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Analysis and measurement of NOx emissions in port auxiliary vessels

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ABSTRACT: This paper is made NOx pollution emitted by port auxiliary vessels, specifically by harbour tugs, due to its unique operating characteristics of operation, require a large propulsion power changes discontinuously, also possess some peculiar technical characteristics, large tonnage and high propulsive power, that differentiate them from other auxiliary vessels of the port.
Taking into account all the above features, there are no studies of the NOx emission engines caused by different working regimes of power because engine manufacturers have not measured these emissions across the range of operating power, but usually we only report the pollution produced by its engines to a maximum continuous power.

1 SUMMARY

Nitrogen oxides emitted to the atmosphere, besides having a natural origin, also occur due to human activities. Although anthropogenic emissions are quantitatively comparable to natural emissions, its impact on the environment is higher because they are produced in very specific areas of the planet. This results in high local concentrations of NOx, with consequent damage to human health and the environment.

This paper is made NOx pollution emitted by port auxiliary vessels, specifically by harbour tugs, due to its unique operating characteristics of operation, require a large propulsion power changes discontinuously, also possess some peculiar technical characteristics, large tonnage and high propulsive power, that differentiate them from other auxiliary vessels of the port.

Taking into account all the above features, there are no studies of the NOx emission engines caused by different working regimes of power because engine manufacturers have not measured these emissions across the range of operating power, but usually we only report the pollution produced by its engines to a maximum continuous power.

There is also the problem with the ports that are located within an urban core.

The "port-city", that kind of ports that co-inhabit a city, has the biggest problem caused by pollutants emitted inside the port industries installed on it and on its periphery, also from ships arriving and dock, ships undocking, etc…Besides all those auxiliary vessels do their job, 24 hours a day, 365 days a year, inside of it.

These pollutants are emitted inside the port, because of the wind and other weather factors and the particular terrain of each territory carry the NOx to the town, causing environmental and health problems for the resident population.

The first goal is to establish the theoretical amount of nitrogen oxides that are emitted by a harbour tug maneuvers performed during docking, undocking and removal of merchant ships, depending on the power developed by it. Setting, therefore, a theoretical relationship between the power developed by the tugship during the performance of mentioned maneuvers and emissions of nitrogen oxides (NOx) during these.

In terms of the amounts of exhaust emissions, the International Maritime Organization (IMO)established air pollution caused by marine machines using emission models based on actual emission factors adopted from measurements performed on the machines on board or theoretical factors deduced from the respective equations of chemical reactions, combined with actual fuel consumption (based on international statistics of fuel sales).

There's been used a number of factors NOx provided by different organisms according to the power and according to the fuel consumption.

Table 1. EMISSION FACTOR 1: Methodology based on vessel power:

Emission rates for medium Speed diesel engines	
	kg/hours
NOx	$4{,}25 \cdot 10^{-3} \cdot P^{1,15} \cdot N$

P is the Engine power (kW) Engine load; N is the Number of engines.
Emission ranges for medium speed engines. Source: Lloyd's Register (1995): Marine Exhaust Emissions Research Programme: Lloyd's Register Engineering Services, London.

Table 2. EMISSION FACTOR 2: Methodology based on fuel consumption:

Emission factors for medium speed engines	
	kg/t fuel
NOx	59

NOx emission factors for medium-speed engines.
Source: Lloyd's Register (1995): Marine Exhaust Emissions Research Programme: Lloyd's Register Engineering Services, London.

Table 3. EMISSION FACTOR 3:

Emission factors for medium speed engines		
	kg/t fuel	g/kWh
NOx	59	13,8

NOx emission factors for medium-speed engines.
Source: Lloyd's Register of Shipping (1990): Marine Exhaust Emissions Research Programme: Steady State Operation, London.

After obtaining these results, they can be extrapolated to other ports operating with a tug of the same technical characteristics. Evaluating, therefore, the amounts of nitrogen oxides emissions emitted

The second objective is to measure, in situ, the actual emissions of nitrogen oxides produced by the tug. These NOx emissions will be measured in different ranges of power output by a gas analyzer combustion in both tugboat propeller engines. Will also be obtained, together with the measurement of NOx emissions, a number of operating parameters of the main engines (engine rpm, power supplied by the engine, engine load, specific fuel consumption, air temperature, etc.). There will be analyzed a large number of operations performed by the tug and measured the actual time is the tug to a power during each docking maneuver, undocking or removal and NOx emission values for each power. Knowing the total number of maneuvers that made the tug over one year (2009) may be obtained, depending on contamination and pollution power total over a year of operation the tug inside the port.

Knowing also the total number of tugs operating in the port is able to know the total pollution emitted by tugs in the inner harbour over a year.

