible, and thus have minimum measurement errors.

On-board measurements need to have a quality and certification system such as ISO 9001-14001, to incorporate an authorized measurement expert for measurement, to own all approved and necessary equipment for measurements and to get them calibrated regularly, and to construct a software system that will evaluate measurement results. The firm should keep all the measurements it performed in a safe way.

Although emission concentration and exhaust flow rate can be done relatively easily by marine type measurement devices, especially torque measurement is an application that is extremely detailed, costly and mostly not applicable in ship conditions. Especially in small boats, even the working condition for brake horse power measurement from engine shaft may not be found. Moreover, in order for the brake horse power in the engine shaft to be calculated, engine speed should be measured simultaneously with the torque. Additional to the simultaneous measurement of torque and power, emission in the exhaust and exhaust flow rate need to be measured simultaneously. Other than that, even if torsional moment is found with an application such as strain gauge, information such as shaft material and shaft torsional moment coefficients and shaft diameter cannot be found even for new engines.

Because of all these problems with these measurements, results should be interpreted by depending on a set of assumptions with the help of torque-cycle-power diagrams from engine instruction book, instead of shaft measurement for engine power. As a matter of fact, NO_x Technical Code left with some room for choice in this topic, because of the difficulty of torque measurements, and defined simplified measurement method in section 6.3.

NO_x limits are determined as g/kW-h. Engines are classified in two main and auxiliary engines as constant-speed or propeller-law-operated. Main engine is used for propulsion and auxiliary engines are used for electricity production. In constant-speed engines, the engine runs at the same speed and the power drawn from the engine changes by changing the pitch angle of the propeller. Speed of the ship increases proportionally with the power obtained from the engine by increasing the pitch angle. Propeller-law-operated engines are connected to fixed-pitch angled propellers; engine speed is variable and as the engine power increases, speed of the ship and the power drawn from the engine increase.

According to Code, weighted average emission factors will be calculated by using the measurements that will be conducted on 25%, 50%, 75% and 100% loads for constant-speed main propulsion (including diesel-electric drive and all controllable-pitch propeller installation) and propeller-law-operated main and auxiliary engines.

Through both shaft measurement and use of knowledge in engine books, kW part of g/kW-h limit value can be found. Since exhaust emission is calculated per task the engine performs, power unit kW should be multiplied by time (h). And this necessitates determination and recording of the time measurement is done. On the other hand, since the duration of measurements depends on the minimum time that will give an accurate result, it should be determined according to the measuring device user guide. Measurement devices measure gases by part per million (ppm) unit. First, $\mu g/m^3$ unit should be reached from ppm unit. Fort his, molecule weight of NO_x ($NO+NO_2$) emission is required. Additionally, volumetric flow rate of the gas passing from the exhaust during measurement should exist. For the volumetric flow rate on the other hand, exhaust gas speed should be measured and calculated by exhaust line diameter. Although different methods exist for the exhaust flow rate calculation, apparatus in addition to emission measurement devices, such as pitot tube that measure gas speed also exist.

Points in Table 1 regarding cabotage applications in compliance with MARPOL Annex VI Regulation 13 should be determined.

NO_x measurement process map regarding agency and institution tasks is indicated in Table 2.

Since the formation of NO_x measurement and regulation infrastructure is a process that includes universities, ship owners, chamber of shipping, chambers of marine engineers and marine stationary engineers, and authorized administration; a most convenient optimum conclusion can be achieved by the co-operation of all stakeholders. Studies to be completed regarding the formation of measurement regulation are shown in Figure 1.

5. NO_X REDUCTION METHODS ON MARINE DIESEL ENGINES

NO_x is emitted by high temperature combustion and therefore its main source is transportation [14]. Diesel engines are challenged to reduce their emissions. NO_x, HCs, PM and CO_2 are most important regulated diesel emissions [18].

Because the relationship between combustion parameters and NO_x formation is highly non-linear and complex, there is less potential for straightforward mitigation strategies compared with, for example, sulphur dioxide, since all the sulphur comes from the fuel [21]. Since emissions requirements for Diesel engines become increasingly tight, it is difficult to meet the limits on NOx emissions by only controlling the in-cylinder combustion [5]. The use of higher compression ratio requires a delayed injection strategy to avoid excessive knocking levels, which results in unacceptable soot emissions [3]. Different NO_x abatement technologies have diffused under the Swedish system of refunded emission payments (REP) and REP had a significant effect on the adoption of post-combustion technologies [4].

