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DEMONSTRATION OF NITROGEN OXIDES EMISSION REDUCTION USING THE ENGINE ROOM SIMULATOR

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Abstract. This article describes the use of the Kongsberg Neptune Engine Room Simulator as a practical and high-quality substitute for demonstrating practical problems that would be challenging in a real demonstration. Nitrogen oxides (NOx) is the name given to the chemical compounds of nitrogen and oxygen. When analyzing pollution, the use of this term refers to NO and NO_2. These two gases are an undesirable consequence of combustion in internal combustion engines and are a significant source of air pollution. They also contribute to the formation of smog and acid rain and to the depletion of the ozone layer. Out of concern for the environment, regulations have been introduced to reduce NOx emissions from shipping and a number of new technologies have been introduced. As a result, various measures and systems have been developed to reduce NOx emissions in the exhaust gases of marine engines. Teaching in this field is mostly limited to theoretical classes, as it is very difficult to show students these systems in operation and demonstrate their functioning practically (the ship must be operated with Heavy Fuel Oil, i.e. at full speed, far from the coast, which increases the cost of the demonstration). The Engine Room simulator presented here and its application have proven to be an excellent substitute to quickly and easily demonstrate to students the two main NOx reduction methods in use on board today (i.e. Selective Catalytic Reduction and Fuel Emulsification), their application and the pollution reduction results achieved, in accordance with MARPOL Annex VI.

Keywords: NOx; Pollutant Emissions; Engine Room Simulator; Pollution Prevention.

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1. INTRODUCTION

The increased occurrence of nitrogen oxides (NOx) in the atmosphere is a consequence of human activities and lifestyle (Crutzen, 2016; Dignon and Penner, 1991). In everyday language, the term NOx is now associated with the global environmental crisis caused by the occurrence of "acid rain", "greenhouse effect", "ozone holes" and many other undesirable effects on the environment (Lammel and Graßl, 1995). In general, NOx is a compound of nitrogen and oxygen in varying proportions, and there are many different compounds. When people concerned with ecology and environmental pollution talk about NOx, only nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are considered. The former is a colorless gas with a sharp, sweet smell, the latter a reddish-brown gas with a pungent, acrid odor. NOx can be produced naturally during thunderstorms due to the extreme heating and cooling within a lightning strike (Keller and Hongo, 1990). The vast majority of NOx is produced by human activities. The main sources of NOx are motor vehicles and other means of transport, which are responsible for about half of NOx emissions. Another 20% of NOx emissions come from electric power plants, while the remaining 30% come from all other sources (industrial boilers, refineries, oil fields, incinerators, various factories, etc.) (Cox, 1999). A more recent estimate of NOx sources is shown in Figure 1.

The most direct negative effects of NOx are on human health. It causes smog, which over time damages the respiratory system. Another major problem is the formation of acid rain due to the formation of nitric acid. This rain can be very corrosive when combined with sulfur dioxide, and its pH can drop as low as 4. This rain has a direct impact on all living organisms and also reduces crop yields as the soil becomes acidic (Posthumus, 1982). To reduce the

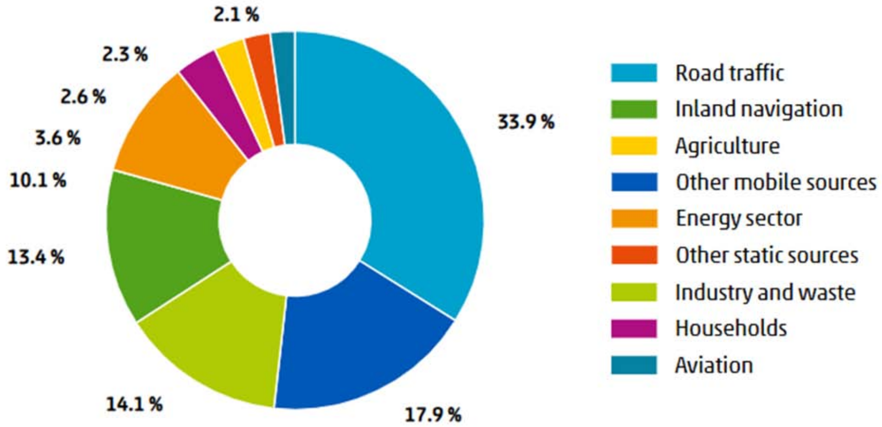

Figure 1. Emission of NOx in Netherlands by source (Statistics Netherlands, 2022).