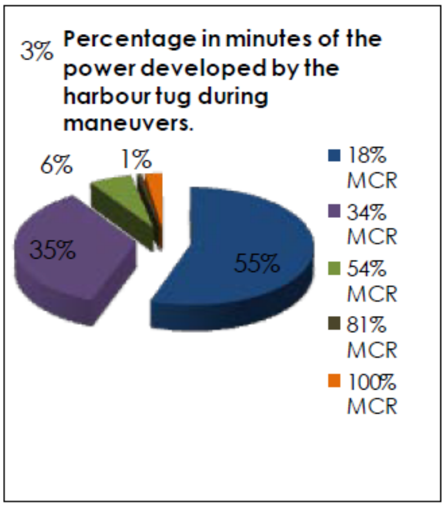
The third goal is to establish a comparison between the results obtained by using emission factors and by taking, in situ, real NOx emissions, approving or rejecting the use of such emission factors for ships operating with large variations power.

The fourth objective is to determine the power range that produces more pollution, for this ship types that work with a large variation of propulsive power per kilogram of fuel consumed.

This analysis will be performed, in the three methods using NOx emission factors, such as actual measurements made with the gas analyzer combustion. Obtaining the NOx emission amount of each drive motor of the tugboat, depending on the power developed by it in relation to the amount of fuel consumed.

At the end, it makes a number of conclusions to reduce or significantly mitigate NOx emissions and emissions harmful effects of these marine engines cause on the environment and on the health of the population, especially in port- city.

To obtain the percentage of operations in terms of the power developed by the tugs, it's been conducted a study on a sample of a total of 200 maneuvers docking, undocking and removal.



Furthermore, it has had to make an extensive study of the power provided by the tugboat when required maneuvers in docking, undocking or removal of merchant ships in the Inner Harbour.

These maneuvers sum up to 14,190 effective minutes and can be broken down according to the power supplied by the towing vessel.

There's been computed a total of 7868 minutes at 18% power, 4993 minutes at 34% power, 870 minutes at 54% power, 106 minutes at 81% power and 353 minutes at 100% power.

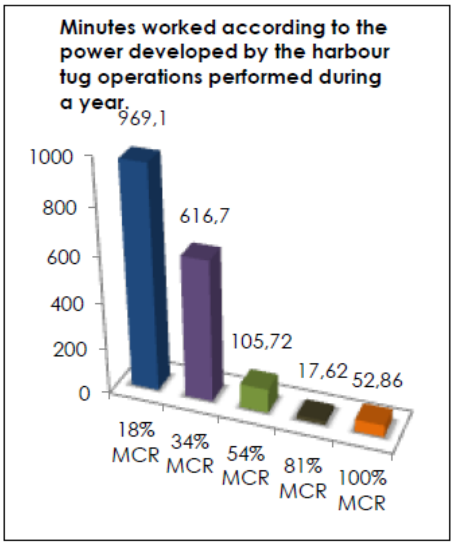


Figure 1. Graphics. Minutes worked according to the power developed by the harbour tug operations performed during one year.

2 RESULTS

2.1 *Comparative results tug "R1"*

To make the comparison between all results we will use the overall results for the tug "R1".

Pilot Instructions	Emission factor ❶ NOx emission	Emission factor ❷ NOx emission	Emission factor ❸ NOx emission	Combustion gas analyzer NOx emission
Minimum	9,12	10,79	11,92	9,03
Slow	18,96	19,76	22,52	15,22
Medium	32,23	29,61	35,72	24,15
3/4	51,36	43,35	53,57	40,94
Full	65,62	56,00	66,29	47,76

NOx Units: kg NOx/h

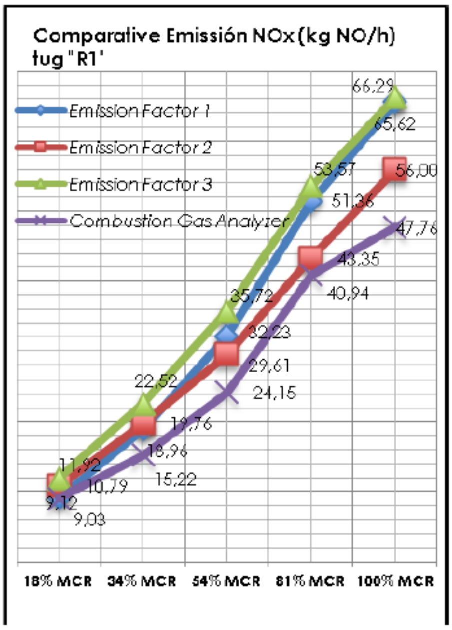


Figure 2. Graphic comparison chart NOx emissions (NOx kg/h) of the tug "R1", using the results obtained by using the three emission factors and the results obtained by the gas analyzer combustion.

