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Analysis of ship performance data for the evaluation of marine engines emissions in ports

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ABSTRACT: A reasonable prediction of the air emissions from ships at port is crucial to evaluate the impact on the surrounding inhabited zones and to evaluate and adopt effective countermeasures. A quantification of the power utilized by ships in port is crucial, since the level of emissions from an engine strictly depends on the power supplied. In order to assess the power profile of a vessel during navigation, maneuvering and docking in the port area, several approaches are possible, although experimental measurements are the most reliable source of data. This paper presents results of the post-processing analysis carried out on a large amount of emission data recorded during the navigation of two small ferries operating in the Gulf of Naples. The research activity aims to identifying the different behavior of the propulsion engine in terms of power and emissions (mainly NO_x, CO_2, Hydrocarbons (HC) in addition to the content of O_2 in the exhausts), during the navigation and maneuvering phases of the vessel in port area. The results are presented by means of numerical tables representing the dependence between emissions patterns and significant engine operational data. The long-term goal is to use such results in connection with the simulation of the engine working conditions to derive a prediction of the emissions.

1 INTRODUCTION

The problem of pollution due to maritime activities in the ports of the so-called "water cities" takes on increasing priority. The worldwide-recognized need to reduce the effects of pollution, both and air, asks for increasingly stringent regulations, especially when ships (together with their noise and exhausts) are close to the people (Coppola et al. 2018; Iodice et al 2015, 2018; Karl et al. 2019, Murena et al. 2018, Mocerino et al. 2020).

The problem, especially as for air pollution, is increasingly felt in the maritime field, which is not always up to date and ready to respond with effective solutions to comply with the regulations issued (Battistelli et al. 2012; Quaranta et al. 2012, Toscano & Murena 2019).

Therefore, it is necessary to characterize, as precisely as possible, the pollutants emission from the engines powering the various types of ships arriving at the harbours, and to carry out, as much as possible, continuous and reliable monitoring of the emissions in the port areas. Many problems arise in setting up a research like this: the main goal should be to monitor and reduce the overall emissions in ports (generally in very inhabited zones) but to this end, first of all a systematic data logging activity should be set with the aim of collecting data about exhaust gas of all ships in ports. Afterwards, by means of robust simulation applications, the diffusion of the noxious substances in the air (NO_x, SO_x, HC, CO_2 and so forth) should be predicted in order to define the scenario created by the presence of many ships in the same port.

Finally, in order to assess/validate the results of the analytic applications; another series of tests on field should reveal the real distribution in the atmosphere of the elements coming from the funnels of the ships. While considering that this series of information will involve any single ship entering the port (in the port of Naples the number of ships expected every day is around 100), it is clear that the size of this activity could result very large. Due to the size of this research program, a step-by-step procedure is necessary; in this work a part of this procedure is considered and, specifically, the knowledge of the power produced in port by the ships engines. Indeed, the only way to know the amount of pollutants emitted from any ship is the knowledge of the power rated by engines. Unfortunately, this datum is rarely available, due to the reticence of ship-owners in spreading data about their fleet; therefore it is necessary to resort to analytic methods whose results need

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be validated - by experimental tests - in order to be reliable. Of course, the final goal of all this should be the development of a complex tool capable of predicting the air pollution starting from the number of ships in port and their characteristics.

In fact, such tool would be very useful and it could represent a very important tool to regulate the ship traffic, to sanction the emission exceeding the maximum tolerable values, to decide in a reasonable way the distribution of the ships in the available wharves in port.