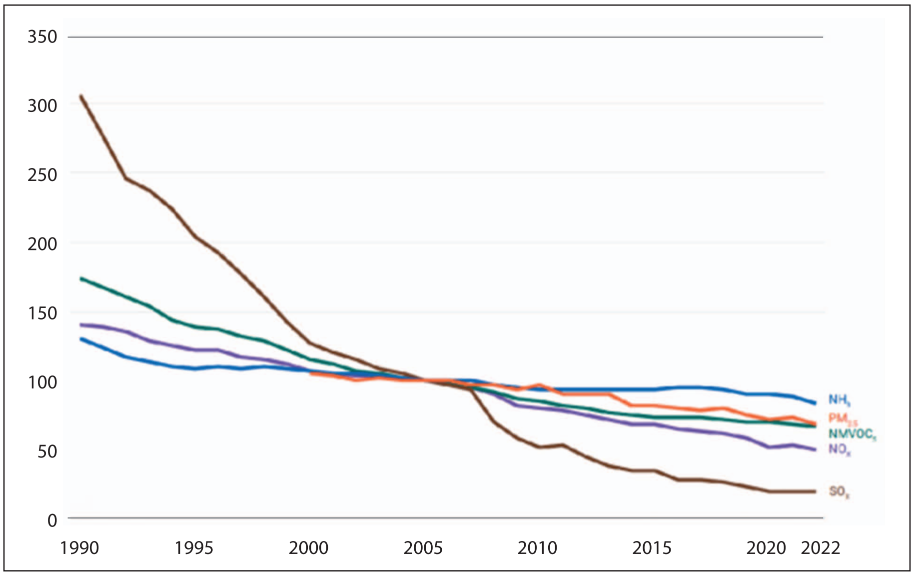

Figure 2. Reduction of HN_3, PM_{25}, NMVOC, NOx, and SOx from 1990 to 2022 (UNECE, 2024).

impact of NOx on the environment, these emissions have been regulated (Miller & Franco, 2017). Among other areas, NOx emissions are also regulated in the maritime sector (Van Roy et al., 2024). As a result of these regulations, NOx emissions have been significantly reduced (UNECE, 2024), as can be seen in Figure 2.

2. METHODS FOR REDUCING NOx EMISSIONS

Due to the problems with pollution and the laws that have been introduced to reduce this pollution (like Marpol Annex VI), a whole range of measures have been introduced to reduce NOx pollution. These measures are basically divided into primary and secondary measures. The primary measure is aimed at preventing the formation of NOx and the secondary measure is to successfully break down NOx after it has already been formed.

2.1. Primary Methods for NOx Reduction

Primary methods for diesel engines include:

- Load reduction,
- Reducing the λ (air/fuel ratio) in the engine,
- Exhaust gas recirculation,
- Increasing the scavenging pressure,
- Emulsification of the fuel.

The first method, **load reduction**, is based on the simple fact that reducing the load lowers exhaust gas temperatures and thus NOx emissions. The main problem with this method is that success is inversely proportional to the speed of the ship, i.e. absolute success is achieved when the ship is not moving at all.

Reducing the λ (air/fuel ratio) in the engine can achieve good results in NOx reduction (Santos et al., 2021). The associated problem is that at a certain point the fuel begins to burn incompletely and the risk of misfiring increases. Due to the problems mentioned, this method has not become established on a larger scale.

Exhaust gas recirculation as a method of NOx reduction is widely used, but has some side effects, such as an increased incidence of corrosion in the engine and a limited reduction in NOx (Kuropyatnyk and Sagin, 2019).

