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TECHNICAL AND OPERATIONAL MANAGEMENT SOLUTIONS TO REDUCING THE MARITIME TRANSPORT ASSOCIATED EMISSIONS

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Abstract: *The maritime transport is a vital component of the logistic and supply chain worldwide and a crucial sector for the EU economy.Although the maritime transport could be less pollutant than other transport means, the fuel oil dependancy and the strong public community position for reducing not only the* CO_2 *emissions, but also other pollutants emissions (SOx, NOx, e.a.) are representing serious reasons for considering this industry as one of the most pollutant worldwide.This article is proposing an indepth view of the actual used technical and operational solutions which are available in the industry in order to reduce the emissions level onboard. Also there are presented the trends for increasing the energy efficiency onboard, by considering the cost – efficiency indicators and also the social and operational results inside the maritime transport companies.*
Keywords: *emission, reduction, solutions, technology, air pollution.*

Introduction

The maritime transport is a vital component of the logistic and supply chain worldwide and a crucial sector for the EU economy. The shipping industry is responsible for about 2% of global CO2 emissions, 14%-15% of the global emissions of NOX and approximately 16% of the global emissions of SOx. (Buhaug et al, 2009;. Endresen, 2007)
Although maritime transport could be compared, less pollutant than other modes of transport, technological advances made in other sectors, the excessive dependence on oil and the trong call from the public opinion in favor of not just the reduction of CO_2 emissions, but also of reducing pollutants (SOx, NOx, particulates), are important reasons why this sector constitutes an important source of air pollution at the global level.(CE 2013)
For the limitation and reduction of exhaust gas emissions from ships, the actors of the world shiping (shipowners, operators, shipbuilders and naval equipment, classification societies, etc.) are determined to find solutions which comply with international regulations in this field.
Options for reducing NOx emissions from seagoing vessels, identified so far can be classified into three broad categories. First of all, technology strategy which are based on technological improvements that can reduce emissions both locally and globally, by replacing or upgrading polluting propulsion engines with more efficient systems and lower emissions.
All the technical measures are considered as well as the use of other types of fuel NOx emissions which correspond to the requirements imposed by international law, in combination with existing fuels on board, or through their complete replacement.
Secondly, operational strategies for reducing emissions are those measures which act by altering the ship's operation time of entry/exit and while the ship is stationary in the port. Although NOx emissions from ships, which occur during port operations are modest in comparison with the emissions emitted during march (excluding CO), they nevertheless have a major impact on local emission inventories and on the public health risks because they generally occur near populated areas.
Thirdly, based on the market, there are the programs of the market, such as the port charges and variable emissions trading programs, which can stimulate both operational and technological strategies, if they are well designed and implemented.

Emission reduction measures

The problem of technical measures to limit polluting emissions proves to be very tricky, due to the multitude of factors that influence those sizes.
Technical factors that affect the level of pollutant emissions are numerous, but the most important are: the shape of the hull and the ship's speed, thruster, an engine's operating arrangements; characteristics of the injection process (the injection advance; the law of construction equipment for injection, injection, injection pressure size) constructive particularities of the engine (air current that penetrates the combustion chamber, the amount of waste combustion, combustion chamber architecture; the heat transfer characteristic of combustion chamber; overeating; characteristics of lubrication), fuel

characteristics, technical condition of the engine. (Trifu, 2010)

Technological strategies for reducing air pollution focus generally on the emissions of NOx and SOx, since they are currently regulated at international level. The use of technological measures for reducing emissions of NOx and SOx, involving a reduction in fuel consumption, leads to reduced levels of CO_2 from the exhaust gases from engines, whereas the percentage of exhaust emissions of CO_2 is directly proportional to the carbon content of fuel.

Solutions for reducing NOx emissions

The IMO annex VI of Marpol 73/78 "Rules for preventing air pollution with emissions from ships reviewed in 2011, with the implementation of the amendments technical and operational measures on board vessels for energy efficiency", imposes requirements and standards on board ships in order to reduce air pollution.