However, this can be achieved only as a result of the abovementioned procedure, i.e.: a relevant number of campaigns of data logging on site, measurements of the main noxious emissions, a real time elaboration of logged data with the study of their diffusion in the environment with the prediction of the local and global pollution due to the marine activities. Many studies have approached the problem: Corbett et al. (2010) studied the emissions of black carbon and other pollutants into the Artic area presenting a mean term scenario, revealing the influence of the emissions on the local climate and indicating some possible countermeasures. Others (De Melo Rodríguez et al. 2017), starting from the fuel consumption data in port of 30 ships, provided an estimate about the emission of the main pollutants in the air of the port of Barcelona (Spain). Corbett et al. (2009) evaluated whether a reduction in ship speed can lead to a significant decrease in CO_2 emissions and to a potential economic advantage for ships calling US ports. In addition, Peng et al. (2016) carried out tests on site on three cruise ships, in order to measure and analyze the particles emitted by their funnels. The complexity of these investigations, their costs and the enormous size of the research activity involved, could not lead to a common, complete and effective result, forcing the world of the science to the abovementioned step-by-step procedure. All the scientific effort in this field leads more to a contribution on particular aspects of the problem rather than a complete procedure to measure and contain the emissions in port. The problem of monitoring the environment in port areas does not seem to have a final solution at hand In this sense, the present work is to be considered a contribution representing a real scenario of emissions from two different kinds of ships, whose characteristics will be declared later.

2 EXPERIMENTAL CAMPAIGN

The data logging campaigns were carried out on two ships owned by CaReMar, the Company that grants the connection between the port of Naples and the islands of the Neapolitan gulf. The first tests were made in 1995 on the ship *Sibilla (Ship 1*, a slow passengers + cars ferry boat) while the second ones in 2003 on the cat *Achernar* (S*hip 2*, a passenger high speed vessel) both in the routes to and from the islands Procida, Ischia and Capri.

Table 1. Ships.

Ships	Ship 1	Ship 2
IMO number	7717250	9086332
Hull type	Monohull	Catamaran
L_{BP}	64.30 m	42.12 m
L_{OA}	69.59 m	44.00 m
B	14.00 m	10.52 m
D	3.61 m	1.83 m
Displacement	2073 t	153 t
Propulsion type	2 x CPPs	2 x Waterjets
Nominal ship speed	16 kn	30 kn
Overall propulsion power	2x1850 kW @1100 rpm	2x2000 kW @2000 rpm
Engines	2x GMT B230.12	2XMTU 16V396

The main characteristics of the two ships are reported in Table 1.

In both cases, a data logging system was capable to register the main parameters of the propulsion and navigation; in some cases, an exhaust gas analyzer was used in order to log the concentration of the main pollutants in the exhausts.

The main characteristics of the data logging system used for the campaigns are reported in Table 2, while Table 3 shows the timetable for the two ships monitored.

The monitored parameters were torque on the propeller shaft (kNm), power (kW) rpm (g/min), specific fuel consumption (cm^3/s) and exhaust gas temperature (^OC).

The pollutants measured are, HC (ppm), CO (% vol), CO_2 (%vol), NO_X (ppm) were measured together with the concentration of O_2 in the air. Since both vessels work with low-sulphured fuels, SO_x was not recorded (Cooper 2001).

The vessels studied are mainly different in hull geometry and propulsion type, being *Ship 1*

Table 2. Data logging system.

Parameter	Sensor	Manufacturer
Torque	Extensimetric torque meter	Binsfeld Eng.
RPM	Magnetic pick-up	
T_{AIR} [^OC]	J thermocouples	Tersid
T_{WATER} [^OC]	J thermocouples	Tersid
$T_{EXHAUST}$ [^OC]	K thermocouples	Tersid
Ship speed	DGPS	
Ship position	DGPS	
NO_X, HC, CO, CO_2, O_2	Gas Analyser	TecnoTest
Data logger		Nat. Instruments

Table 3. Timetable (Na= Naples, Is= Ischia, Pr= Procida).