Increasing the scavenging pressure as a method of NOx reduction leads to good results. According to (Yu et al., 2024), "*for every 0.25 bar increase in scavenging air pressure, NOx emissions decrease by 3.53%*". This method is already being used, but is limited due to the design of engines and turbochargers.

Fuel emulsification is the most widely used primary method for NOx reduction (Lalić et al. 2009). It is relatively inexpensive and safe to use, it does not affect materials or people, but the end result is limited and the best systems achieve up to 40% reduction in NOx emissions (Gowrishankar and Krishnasamy, 2022).

2.2. Secondary Methods for NOx Reduction

There are several secondary methods of NOx reduction, the best known and most commonly used of which is Selective Catalytic Reduction (SCR) (Engine Technology Forum, 2025). SCR is a technology for reducing nitrogen oxides (NOx) emissions by neutralizing them through reaction with a reducing agent, usually a urea solution. This solution reacts with NOx in a chemical reaction described by the following equations:

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 2\,N_2 + 3\,H_2O \tag{1}$$

$$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 3\,N_2 + 6\,H_2O \tag{2}$$

$$NO + NO_2 + 2\,NH_3 \rightarrow 2\,N_2 + 3\,H_2O \tag{3}$$

As can be seen from the equations above, SCR uses a reducing agent that is injected into the exhaust gases upstream of a catalyst, where it forms ammonia (NH_3), which reacts with NOx and converts these gases into nitrogen (N_2) and water (H_2O) (Busca et al., 1998). This process has a very high NOx removal efficiency of up to 95 % (Mitsubishi Power, 2025). The consumption of this reducing agent causes additional costs for ship operators. In 2014, these costs amounted to "*between $104,000 and $224,000 per year, or approximately $900 to $2,000 per tonne of NOx reduced*" (ICCT, 2025).

3. CHALLENGES IN TEACHING NOx EMISSIONS REDUCTION IN PRACTICE

In practice, emulsification and SCR are the most frequently used NOx reduction methods on ships. For this reason, these two methods are also in the curriculum of marine engineering students. Since hands-on demonstrations are the best way to learn, it would be ideal if students could be taken on a ship (or several ships) to see how these systems work. The idea of taking them on a ship has many disadvantages. The first is finding a suitable ship that often sails close to our location, as it is impossible to take all the students on board (in the engine room) at the same time. In addition, the ship must sail under considerable load (i.e. far from the coast) and preferably be powered by Heavy Fuel Oil (HFO). The organization of such trips would be quite complex and expensive, and we refrain from this kind of practice. Instead, students are given a demonstration on Engine Room (ER) simulators where they get a fairly realistic picture of how the system works.

4. NOx EMISSION REDUCTION ON ER SIMULATOR

During the research for this paper, the authors decided to use the Kongsberg Neptune MC-90V engine room simulator. To better illustrate how the NOx reduction system works, the ship is loaded with cargo and driven at maximum speed in this simulation. In this simulation, there is no watch in the engine room, but the system is organized as an Unattended Machinery Space (UMS). For this reason, the main control point of the propulsion engine is located on the bridge (Figure 3).

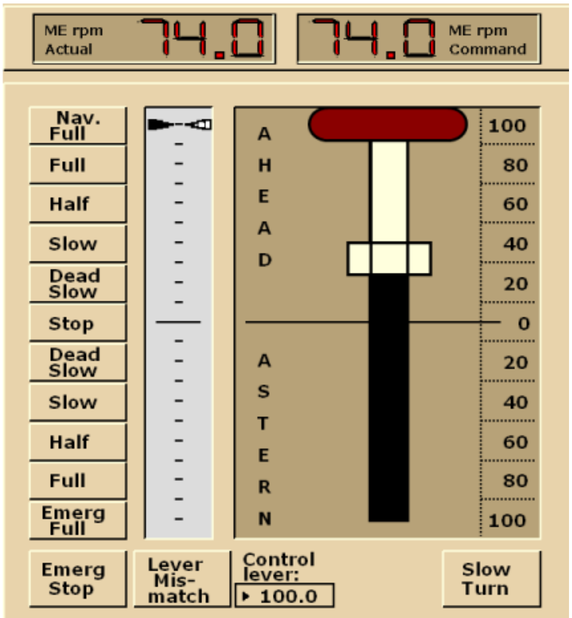

Figure 3. Bridge telegraph in Navigation Full position (Kongsberg Maritime, 2025).