Biodiesel fuels have the potential to become a reliable substitute for diesel which is used moderately to meet the current energy demands. In spite of the many advantages of using biodiesel, most of the researchers have reported that they produce higher NO_x emissions compared to diesel [17]. Dimethyl ether (DME) is one of the most promising alternative fuels emerging in the past few decades. At present, DME is mainly applied to the compression ignition (CI) engines, and numerous studies showed its superior performances in CI engines versus the traditional fuels [11]. The performance and NO_x emissions of a biogas-fuelled turbocharged internal combustion engine were investigated using one-dimensional cycle simulation. The combustion behaviours were improved as the CH4 content in the biogas increased. The brake power, brake thermal efficiency, and NO_x emissions increased as the CH4 content or the boost pressure increased. The NO_x emissions were reduced by more than 90% via a reduction in the combustion temperature, which was achieved as a result of the lean combustion [11]. The effects of increasing water concentration in biodiesel emulsions on reducing NO_x and soot from a 4-cylinder diesel engine. Emulsified biodiesel fuel is a promising alternative method for reducing harmful emissions from diesel engines without requiring significant engine modifications [12]. The addition of N,N'-diphenyl 1,4-phenylenediamine (DPPD) antioxidant could reduce NO_x emissions significantly with a slight penalty in terms of engine power and Brake Specific Fuel Consumption (BSFC) as well as CO and HC emissions. Moreover, the addition of DPPD additive to all biodiesel blend samples reduced the exhaust gas temperature [16].

Table 1: Necessary points for the measurement system.

NO_x Measurement Procedures	Measurement Method Measurement Period
Authorization Criteria for NO_x Measurement	Firm/Agency/Institution Competence Measurement Equipment and Characteristics Measurement Equipment Calibration Measurement Cost Training and Certification of Measurement Experts Post-Measurement Reporting Method
Determination of NO_x Values for Cabotage Line	Interpretations According to First Measurement Results Determination of a Specific Limit Value
Improvement Methods, in Case NO_x Value Cannot be Assured	Change of Engine Settings Engine Renewal Pre-combustion Improvement Post-combustion Improvement
Certification Period	Measurement Reports Technical File Certificate

Table 2: Necessary points for the measurement system.

Foundation	Responsibilities	Document to prepare
Administration	Authorization of measurement firms Authorization of measurement experts	Approval of documents prepared by the Commission on behalf of the Administration
GMO-GEMIMO Measurement Commission	Forming a record system about NO_x emission from ships. Creating a database according to measurement results. Providing training for topics of measurement personnel, shipper representatives and surveyors. Co-operating with the Administration on the topic of training, documentation, and record and archive system and regulation improvement. Auditing and certification of measurement firms, equipment, calibration, software, personnel training and qualifications. Auditing the convenience of measurement done, test report prepared and technical files to the legislation.	Preparing certificate of competency for the measurement personnel Preparing Air Pollution Prevention Conformity Report for Engine
Measurement Firm Evaluation Board	Authorizing the measurement firm	Declaration of the measurement firm assessment report to the Chamber
Measurement Firm	Meeting the necessary pre-conditions for authorization Fulfilling all the required conditions for authorization by applying to the Administration Having all necessary and approved measurement devices for measurement	Making the calibration of devices within determined periods Having personnel competent for measurement Documenting measurement results Reporting measurement results to the Commission
Measurement Expert	Having necessary pre-conditions for measurement Participating in the trainings of measurement devices producers Attending the training of the Commission regarding measurement	Performing measurements within the measurement firm according to legislation Entering measurement results to the software
Boat Owner	Making the necessary application to the Admission for NO_x emission adequacy Having the measurements done by one of the authorized measurement firms Applying necessary improvement methods, in case measurement results do not comply with the limits	
TL or Vessel Survey Board (GSK)	Making on-board measurements for ships larger than 400 grt	
IMEAK-DTO	Informing and updating the sector about the issue.	

Direct aqueous urea solution injection strategy was successfully investigated on a four cylinder, turbocharged, direct injection diesel engine to secure the normal NO_x removal rate without severe impacts on the CO emissions and BSFC, suggesting that urea direct injection could be an effective method to reduce the NO_x emissions of a biodiesel fueled diesel engine [1]. The NH3/urea SCR is recognized as the most effective technology for the abatement of NO_x emissions from HD (Heavy Duty) diesel vehicles. The NSR, also referred as Lean NOx Traps (LNT), is more economically attractive for lighter vehicles, since no big layout modifications are needed and of the relatively fixed cost of the on-board urea system [9].

6. CONCLUSIONS

With this purpose, a measurement and certification system must be modelled, in which institutions such as ship owners, authorized administration, port authorities, The Chamber of Turkish Naval Architects & Marine Engineers, The Chamber of Marine Engineers, Istanbul, Marmara, Aegean, Mediterranean and Black Sea Regions Chamber of Shipping and Turk Lloyd will take place.

Although NO_x Technical Code includes quite detailed information originating from ships, it does not give enough knowledge regarding the very necessary and a comprehensive system that includes all stakeholders, except from survey and certification. In order to fulfil the very detailed measurements given in NO_x Technical Code wholesomely, a system that brings together quite different applications from the audit of the reliability of measurement devices, to training of people that will do the measurement, determination of ships required for measurement and procedures to be implied to ships that fail measurement needs to be established.

In measurements and measuring instruments, there are too many uncertainties. In this case, it is not possible to reach definitive results on on-board measurements as laboratory conditions.

In small boats neither in-cylinder nor in the exhaust line NO_x reduction methods is not applicable. The best method could be replacement of those engines with new ones by allowing boat owners a certain respite period.

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