NOx emission limits (Regulation 13-Marpol, Annex IV) are set out for diesel engines, depending on the maximum speed of engine operation (n, k). The limits of grade I and grade II are at the global level, while level III standards only apply to EU-emissions control area (see figure 1). (International: Marine: Emissions)

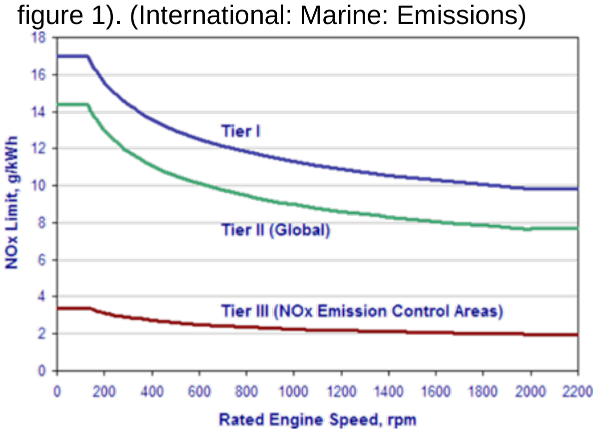

Figure 1. Limits IMO NOx reduction

In order to meet these limits, NOx emissions can be reduced by adopting technological solutions that involve changing processes of combustion, inlet or exhaust engine.

At the present time numerous systems to reduce NOx have been developed by the naval engines constructors, by optimizing the functional parameters of the engine, which can be grouped into three categories:

Technologies which prevent the formation of NOx during combustion process (Trifu, 2010)

- Water injection in the engine cylinders:
  - DWI – Direct Water Injection;
  - IWI – Indirect Water Injection;
  - FEI – Fuel Emulsion Injection;
  - SFWI – Stratified Fuel-Water Injection.
- Humidifying air supply:
  - CAH - Charge Air Humidification
  - CASS – Combustion Air Saturation System
  - HAM - Humid Air Motor
  - SAM – Saturation air motor

These technologies are based on lowering the temperature in the combustion chamber through various methods of water injection into cylinders, as well as through various methods of humidification of the air supply in the fuel mixture. NOx reduction efficiency of the exhaust gas is influenced by the type of engine, but generally the reduction potential is between 20-55% (Litehauz, 2013).

Afterburner technology

- Exhaust gas recirculation (EGR)
- Selective catalytic reactors (SCR)

The exhaust gas recirculation (EGR) works on the principle of introducing some of the exhaust gases into the combustion chamber of the engine, after they have been cleaned and cooled, to reduce peak combustion temperatures and, hence, to reduce emissions of nitrogen oxides in an effective manner. The EGR system is very effective in reducing NOx and can reach values of reduction between 60 ... 70%, without affecting the engine power.

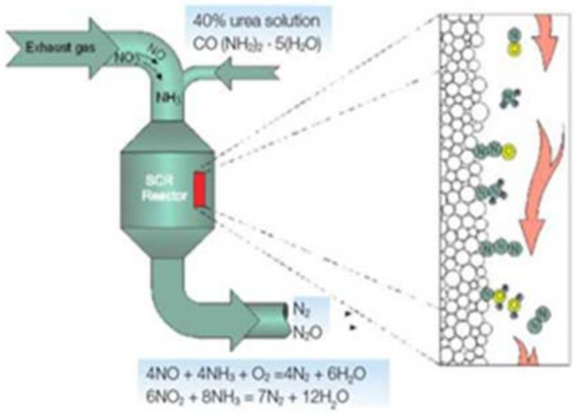

Figure 2. Chemical reaction of SCR

Selective catalytic reactors (SCR) treat the exhaust emissions of the diesel engines with a reagent (urea or ammonia) by passing them into model converters, in the form of honeycomb, a fine cellular structure. Oxides of nitrogen react with the active reactanton an active surface of the converter and are reduced to water and nitrogen. (Figure 2) (SELAS 2010)

The implementation of these technologies involves a big gas investment both in installation and service on board. Table 1 shows the main technologies for reducing NOx reduction yields and the costs of installation.

Table *1*(source: Trifu, 2010)

System	NOx Control	Installation costs
DWI / 443 $/t NOx	40 – 60 %	36 $/kW
FEI / 217 $/t NOx	30 – 50 %	28 $/kW
HAM / 206 $/t NOx	60 – 80 %	98 $/kW
EGR	50 – 60 %	2 % the price of the engine
SCR / 552 $/t NOx	Up to 99 %	100 $/kW

The use of alternative fuels

Large ships use sluggish and usually the least expensive and the most polluting fuel, derived from diesel called HFO. This fuel can have a sulphur content of up to 5 percent.

Marpol Annex VI requires that by 2020 the concentration of sulphur in the fuel can be reduced from 3.5%, as it is currently, up to 0.5%. This limitation requires the replacement of residual fuel (HFO) with high sulfur content up to 5% with other fuels with a low sulphur content. Alternative fuels used for reducing sulphur emissions are:

- gas and liquid mixtures (Dual – Fuel);
- fuels with very low sulphur content;
- LNG fuel;
- Biofuel.