Ships	Route and departure time	Date
Ship 1-**1**	Na-Pr-Is 04,30	24/06/95
Ship 2-**1**	Is-Na 08,50	26/06/03
Ship 2-**2**	Na-Pr-Is 09,55	“
Ship 2-**3**	Na-Is 13,10	“
Ship 2-**4**	Is-Na 14,10	“
Ship 2-**5**	Na-Is 07,50	27/03/03
Ship 2-**6**	Na-Is 09,50	“
Ship 2-**7**	Is-Na 12,05	“
Ship 2-**8**	Na-Is 13,10	“
Ship 2-**9**	Is-Na 14,10	“

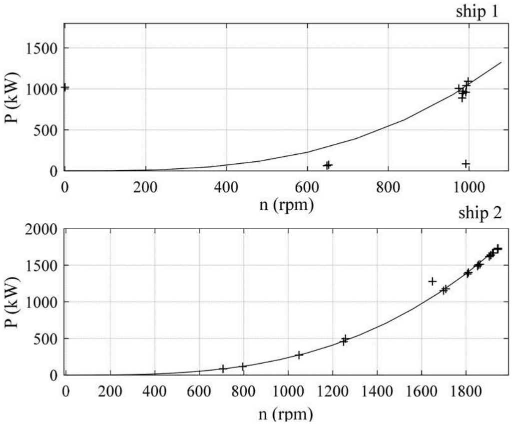

Figure 1. Rpm-power curves and experimental data. On the top *Ship 1*, on the bottom *Ship 2*.

a monohull equipped with controllable pitch propellers (CPPs) while *Ship 2* is a catamaran driven by two waterjet units, but enough similar in the main engines power. Figure 1 illustrates the power vs rpm curves for both ships, where the solid lines indicate the cubic propeller curves, while the cross points represent the average values obtained from the steady state conditions analysis. The figure shows that the data measured for *Ship 2* are perfectly set on the cubic line, thus reproducing the typical behavior of a jet impeller (Altosole et al. 2012). On the contrary, the required power is slightly lower for *Ship 1* at low revolutions, revealing a change in the propeller pitch, being *Ship1* equipped with CPPs.

The time histories of all the measured parameters are similar to the speed curves illustrated in Figure 2.

3 NUMERICAL ANALISYS OF EXPERIMENTAL DATA

Once gathered the raw data, they were post processed to evaluate some specific emissions, especially as regards nitrogen oxides, in view of the use of the same data for the validation of a numerical simulation model reproducing the engine behavior. To this end, it is important to associate NO_x emission values to the engine performance, therefore the results of measurement has been converted from concentration in ppm into specific emission in g/kWh.

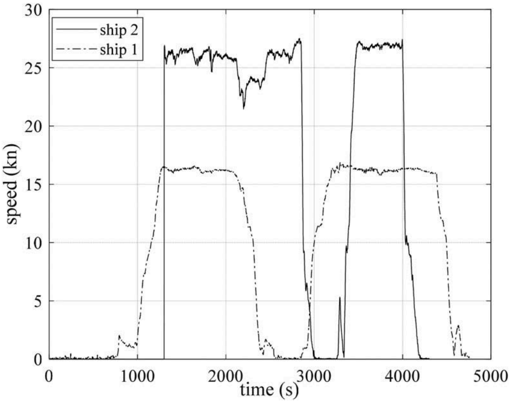

Figure 2. Example of time histories acquisitions for the two ships.

In order to obtain this, the NO_x values, measured in ppm by the instruments, have been processed. Four methods have been considered for the conversion.

3.1 *NO_x conversion: Method A*

The first conversion performed is based on the torque and engine data and chemical-physical parameters of the process.

As for nitrogen oxides in g/kWh, the following formula is used:

$$\mathrm{NO_x} = \beta \cdot \frac{\mathrm{NO_x} \cdot (\mu_{nox}/\mu_{\mathrm{air}}) \cdot \mathrm{V_c} \cdot \rho_{air} \cdot \eta_m \cdot \eta_v}{|C| \cdot 10^3} \tag{1}$$

where C = propeller shaft torque measured in kNm; NO_x= nitrogen oxides ppm; β = numerical correction equal to 0.000277; μ_{NOx} = nitrogen oxides molecular weights equal to 44.48 g/mol; μ_{air} = air molecular weights equal to 28.962 g/mol.