As can be seen in Figure 3., the propulsion engine runs at 74 revolutions per minute. It consumes 3.16 tons per hour and emits 15.06 g/kWh of NOx (Figure 4).

ME Speed	N 73.98	rpm
ME Fuel Link	X 56.69	%
ME Shaft Torque	Q 2159.7	kNm
ME Fuel Consumption	G 3.16	ton/h
ME Spec Fuel Oil Cons.	G 184.53	g/kWh
ME NOx Content	Z 15.06	g/kWh

Figure 4. Engine data at full load, without NOx reduction (Kongsberg Maritime, 2025).

The next step in the simulation is to start the NOx reduction and check what will happen.

4.1. Emulsification on ER Simulator

The engine's fuel system contains an emulsifier, i.e. a device for mixing fuel and water. It is marked in red in Figure 5. The picture shows that the water valve leading to the system is closed and the control button is switched off.

The simulation of the start of this system takes some time, the water content in the fuel is gradually increased so that the automatic system can properly regulate the viscosity of the fuel. After some time, the system reaches a mixture with 20% water (simulated value), as shown in Figure 6.

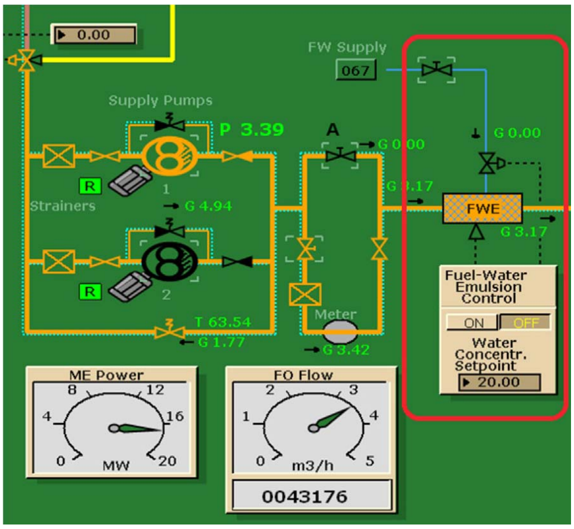

Figure 5. Fuel Water Emulsifier is stopped (Kongsberg Maritime, 2025).

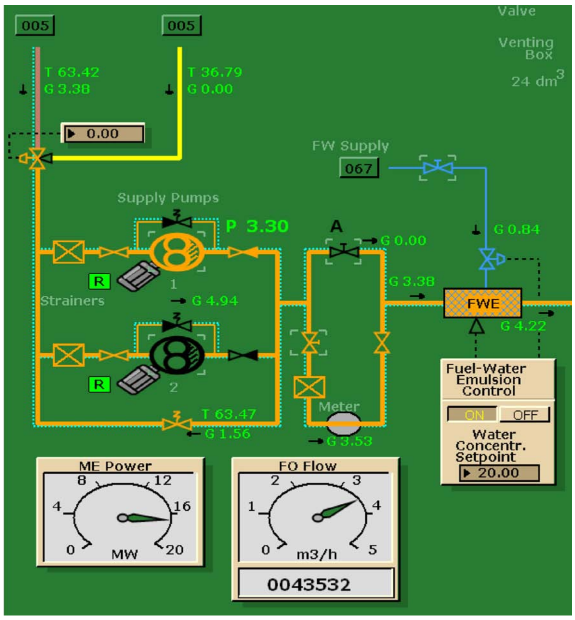

Figure 6. Fuel Water Emulsifier is running (Kongsberg Maritime, 2025).

The consequences of including the emulsifier can be seen in Figure 7. The total NOx reduction is about 20%, which is the expected value (Lalić et al., 2009; Gowrishankar and Krishnasamy, 2022). At the same time, Figure 7 shows that fuel consumption has increased. Since a considerable amount of water was added to the fuel, it was expected that the fuel consumption would be higher to maintain the same engine power required to maintain the desired speed.