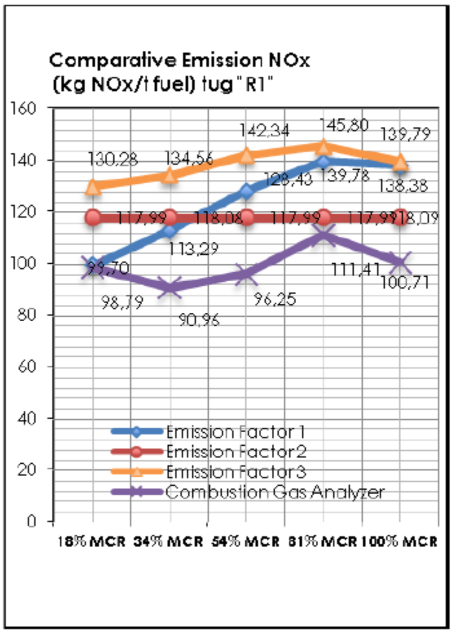


Figure 3. Graphic comparison chart NOx emissions (NOx kg/h) of the tug "R1", using the results obtained by using the three emission factors and the results obtained by the gas analyzer combustion.

2.2 *Comparative results tug "R3".*

To make the comparison between all results we will use the overall results for the tug "R3".

Pilot Instructions	Emission factor ❶ NOx emission	Emission factor ❷ NOx emission	Emission factor ❸ NOx emission	Combustion gas analyzer NOx emission
Minimum	9,47	10,96	12,32	10,21
Slow	18,82	19,32	22,38	17,88
Medium	32,20	29,43	35,70	30,08
3/4	51,40	43,23	53,61	49,36
Full	65,72	55,01	66,37	60,36

NOx units: kg NOx/h

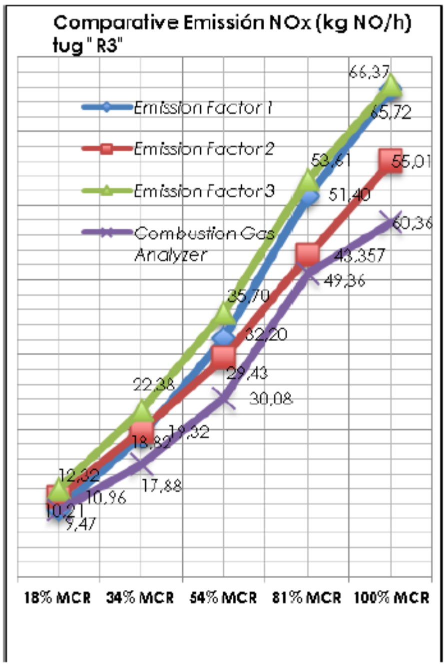


Figure 4. Graphic comparison chart NOx emissions (NOx kg/h) of the tug "R3", using the results obtained by using the three emission factors and the results obtained by the gas analyzer combustion.

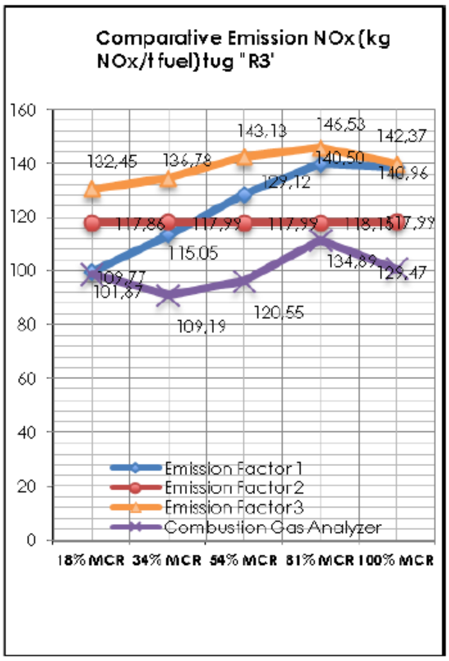


Figure 5. Graphic comparison chart NOx emissions (NOx kg / h) of the tug "R3", using the results obtained by using the three emission factors and the results obtained by the gas analyzer combustion.

2.3 *Comparative results tug "R6".*

To make the comparison between all results we will use the overall results for the tug "R6".

Pilot Instructions	Emission factor ❶ NOx emission	Emission factor ❷ NOx emission	Emission factor ❸ NOx emission	Combustion gas analyzer NOx emission
Minimum	9,07	11,17	11,86	8,63
Slow	18,84	20,37	22,39	17,04
Medium	32,23	30,46	35,72	28,71
3/4	51,48	43,61	53,68	45,64
Full	65,64	55,08	66,30	53,57

NOx units: kg NOx/h

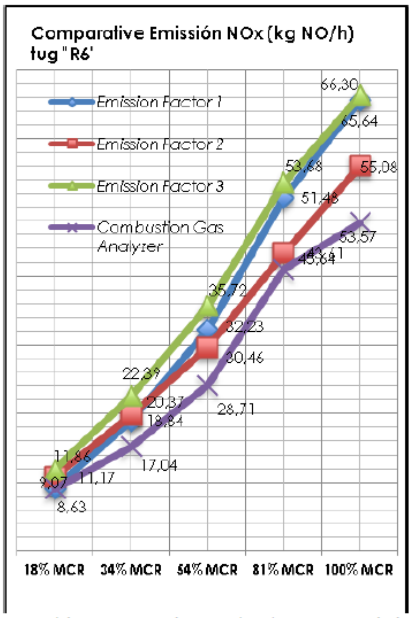


Figure 6. Graphic comparison chart NOx emissions (NOx kg/h) of the tug "R6", using the results obtained by using the three emission factors and the results obtained by the gas analyzer combustion.