Table 4 reports the characteristics of the engines.

Table 4. Characteristics of the engines.

	Ship 1	Ship 2
V_c, cylinder capacity [m^3]	0.134	0.063
η_m, mechanical efficiency	0.950	0.950
τ, ratio between propeller and motor	3.85	2.33
η_v, volumetric efficiency	1.20	2.00

3.2 *NO_x conversion: Method B*

According to Balzani (2014), the specific emissions in g/kWh are obtained by means of equation (2):

$$NO_x = 0.87 \cdot C_s(g/kWh) \cdot NO_x(ppm)/CO_2(ppm) \tag{2}$$

where C_s = specific fuel consumption; and 0.87 is the percentage by mass of Carbon in the fuel.

3.3 *NO_x conversion: Method C*

By this conversion method, NO_x emission is depending on the airflow rate; the latter can be considered as a function of the air fuel flow ratio (A/F), estimated downstream of the emission measures by Heywood (1988):

$$\frac{A}{F} = 4.773 \cdot \left(\frac{\mu_{air}}{\mu_f}\right) \cdot \frac{(CO_2)+\left(\frac{CO}{2}\right)+\left(\frac{H_2O}{2}\right)+\left(\frac{NO}{2}\right)+(NO_2)+(O_2)}{(HC)+(CO)+(CO_2)} \tag{3}$$

where μ_{air} = air molecular weight; μ_f = fuel molecular weight fixed to 13.89. Between brackets, the measured concentrations of the single chemical compounds.

The concentrations of NO and NO_2 have been neglected, while the molar percent water in the combustion products has been estimated as:

$$H_2O = 0.5y \cdot \frac{(CO_2) + (CO)}{(CO)/K[(CO_2)] + 1} \tag{4}$$

where K = constant value equal to 3.50; and y = H/C ratio of the fuel.

Thus, it is possible to assess the flow rate of air (m_a):

$$m_a = C_S \cdot P \cdot (A/F) \cdot 10^{-3} \tag{5}$$

where C_s = fuel consumption in g/kWh; P = engine power in kW; and A/F = air fuel ratio.

The final relationship for NO_x conversion into g/kWh is:

$$NO_x = (m_a \cdot NO_x \cdot 10^{-6})/(\rho_{air} \cdot P) \tag{6}$$

where m_a= flow rate of air in kg/h; NO_X = the concentration of NO_X in μg/m^3; ρ_{air}= the air density in kg/m^3; P= engine power in kW.

3.4 *NO_x conversion: Method D*

In this case, the specific emissions are obtained by fixing a fuel air ratio equal to 35, which, assuming a stechiometric ratio of 14.6, is equivalent to a λ=2.4.

Finally, the airflow rate and NO_x in g/h have been calculated according to method C, by equations (5) and (6).

4 EMISSIONS AND ENGINE BEHAVIOUR

This chapter presents some qualitative and quantitative trends of the results achieved from the experimental campaigns. The temporal acquisitions clearly show peaks in correspondence of the acceleration and deceleration phases of the ships. The first methodology used (method A), although effective, is customized for these types of ships and therefore cannot be generalized.

The method B, fairly simplified, offers values of first attempt and to be obtained in the absence of more detailed information, necessary for the application of the other methods presented.

For all the ship runs analyzed, method B offers the specific emissions lower and far from the classics Emission Factor (EF) (Trozzi C. et al 2016) proposed for these types of vessels (see Figure 3 for *Ship 2*).

Methods C and D, mainly for the navigation phases, return practically coincident results.

Consequently, they have been considered as the two most accredited methods for these types of analysis; method C, in particular, is easy to apply when all the concentrations of pollutants from the engine exhaust gas are known. Method D allows an estimate of the specific emissions once the air fuel ratio is assumed and not calculated by equation (3): therefore the procedure may be usefully followed in case of lack of information about the several chemical compounds.