Among these, the most widely used fuel in ships is natural gas (LNG) alone or in combination with classical fuels (Dual-Fuel). Natural gas (methane) is one of the most important sources of energy used worldwide. Naval engine operation with natural gas leads to significant reductions in pollutant emissions due to cleaner combustion and a lower content of polluting components. To emphasize this, in Figure 3 is shown the contribution of LNG and HFO in the issuance of SOx, NOx, and PM.(Maritime Institute in Gdansk, 2013)

The use of LNG as fuel for the propulsion of the ship, although it is effective in reducing exhaust emissions is not deployed at large scale to date (the year 2012 just 350 vessels) due to the following issues:

- Low temperature LNG storage aboard ship requires the use of insulation materials for the construction of storage tanks and related facilities;
- The construction of terminals in ports for supplying ships with LNG.(DNV, 2012)

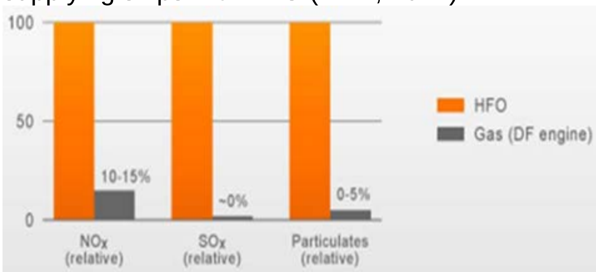

Figure 1. Influence of the type of fuel on emissions

At the global level methods of preventing the formation of NOx are considered to be much more effective than its reduction of exhaust gases, due to the cost of implementation of technologies on board, even if the NOx reduction yields are much lower compared to postratare gas technologies.

Solutions for reducing SOx emissions

Annex VI to the MARPOL Convention, revised in 2008, regulates emissions of SOx for ships, mainly by setting a limit for the sulphur content of marine fuel oil. In the ECA, sulphur limit will be even tighter than the MARPOL Annex VI.

SOx emissions are reduced by first reducing the sulphur content of fuel through the use of distillates fuels with a low sulphur content, or by using LNG. They can also be reduced through the use of technological solutions to flue gas wet type scrubber.

By using a scrubber with sea water, emissions of exhaust gases can be washed in SO2. Sea water is alkaline and neutralizes sulphur oxides in the scrubber. Oxides of sulphur In result from this chemical reaction and they turn into sulfates. Concentrations of sulphates from evacuated sea water have negligible effect on the pollution of the sea. In case of limited water alkalinity from the sea, fresh water and scrubber together with washing agents can be used. This method SOx emissions of exhaust gases reduces almost completely (90-95%) and the mechanical particles by up to 80%, but no reductions have been observed in concentrations of NOx gas washing.

Table 2.Sulphur emissions limits (source: Clean North Sea Shipping, 2011)

<table>
<tr><th></th><th>SECA</th><th>Global</th></tr>
<tr><td>2000</td><td>1.5%</td><td rowspan="2">4.5%</td></tr>
<tr><td>2010</td><td rowspan="2">1.0%</td></tr>
<tr><td>2012</td><td rowspan="2">3.5%</td></tr>
<tr><td>2015</td><td rowspan="2">0.1%</td></tr>
<tr><td>2020[a]</td><td>0.5%</td></tr>
<tr><td colspan="3">a - alternative date is 2025, to be decided by a review in 2018</td></tr>
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Solutions for reducing CO_2 emissions

In recent years, Governments, civil society and the international shipping industry have recognized more and more the importance of the contribution of this sector to the global activities to reduce GHG emissions. (Hackmann 2012).

At EU level, international maritime transport remains the only mode of transport that is not included in the EU's commitment to reduce GHG emissions. GHG emissions from shipping is currently 4% of all EU GHG emissions. (CE 2013)

So, IMO, in 2011 brought amendments to Marpol Annex VI, with energy efficiency measures on board ships by introducing energy efficiency index (EEDI) design for new ships and the Management Plan of the energy efficiency of vessels (SEEMP), for vessels in service.

Currently, the main ways of reducing CO2 emissions to 2050 are believed to be a mix of operational measures, technological developments and the use of alternative fuels with lower carbon content.