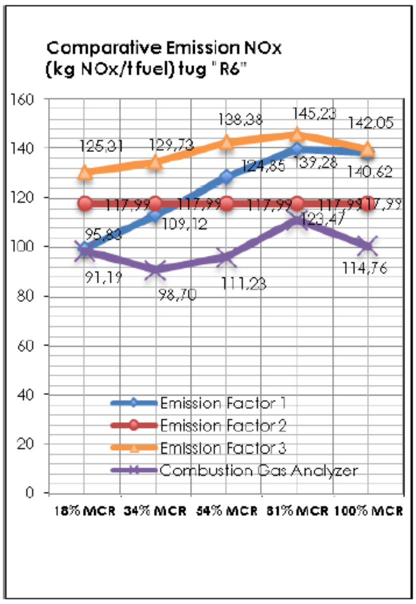


Figure 7. Graphic comparison chart NOx emissions (NOx kg/h) of the tug "R6", using the results obtained by using the three emission factors and the results obtained by the gas analyzer combustion.

2.4 *Comparative annual emissions tug*

Below is the comparison table of annual NOx emissions from tug type "R1", "R3" and "R6" in terms of the power supplied to perform towing maneuvers.

Table. Annual NOx emissions (kg NOx/year) of the tug type "R1". Using to calculate the 3 emission factors and the values obtained in situ with gas analyzer combustion "TESTO 350-S".

Pilot Instructions	Emission factor ❶	Emission factor ❷	Emission factor ❸	Combustion on gas analyzer
	NOx emission/ year	NOx emission/ year	NOx emission/ year	NOx emission/ year
Minimum	8842,746	10465,31	11554,77	8759,98
Slow	11693,24	12187,84	13889,07	9389,12
Medium	3407,93	3131,27	3777,18	2553,28
3/4	905,01	763,95	943,93	721,50
Full	3469,00	2960,53	3504,36	2525,09

NOx units: NOx kg/year

Table. Annual NOx emissions (kg NOx/year) of the tug type "R3". Using to calculate the 3 emission factors and the values obtained in situ with gas analyzer combustion "TESTO 350-S"

Pilot Instructions	Emission factor ❶	Emission factor ❷	Emission factor ❸	Combustion on gas analyzer
	NOx emission/ year	NOx emission/ year	NOx emission/ year	NOx emission/ year
Minimum	9185,42	10628,41	11942,60	9901,35
Slow	11610,85	11915,44	13803,96	11031,66
Medium	3404,92	3111,97	3774,26	3180,34
3/4	905,81	761,71	944,66	869,76
Full	3473,98	2907,96	3508,74	3190,70

NOx units: NOx kg/year

Table. Annual NOx emissions (kg NOx/year) of the tug type "R3". Using to calculate the 3 emission factors and the values obtained in situ with gas analyzer combustion "TESTO 350-S".

Pilot Instructions	Emission factor ❶	Emission factor ❷	Emission factor ❸	Combustion on gas analyzer
	NOx emission/ year	NOx emission/ year	NOx emission/ year	NOx emission/ year
Minimum	8795,74	10830,08	11501,27	8369,95
Slow	11619,12	12563,53	13812,47	10509,07
Medium	3407,93	3220,87	3777,18	3036,04
3/4	907,15	768,54	945,87	804,21
Full	3469,83	2911,69	3505,09	2831,88

NOx units: NOx kg/year

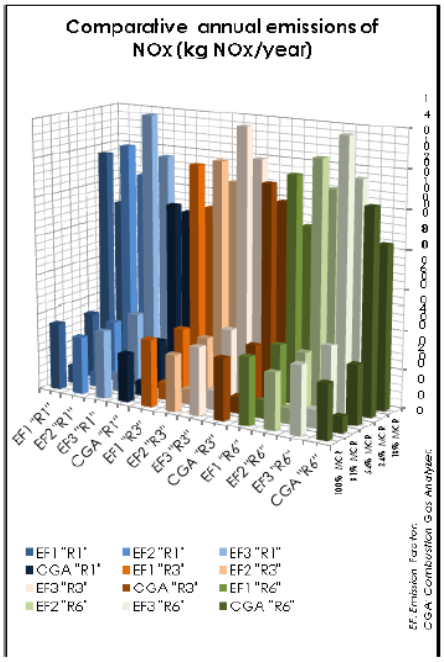


Figure 8. Comparison I annual NOx emissions (kg NOx/year) of harbour tugs type "R1", type "R3" and type "R6". Using the 3 to calculate emission factors and the values obtained in situ with gas analyzer combustion "TESTO 350-S".