According to Trozzi (2016), the NOx emission factors for the main engine (high-speed diesel), burning marine gas oil (MGO), are 11.2 g/kWh for cruising condition and 8.9 g/kWh for phase of maneuvering and hotelling.

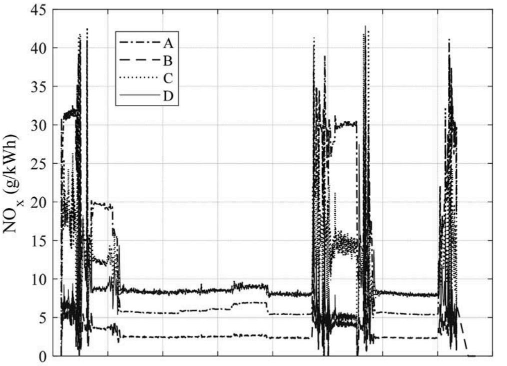

Figure 3. Comparison among the four methods considered for calculating NOx-specific emissions *(Ship 2).*

Regarding the maneuvering phases, the two methods are opposite: the first, Method C, provides a higher specific emission of NO_x in comparison with the navigation condition; on the contrary, the second one, Method D, provides an average lower specific emission (if peaks due to measurement errors are excluded) during the maneuver. In accordance with the results found by Trozzi (2016) in maneuver condition, the method D is chosen for the comparison in Table 5.

As a general comment, the average values for *Ship 1* and *Ship 2* are lower than EF reported by Trozzi. This should be due to a difference in engine efficiency and fuel characteristics. In addition, the behavior of the two ships for maneuvers in port is similar; while comparing the two phases for each ship, it is also noted that the ratio (b/a in the Table 5) is quite similar to that proposed by Trozzi.

With regard to CO_2 emissions, the data are shown (as % volume) for the two ships in Figure 4.

Figures 5, 6 and 7 respectively show the efficiency of the *Engine 2,* in terms of specific fuel consumption and NO_X and CO_2 emissions measured at the power cubic line of the jet impeller.

Unfortunately, a comparison with *Engine 1* is not possible due to the lack of useful emission data from the experimental campaign of *Ship 1*.

As shown in the figures, a maximum NO_X emission value (Figure 6) is found at the minimum specific fuel consumption (Figure 5).

Table 5. EF comparison between experimental data and literature (Trozzi 2016).

NO_x Specific emissions (g/kWh)	Ship 1	Ship 2	EF Trozzi
Cruise (**a**)	6.38	8.39	11.2
Maneuvering (**b**)	5.50	7.40	8.9
Ratio **b/a**	0.86	0.88	0.79

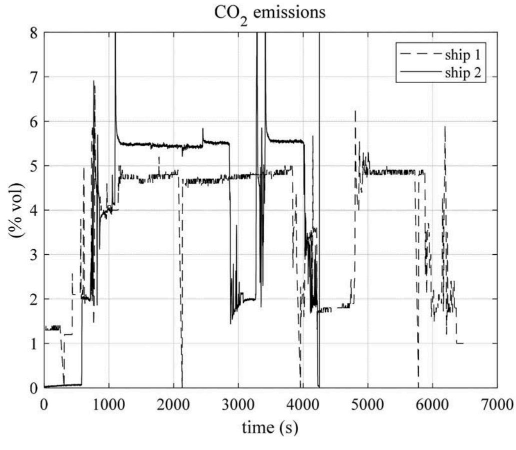

Figure 4. Time history of CO_2 emissions for the two ships.

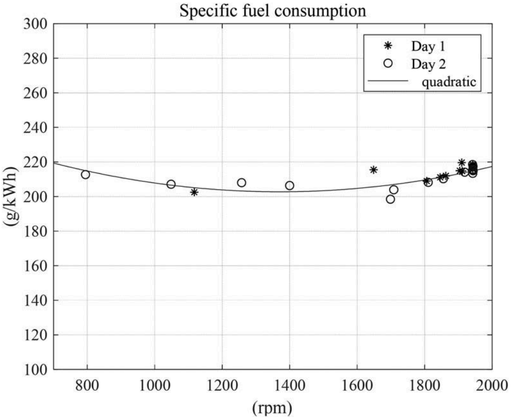

Figure 5. Specific fuel oil consumption (SFOC).