Design index (EEDI energy efficiency) – It is a mechanism based on performance, requiring a certain minimum energy efficiency for new ships, depending on the type of ship and its transport capability. EEDI is expressed in grams of carbon dioxide (CO_2 grams) per mile of vessel capacity and is calculated according to a formula based on engineering design parameters for a given vessel. The reduction of CO_2 (grams CO_2 per tonne-mile) in the first phase will have an energy efficiency of yield 10 percent by early 2015 and will increase every five years (20%-30% by 2020-2030) in order to keep peace with technological developments and with the measures to reduce CO_2 pollution. Designers and builders of ships are free to choose the most cost-effective technologies to meet the requirements of the EEDI in a specific ship.

Energy efficiency technological solutions the most used are shown in Table 3.

Table 3.Technological solutions for energy efficiency (source: Bazari 2011)

Optimised hull dimensions	Lightweight construction	Hull coating
Hull air lubrication system	Reducing on-board power demand	Waste heat recovery
Contra-rotating propeller	Engine efficiency improvement	Gas fuelled (LNG)
Hybrid electric power and propulsion concepts	Optimisation of propeller-hull interface and flow devices	Variable speed drive for pumps, fans, etc.
Wind power (sail, wind engine, etc.)	Solar power	Design speed reduction (new builds)

Technological options to streamline ships which are to be constructed include the increasing size, optimizing the shape of the hull and propeller, increased efficiency and decreased resistance engines forward of the ship through the adoption of new techniques for live coverage of the work. For example, a large spacecraft with cargo capacity as two smaller ships, not only weighs less than the two ships, but it also has less surface of the body that is in contact with water, thereby reducing the frictional resistance and thereby reducing energy requirements for propulsion. So, the construction of large ships would be able to increase the efficiency of the fuel consumption of the fleet worldwide. However, there are some practical limitations in terms of increasing the size of the vessels.For example, the dimensions of the Canal, Harbour depths, as well as the limited capacity of the handling equipment from the port. Other benefits can be obtained by optimization of hull and engine design. The ships currently use diesel engines which operate effectively within a narrow range of RPMs. Replacing these engines with a range of diesel-electric would allow smaller more efficient engine operation at a wider range of speeds. The ships could also use combined-cycle diesel engines, which convert waste heat into usable energy. More advanced efficiency technologies involve new work live coverages (such as special polymer or air bubbles), which reduce the resistance of the hull above the water.

Figure 4 shows an example of implementing technology to reduce CO_2 emissions,a concept called ISHIN-III, developed by the Company MOL for an ore carrier vessel type. The concept aims to reduce CO_2 emissions by 30%.

Figure 4. EEDI deployment technologie (source: Mol, 2011)

The management plan for energy efficiency to the ship (SEEMP) establishes a mechanism for the operators to improve the energy efficiency of vessels in service.

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SEEMP is a document with specific objectives, actions and responsibilities in order to improve shipenergy efficiency.
The plan encourages the owner and operator to analyze new technologies and operational practices aboard the ship throughout the service life of the plan.
For example, a tool for monitoring fuel consumption, is the pointer,SEEMP energy efficiency in operation (EEOI). EEOI is used to help owners and operators to predict the outcome of any amendments to the vessel, such as improving the planning of the trip, more frequent cleaning of the propeller, live work, injection system of engines etc.
SEEMP regulations apply to all ships with a capacity equal to or greater than 400 gross tons and came into force on January 1, 2013.
In Table 4 there are some of the most common operational measures in the context of SEEMP.
Modifying operational practices of the shipping fleet worldwide could reduce emissions across the entire sector. Immediate reductions in GHG emissions are available on all ships by reducing speed. For example, reducing the speed with 3 knots compared to the average speed from a ship container would reduce the frictional resistance of the hull above the water by 50%, thus requiring less energy to propel the ship. (CCES)
However, the reduction in speed would reduce the carrying capacity of the ship because they would carry the same volume of merchandise in a period of time. In order to maintain the current shipping offer with low average speeds, it would be necessary for the ship to perform more frequent trips or to increase the efficiency of use of vessels (e.g., increased load factors). Other operational strategies that can compensate for reduced transport capacity at lower speeds are: port logistics efficiency through the adoption of new techniques for faster loading and reducing the time at anchor in the roadstead, better voyage planning by establishing real-time travel routes taking into account the distances, the climatic conditions of the air and sea as well as planning and a streamlined execution of the body, engine and propeller maintenance.