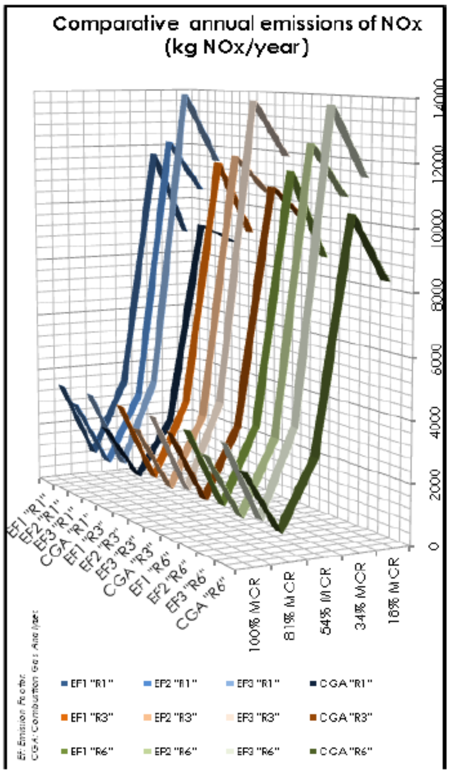


Figure 9. Comparison II annual NOx emissions (kg NOx/year) of harbour tugs type "R1", type "R3" and type "R6". Using the 3 to calculate emission factors and the values obtained in situ with gas analyzer combustion "TESTO 350-S".

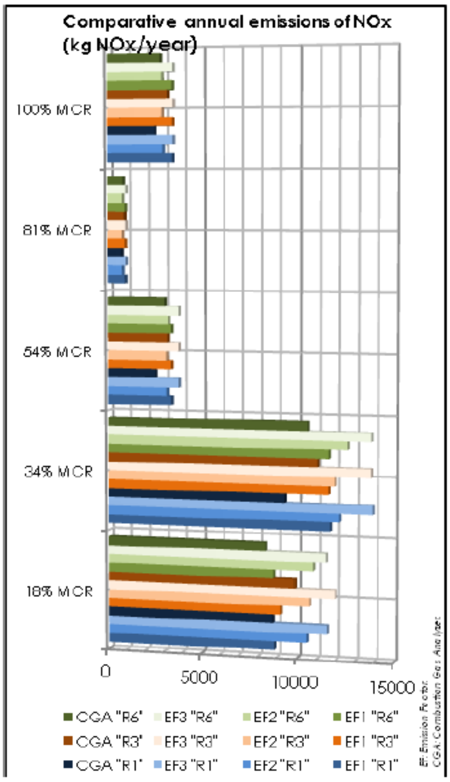


Figure 10. Comparison III annual NOx emissions (kg NOx/year) of harbour tugs type "R1", type "R3" and type "R6". Using the 3 to calculate emission factors and the values obtained in situ with gas analyzer combustion "TESTO 350-S".

3 CONCLUSIONS

It is found that the percentage of nitrogen oxides emissions calculated emission factor No. 1 (4.25 · 10-3 · P1, 15 · N = kg NOx/h) and No.3 (13.8 g NOx/kWh) are higher than those calculated with the emission factor No.2 (59 kg NOx/t fuel consumed).

The emission computed different emission factors from the minimum range machine (18% load and ≈ 431 kW) to full speed range (100% load and ≈ 2400 kW), to the ranges of low (34 % load and ≈ 816 kW), medium (54% load and ≈ 1293 kW) and three quarters (81% load and ≈ 1944 kW) is slightly increased. It is found that the nitrogen oxide emission in kg NOx/h, is slightly lower at low powers and as it increases engine power, increases the amount of nitrogen oxide emissions gradually, reaching a value maximum at full power (2400 kW).

Measurements of nitrogen oxide emissions analyzed in situ with combustion gases equipment to the same power range, we show a graph with the same behaviour for different powers of work, except for the maximum power (100% charging and 2400 kW). Said emission (kg NOx/h) at full power undergoes a slight tendency compared to the other recessive measured emission values and therefore does not extend the behaviour and gradual increasing of nitrogen oxides emissions at full power are present when using issue three factors.

The values of nitrogen oxide emissions obtained in situ gas analyzer combustion tugs are similar in all models analyzed tugboat (tug type "R1", type "R3" and type "R6").

If we analyze the NOx emission values (kg NOx/t comb.) Obtained in situ gas analyzer combustion and compared with those calculated with the three given emission factors showed that all emission graphs follow a same behaviour. The emission factor number 3 is the reaching values higher NOx emission. Comparing the NOx emission factor between No.1 and No.2, we see that NOx emissions are higher with the emission factor number 2 in the low power range and lower in the range of medium to high power.

The measures of actual NOx emissions (kg NOx / t comb.) Made in situ gas analyzer combustion and calculated emission factor No. 3, we show a graph with the same behaviour for different powers of job. This NOx emission maximum power, also experiences a slight recessionary trend compared to other measured emission values and therefore, does not extend the growing and progressive behaviour of nitrogen oxide emissions at full power. There is therefore a peak, which is reaching the maximum emission level of NOx (kg NOx/t comb.) to 3/4 of machine.

Therefore, the use of these emission factors could be generalized and should be used in a less restricted depending on the type and power of the engine, since it has no significant deviations between them, leading to emission values approximate values emission of nitrogen oxides real.