ME Speed	N 73.99	rpm
ME Fuel Link	X 74.32	%
ME Shaft Torque	Q 2162.3	kNm
ME Fuel Consumption	G 3.38	ton/h
ME Spec Fuel Oil Cons.	G 197.38	g/kWh
ME NOx Content	Z 12.24	g/kWh

Figure 7. Engine data at full load, with Emulsifier running (Kongsberg Maritime, 2025).

In Chapter 2 it was stated that Emulsification is the primary method for reducing NOx, i.e. that it prevents the formation of these gases. This statement is confirmed by Figure 8, in which can be seen that the NOx percentages are the same at the exit of the exhaust gases from the engine and later at the exit of the gases from the ship.

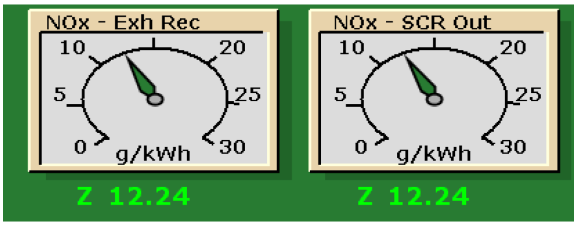

Figure 8. NOx concentration on HFO when Fuel Water Emulsifier is running (Kongsberg Maritime, 2025).

In demonstrating different techniques to reduce NOx emissions in exhaust gases, one of the methods is to change the type of fuel. Figure 9 shows the reduction in NOx emissions when the engine is fueled with MDO using an emulsifier. Compared to Figure 8, a smaller reduction in emissions of around 7% can be seen.

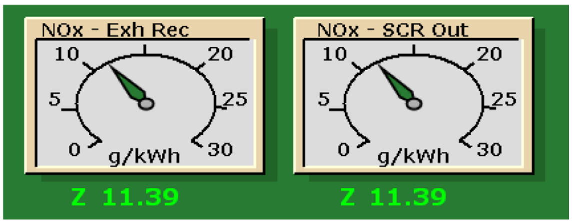

Figure 9. NOx concentration on MDO when Fuel Water Emulsifier is running (Kongsberg Maritime, 2025).

A comparison of the data in Figures 8 and 9 raises the question of the cost-effectiveness of introducing alternative fuels as a means of reducing NOx emissions. This question is taken up again in the paper after the system has been simulated with SCR switched on.

4.2. Selective Catalytic Reduction (SCR) on ER Simulator

The following simulation was carried out using the SCR system shown in Figure 10. The system presented reproduces the appearance of real systems well and also mimics their functionality.

The activation of the system takes a certain time, the NOx emissions gradually decrease and the values of engine data at full load are shown in Figure 11. The value of NOx has dropped to only 0.91 g/kWh, which represents 94% reduction and is very close to the maximum value of 95% (Mitsubishi Power, 2025).