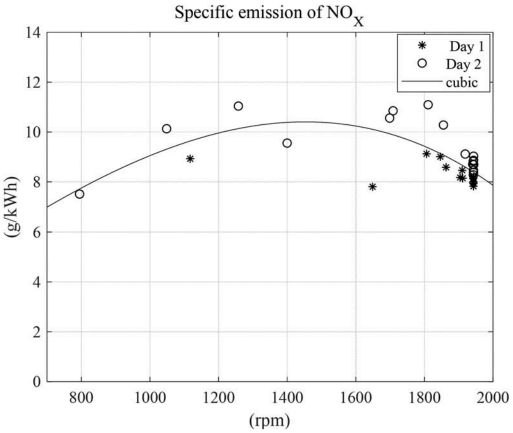

Figure 6. Specific emission of NO_X.

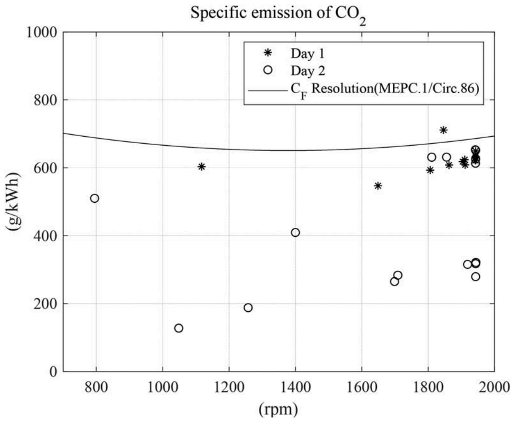

Figure 7. Specific emission of CO_2.

As for CO_2, experimental data in Figure 7 are more scattered (a temporary unavailability of the CO_2 sensor in the campaign of the second day is conceivable), however it is possible to imagine a minimum around 1300÷1500 rpm, as in the case of Figure 5. The latter consideration is supported by the comparison with the solid line represented in Figure 7 and obtained from multiplying the emission factor ($C_F = 3.206\ t_{CO2}/t_{fuel}$ for Gas Oil) available in IMO 2014 by the SFOC data reported in Figure 5.

Figures 8 and 9 show the flow rates of NO_X and CO_2 as a function of the load on the engine, including both steady-state and transient conditions.

Table 6 shows the total fuel consumption for *Ship 1* and *Ship 2* (during the first test day), while the total emissions of nitrogen oxides and CO_2 are shown inTable 7.

The last column of the Table 7 indicates the percentage of emissions produced in port during the ship's arrival and departure (i.e. navigation at reduced speed, maneuver and mooring).

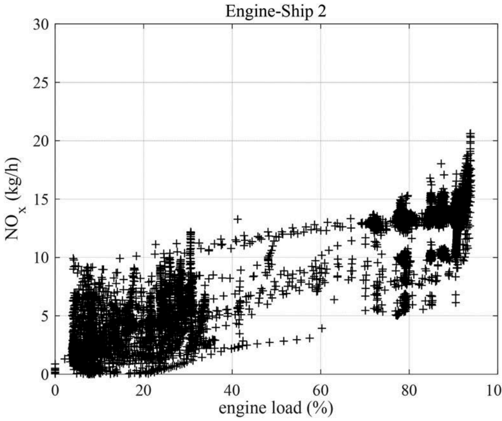

Figure 8. Flow rate of NO_X.