Performing maneuvers statistical study it is found that service for operational reasons, the working harbour tugs 55% of the minimum time machine, 35% of the time walking machine, 6% of the time at half speed, 1% three-quarter time machine and 3% of the time at full speed. With these percentages of working time, and taking the maximum and minimum annual pollution using the three emission factors and actual results obtained in situ gas analyzer combustion, we can calculate the percentage of total annual pollution (kg NOx/year) of the tugboat and to confirm that the major contamination is produced by this machine corresponding to low (42% -39%), followed by machine contamination to a minimum (31% - 37%), at half speed (11% -12%), full speed (10% -12%) and lower pollution produced machine three quarters (3%).

As a result of the comparison between the values of nitrogen oxides emission models calculated with emission factors and the values obtained in situ gas analyzer combustion, would that make a small review of the emission factors used to this calculation to resemble a more proportionate to actual results. Then we will have accurate emission values obtained with emission factors that might apply to such ships. It would also be desirable to perform this same type of measurements boat engines greater propulsion power, in order to verify that the emission factors used are formulated for engines operating at higher power.

In order to reduce pollution in the ports facilities, which would be considered as special protection areas for the purpose of reducing nitrogen oxide emissions, as most are located in densely populated areas, would be needed more research in engine design and technology to make them more efficient and less polluting:

- Promoting increased energy efficiency, ie perform more work with the same energy consumption. Researching in:
  - The design of the power transmission. The energy can be transmitted to the propeller of ways, by direct mechanical transmission, by mechanical transmission gearbox by electric drive or electric drive means controlled rate, reducing from 15% to 35% fuel. Driving a high efficiency is obtained with a rotating propeller at low revolutions per minute. Moreover, we should minimize the number of propeller blades to reduce blade surface and hence the frictional resistance. The propeller size will always be limited by the design of the boat, engine torque and draft of the port where operating.
  - Improvements of the design by optimizing the hull and superstructure. Normally developed in research hydrodynamic test tanks for large vessels.
  - Rate and optimization of indoor and outdoor lighting LED technology tug "Light- Emitting Diode", reducing fuel consumption tug auxiliary engines.
  - Recovering energy from the propeller through various mechanisms:
    - Coaxial contra- rotating propeller (CCRP). Consists of two propellers mounted one in front of the other and which rotate in opposite directions, recovering the rear propeller of the rotational energy which leaves the front propeller slipstream. Rear propeller to avoid cavitations problems, has a smaller diameter than the front propeller, and provides a lower load to the front propeller and therefore greater efficiency. Save between 10% -15% more power than a conventional propeller boat.
    - Blade wheel or wheel freewheeling Grim. Additional propeller is a freely rotating mounted behind the conventional propeller, designed to act as a turbine on the inside as on the outside propeller. This propeller recovers some of the energy lost in the wake produced by the conventional propeller and becomes an extra push. Improvements in power savings are about 10%.
    - Propeller nozzle. Consists of a propeller mounted on a fixed ring conduit providing a large mass of water supply to the propeller, improving the operating conditions and efficiency of the propeller. Is used in ship that require high power loads, since the duct generates additional thrust and reduces the power consumption by approximately 15%.
    - Pre-swirl devices. Are devices placed upstream from the propeller which is intended to improve the flow of water into the propeller to achieve greater uniformity of this, generating a pre-swirl in the opposite direction of rotation of the propeller and therefore improve propulsive efficiency. Save approximately 3% -10% power.
    - Integrated unit with rudder and propeller. Provides increased propulsion efficiency without losing maneuverability by adjusting the propeller and rudder in the town as a single drive unit. Power saving is estimated at 5%.
  - Reduced friction in pumps and pipes of all tug circuits. Performing an internal coating of these surfaces results in a reduction in electricity demand of the auxiliary engines between 2% and 4%.
  - Hull coatings. We know that the frictional resistance contributes very significantly to the total resistance, especially at low speeds. Therefore, you must make well hull maintenance to retain top performance, i.e., the rate obtained in connection with the consumption of power or fuel. Also the frictional resistance can be reduced by modifying the wet surface of the hull, injecting air bubbles around the hull of the boat hull.
  - Modification and optimization of various elements of the tug, such as coolers, turbochargers, nozzles, ventilation of the engine room, etc.
  - Maintenance and updating of the propellers models. Consists mainly of cleaning and polishing the rough surfaces of the propeller, as the polished surface of the same represents a decrease in fuel consumption of more than 3%. Also are changing propellers in small diameter operating at high RPM, Antique Boat by other larger diameter and operate at low RPM and are being achieved fuel savings of around 5% - 10%.
  - Combining different propulsion technologies. Currently there are hybrid tugs, which are powered by diesel engines when performing maneuvers harbour towage and electric propulsion when travelling, without requiring large propulsion power, to the maneuvers. These tugs reduced by approximately 44% and NOx emissions by 30% fuel consumption.
- Using fuels with lower fuel-cycle total emission per unit of work performed, as:
  - Bio-fuels. The first generation are made from sugar, starch, vegetable oils or animal fats. Bio-fuels some of these may be used in marine diesel engines but present some stability problems during storage, acidity, clogged fuel filters, formation of wax, etc. But mixing fractions of bio- derived fuels with conventional diesel fuel use is feasible from a technical perspective, but must complete the full compatibility study. Research is also in the process of conversion of biomass to liquid fuels to be used as marine fuel.
  - Liquefied natural gas (LNG or LNG "liquefied natural gas"). The LNG will be the fuel of the future for the ships, since their use is to reduce emissions of NOx, SOx and particulate matter also contains more hydrogen and less carbon than diesel fuel, thus also reducing CO2 emissions. Vessels using LNG are especially suitable if they have to work within the control areas or zones especially NOx emissions as