Table 4.Operational energy efficiency measures(source: Bazari 2011)

Engine tuning and monitoring	Hull condition	Propeller condition
Reduced auxiliary power	Speed reduction	Trim/draft
	(operation)	
Voyage execution	Weather routing	Advanced hull coating
Propeller upgrade and aft body flow devices		

Technical and operational measures for energy efficiency, if they are applied individually, have a low potential for CO_2 reduction. But various studies have shown that, if these measures are taken together, depending on the measures used, the cost of fuel, and increased transport activity, the CO_2 reduction potential is significant. A study carried out by the IMO demonstrates that, if these measures are implemented together, can achieve reductions of at least 25% CO_2(Buhaugh 2009).Also, in a report to the European Commission on the reduction of GHG at Delft ship a cost-effectiveness analysis for 29 measures was presented. It was applied to 14 different types of ships, and obtained a reduction of 35% of GHG in the year 2030. (Faber et al., 2009) Det Norske Veritas (DNV), looked at the 28 power-saving options resulting in a more optimistic forecast for reducing carbon emissions, more than 50% by 2030. (Alvik, Eide, Endresen, Hoffmann, & Longva, 2010). Also Figure 2 shows the potential global CO_2 reduction for SEEMP and EEDI, based on various specific scenarios (IPCC).(Vlachos 2014; Bazari, 2011) The different results obtained from these studies as the cause number and type of operational measures and ship taken in the analysis.
A study of the IMO (Buhaug et al, 2009) concluded that GHG emissions from vessel could be reduced by 20-40% depending on the measure used, the cost of fuel, and as a function of increasing transport activities.

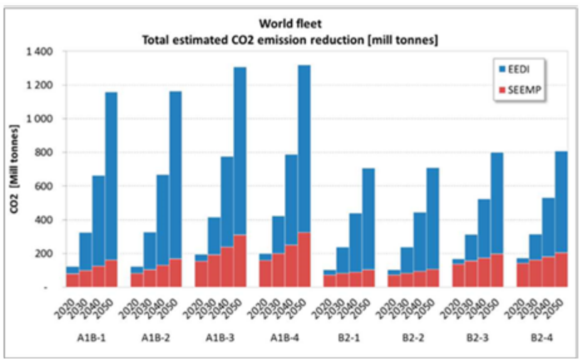

Figure2.The potential global CO2 reduction for SEEMP EEDI and based on different scenarios

CONCLUSIONS

Worldwide, the emissions generated by the transport currently accounts for 3 percent of world emissions, but it is expected that they will represent 5 percent of global emissions in 2050, taking into account the expected growth of the global economy and demand for transport. (CE 2013)

Therefore, the civil society as well as Governments and the shipping industry have recognized the increasingly more important international shipping industry in the activities of global GHG emissions reduction (Vlachos 2014). Thus, reducing emissions from shipping is a topical issue on the international policy agenda.
The range of feasible technologies and operational measures which are available to reduce exhaust emissions from ships creates the need for a rational and coherent system for the selection of the most appropriate measures. Cost effectiveness is a rational system of decision-making at the level of transportation companies.
Also, in order to choose the optimal solutions to reduce emissions, the owner of the vessel must have knowledge of existing technologies and measures, as well as keep in mind the side effects, operational and social implications which result from the application of these measures. At present, there is no unified approach with regard to the implementation of the solutions for reducing emissions of gases on the ship. Each transport company has a design of their own on the use of technologies and operational energy efficiency measures.
In recent years, decissions made by the transport companies have focused on the adoption of environmental measures that are simple and transparent. Of the solutions adopted, operational measures were the most attractive because they required low investment and moderate operating costs. Also, the implementation of many of these measures requires only the execution of programs that involve changes in management and training.
Increasingly restrictive regulations imposed by international maritime legislation create pressure on shipowners to implement aboard the ships technologies that require larger investments.
Thus, energy efficiency technologies will exist onboardthe ships that will be built in 2016.
The future scenarios show the useof LNG as fuel for naval engines due to the fact that the exhaust emissions fall within the limits imposed by the Marpol Annex VI (NOx can be reduced by 60%, SOx 90-100% and CO_2 by 20-25%) and due to the purchase price of 70% cheaper compared to HFO.(Bazari, 2011)
Encouraging efficiency and an increased sustenability in the maritime transport sector through the implementation of technical and operational solutions to reduce exhaust emissions,as well as better meeting the customer's expectations will maintain the competitiveness of the sector: worldwide by ensuring the functioning of commercial ties and at EU level by keeping the leading position in terms of quality. (CE 2013).

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