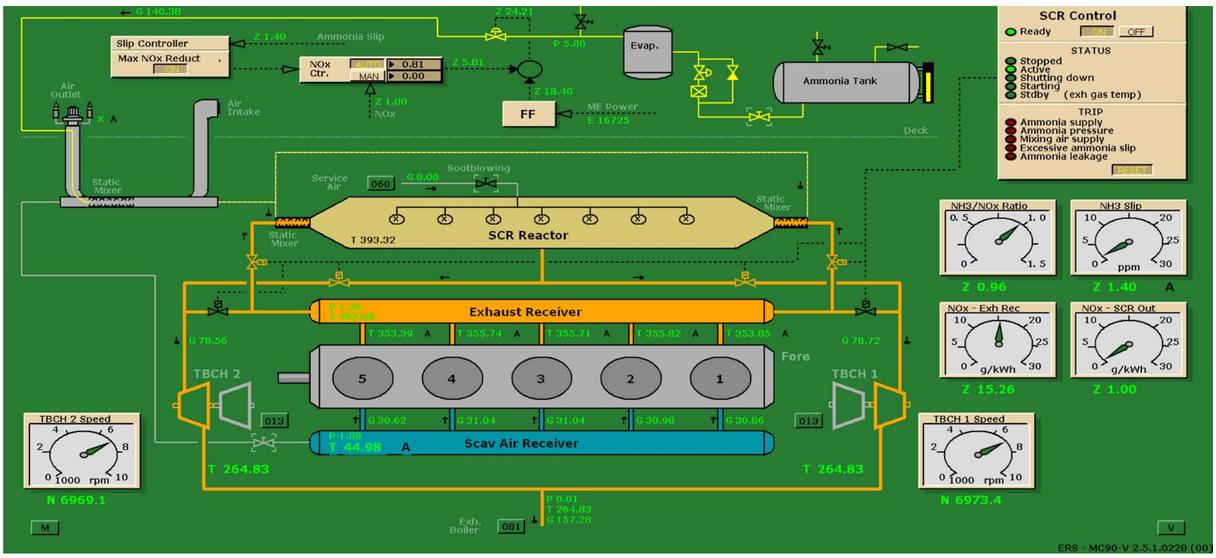

Figure 10. Selective catalytic reduction system (Kongsberg Maritime, 2025).

ME Speed	N 74.00	rpm
ME Fuel Link	X 56.31	%
ME Shaft Torque	Q 2162.9	kNm
ME Fuel Consumption	G 3.14	ton/h
ME Spec Fuel Oil Cons.	G 185.18	g/kWh
ME NOx Content	Z 0.91	g/kWh

Figure 11. Engine data at full load, with SCR running (Kongsberg Maritime, 2025).

Confirmation that this is a secondary form of NOx reduction, as claimed in Section 2, is shown in Figure 12. It can be seen that produced NOx gases are 15.24 g/kWh when leaving the engine (there are no primary reduction) and these are reduced to 0.92 g/kWh by the SCR system.

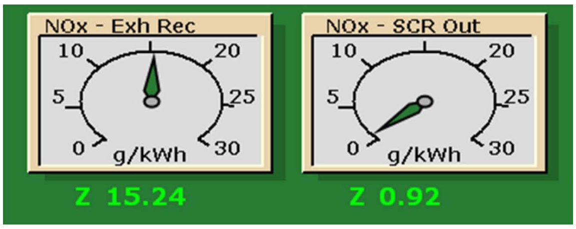

Figure 12. NOx concentration on HFO when SCR is running (Kongsberg Maritime, 2025).

Figure 13 shows the combination illustrated in Figures 9 and 12. Here, too, the engine is running with MDO as in Figure 9, and the SCR is switched on as in Figure 12. A comparison of the data shown in Figures 12 and 13 shows a reduction in NOx emissions of around 10% when the engine is running on diesel fuel.

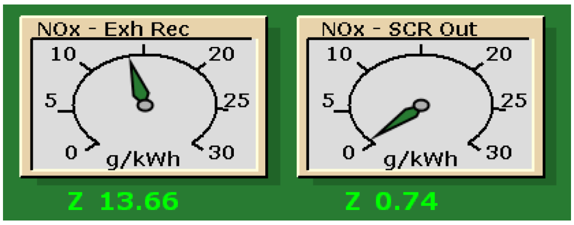

Figure 13. NOx concentration on MDO when SCR is running (Kongsberg Maritime, 2025).

Considering the reduction in pollutant emissions, the cost of the alternative fuel and the engine wear (comparison of HFO and MDO), it is concluded that this type of fuel substitution is not advisable for the engine.

5. CONCLUSION

The demonstration of two methods for NOx reduction with the ER simulator has shown the suitability of these methods for the training of marine engineers. The real-time simulation on the ER simulator provides students with all the necessary information about the operation of the system, and the results obtained are very close to the real ones. In addition, the ER simulator allows students to study working conditions that would not be available to them in reality. One of these simulations is the use of SCR during a storm, where there are large fluctuations in engine operation due to ship pitching and load changes, resulting in a large NH_3 slip (in reality this occurs due to a delay in the system response). These advantages and the ease of organizing lessons are the main benefits of training students on the ER simulator.

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