they can fulfill the Tier III emission levels without any post-treatment of exhaust gases. The only absolute requirement is that the port where the vessel operates have a supply of LNG terminal, as in Barcelona, Huelva, Bilbao, Cartagena, etc. It is for this reason that the tugs are very suitable and suitable vessels for LNG as fuel consumption when operating on these ports.
  - Also being investigated in other fuels to be used on tugship, such as liquefied petroleum gas (LPG "liquefied petroleum gas"), including propane ethanol blended with diesel fuel, as the E- diesel, Oxydiesel, oxygenated diesel, etc..; the Symtroleum as synthetic diesel, etc..
- Using technologies of emission reduction:
  - Fuel modifications includes fuel-water emulsion and the use of fuel with low nitrogen content. The fuel-water emulsion reduces NOx emissions about a 20%.
  - Switching the use of different fuels. Using diesel fuel with low sulfur content and periodically switching fuel for a very low sulfur (ULSD "ultra low sulfur diesel").
  - Modifications of air humidification and load includes reducing the temperature through the exhaust gas recirculation (EGR), decreasing the oxygen concentration inside the cylinder and reducing NOx in approximately 35% or the using internal membranes which reduce the oxygen partial pressure in said air, decreasing by about 6% in NOx emission.
  - Modifications in the combustion process includes adjusting the advance of fuel injection, compression rate, etc. to minimize the formation of NOx. For example, direct injection of water into the interior of the cylinders or by using the Miller cycle reduces the charge air temperature. With the use of engines using natural gas is reduced by approximately 90% the emission of NOx.
  - In order to reduce NOx emissions by treating in the exhaust gases, there is currently a catalytic reduction system (CRS). Other post-treatment technologies are being researched and developed, as the cleaner of NOx, the NOx absorption traps, diesel particulate filter (DPF "Diesel Particulate Filter"), diesel oxidation catalysts (DOC "Diesel Oxidation Catalysts"), filters mixture catalysts (CWMF "Catalyzed filters Wire Mesh") to reduce by 9% the emission of NOx catalytic technology "lean NOx" which reduces by 30% and 50% NOx, etc.

Because of annual NOx pollution produced by harbour tugs, it should investigate the possible use and application of these technologies to reduce pollution and be more respectful of the environment and environmental work. This practice should also apply to the large number of merchant ships made inputs, outputs and also remain moored in harbour with auxiliary motors are running, uninterrupted emitting nitrogen oxides and other greenhouse gases into the atmosphere, to the great amount of traffic present in the port (trucks, cars, motorcycles, etc.) freight trains circulating in the inner harbour and port machinery countless running internal combustion engines.

It can also reduce pollution caused by the emission of nitrogen oxides by harbour tugs in the port areas, by:

- Optimizing any towing:
  During the time the tug is low (55% of the total time of operations), the tug is on stand-by without doing any work waiting to be required. With the statistics of annual labour of every tug, it is considered that could reduce by more than two-thirds the emissions produced in this power range. Therefore, it produces unnecessary pollution and could be avoided if there's a reduction in the operating time harbour tug. This reduction is possible with good logistics and planning maneuvers entry, exit and removal.
  The emission of these nitrogen oxides produced minimal machine can also be cut in half, if waiting times or stand- by for a main engine of the tug and it is only with a drive motor running. This does not imply a reduction in the security of the tug.
- Reducing the speed of the tug:
  NOx emissions is proportional to the speed of the ship resulting from propeller cubic law, therefore reducing the speed of the tug reduce the emission of NOx. In addition to reduce approximately 10% the speed of the tug, reduce by 25% the fuel consumption of this.
- Reduction of maximum propulsion power tug:
  It should also be reconsidered in view of the short time of use of the maximum power of the tug (only 3% of the total time at maximum power maneuvers and 1% of the time of maneuvering to 3/4 power), reducing the propulsion power of harbour tugs. With the experience is verified and confirmed that it is not needed as much power propulsion in harbour tugs, and you can perform the same maneuvers of docking, undocking and removing smaller tug propulsion power and therefore less polluting.

We have to finally say that with the implementation of these measures would avoid or significantly reduce the harmful effects posed by nitrogen oxides emitted from marine engines, on the health of the population. This risk is further increased in the "port-city" that co- inhabit a city where nitrogen oxides are emitted inside the port, due to winds and other weather factors and the particular terrain of each territory, take these oxides of nitrogen to the town, causing major environmental problems (changes in red tide phytoplankton, acid rain, etc.) and health services to the resident population (reduced levels of lung function, impaired the genetic material of cells, premature death, etc.).

BIBLIOGRAPHY

1. United Nations Convention Framework on Climate Change. [Online]. [consultation: July 2009]: <http://unfccc.int7essentia_background/convention/items/2627. php>
2. IMO. Main events in IMO´s work on limitation and reduction of greenhouse gas emissions from International Shipping. London: November 2008.
3. Intergovernmental Panel on Climate Change (IPCC). Guidelines for National Greenhouse Gas Inventories.

[Online]. [consultation: July 2009]: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/in dex.html >.
4. R. Thomas, R. D. Lauretis, J. P. Fontelle, N. Hill, N. Kilde, K. Rypdal. Shipping Activities EMEP/CORINAIR Emission Inventory Guidebook. Copenhagen, Denmark: 2002.
5. J. J. Corbett, H. W. Köhler. Updated emissions from ocean Shipping. 2003. Doi:10.1029/2003JD003751.
6. U.S. Environmental Protection Agency. Emissions factors and AP 42. [Online]. [consultation: August 2009]. Disponible en: <http://www.epa.gov/ttn/chief/ap42/>.
7. Lloyd´s Register Engineering Services. Marine Exhaust Emissions Programme (Main report, steady State operation and slow Speedy addendum). Croydon, UK: 1995.
8. Entec UK Ltd for European Commission. Quantification of emissions from ships associated with ship movements between ports in European Community. [Online]. 2002 [consultation: September 2009]: <http://ec.europa.eu/environme nt/air/quality/background.htm# ansport >.
9. IMO. Resolution MEPC.82(43). Guidelines for monitoring the World-wide average sulphur content of residual fuel oils supplied for use on board ships. [en linea]. 1999 [consultation: September 2009]: <http://www.imo.org/includes/blastDataOnly.asp/data_id%3D15684/82%2843%29.pdf>.
10. IMO. Resolution MEPC. 170(57). Guidelines for exhaust gas Cleaning Systems . [Online]. 2008 [consultation: September 2009]: <http://www.imo.org/includes/blast DataOnly.asp/data_id%3D22480/170%2857%29.pdf>.
11. CIMAC. Guide to diesel exhaust emissions control of NOx, SOx, particulars, smoke and CO2 – seagoing ships and large stationary diesel power plants, 2008. CIMAC recommendation 28. [Online]. 2008 [consultation: September 2009]: <http://www.cimac.org >.
12. R. Betz. Emissions Trading to combat climate change: The impacto f sheme design on transaction cost. Sydney, Australia: Center for Energy and Environmental Markets, 2007.
13. J.J. Corbett, J.J. Winebrake, E.H. Green, P. Kasibhatla, V. Eyring, A. Lauer. Mortality from ship emissions: A global assessment. Envronmental Science & Technology. 2007. 41: 8512-8518.
14. V. Eyring, H.W. Köhler, A. Lauer, B. Lemper. Emissions from International Shopping: 2. Impacto f future Technologies on scenarios until 2050. J. Geophys. 2005. 110.
15. P.M. Einang. Gas fuelled ships. 25th CIMAC World Congress on Combustion Engine Technology. Viena, Austria: 21-24 May 2007.
16. R. Ollus, K. Juoperi. Alternative fuels experiences for medium- speed diesel engines. 25th CIMAC World Congress on Combustion Engine Technology. Vienna, Austria: 21-24 May 2007.
17. J.J Corbett. New direction: Designing ship emissions and impacts research to inform both science and policy. Atmospheric Environment, 2003. 37: 4719-4721.
18. J.J Corbett, P.S. Fischbeck, S.N. Pandis. Global nitrogen and sulphur inventories for oceangoing ship. Journal of Geophysical Reseach, 1999. 104: 3457-3470.
19. P. Kasibbhatla, I. Levy, J.J Corbett, S.N. Pandis, , P.S. Fischbeck, W.J. Moxim, G.J. Frost, D.D. Pattish, T.B. Ryeson. Do emissions from ships have a significant impacto n concentration of nitrógeno oxides in the marine Boundary layer?. Geophysical Reseach letters, 2000. 27: 2229-2233.
20. V. Eyring, H.W. Köhler, J. Aardenne, J. Lauer. Emissions from International Shipping: 1.The last 50 Years. Journal of Geophysical Reseach, 2005. 110: D17305, doi: 10.1029/2004JD005619.
21. EMEP/CORINAIR. Emission Inventory Guidebook. Copenhagen, Denmark: 2002.
22. Wärtsillä. Boosting energy efficiency. Energy efficiency catalogue, 2008.
23. IMO. Update Study on Greenhouse Gas Emissions from Ships. Phase 1 Report, September 2008.
24. United Nations Conference on Trade and Development (UNCTAD). Review of Maritime Transport. 2008.