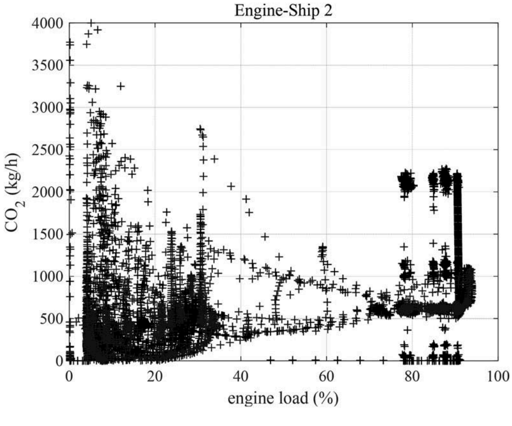

Figure 9. Flow rate of CO_2.

Experimental data show that the two ships emit on average the same percentage of pollutants in port, i.e. around 20% in NO_x and around 17% in CO_2, and the remaining percentage during navigation (see Table 7).

As regards the rate of O_2 and HC from the engine exhaust gas, statistical data are illustrated respectively in Table 8 and Table 9.

Unfortunately, some inaccuracies doe to zeroing and/or spaming phases of the measuring instruments occurred during the experimental campaign and reduced the emissions data useful for the present analysis.

Table 6. Total fuel consumption.

Ship	FC (t)
Ship 1-**1**	1.65
Ship 2-**1**	1.22
Ship 2-**2**	1.28
Ship 2-**3**	1.27
Ship 2-**4**	1.27

Table 7. Total emission of NO_X and CO_2 and the % emitted during the maneuvering phases.

Ship	NO_X	CO_2	In port	
			NO_x	CO_2
	(kg)	(t)	(%)	
Ship 1-**1**	37.38	3.81	17.39	17.60
Ship 2-**2**	49.83	3.67	20.31	17.14
Ship 2-**3**	48.72	3.58	20.52	14.72
Ship 2-**4**	47.36	3.62	21.11	18.78

Table 8. Data statistics for O_2 content (%vol) in exhaust gas.

Ship	Min	Max	Mean	Standard deviation
Ship 1-**1**	12.91	21.1	15.1	1.79
Ship 2-**2**	2.74	22.37	13.92	2.82
Ship 2-**3**	4.65	21.04	12.92	2.93
Ship 2-**4**	4.67	22.6	13.48	3.54

Table 9. Data statistics for the emissions of HC (ppm).

Ship	Min	Max	Mean	Standard deviation
Ship 1-**1**	0.00	26.9	14.2	3.31
Ship 2-**2**	0.00	32.6	6.40	6.94
Ship 2-**3**	0.00	14.8	0.77	2.45

5 CONCLUSIONS AND FUTURE WORK

This work presents the results of a post processing analysis regarding experimental data in pollutants production from marine engines. The main purpose is to draw useful considerations for the numerical modeling of air pollution processes in “water cities”. To this end, emissions measurements were carried out for two small ferries operating in the Gulf of Naples. Some methods to associate the emission rates to engine power have been illustrated, identifying the most appropriate one and presenting the most reliable results. Despite the similar power of the two different main high speed diesel engines, some instruments failures have reduced the large initial availability of the recorded data, not allowing a proper comparison between the performance of the two engines (in fact reliable emissions data are available only for one engine type). In addition, the engine efficiency in terms of pollutants emissions has been mainly limited to NO_x and CO_2.

However, two interesting considerations can be outlined from the present analysis:

- from NO_x and CO_2 data, it is possible to suppose an opposite behavior for the considered engine (i.e. at the maximum efficiency in terms of fuel consumption and CO_2 emission corresponds a worse efficiency in NO_x production);
- for the two examined ships, the same mean rate of NO_x and CO_2 is emitted in port.

The obtained database will be used in a future work for the validation of an engine simulation model including also emission aspects. Once developed the engine code, the contribution to air pollution of this kind of vessels in ports can be more easily assessed and then addressed.

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REFERENCES

Altosole, M., Benvenuto, G., Campora, U., Figari, M. 2012. Dimensionless numerical approaches for the performance prediction of marine waterjet propulsion units. *International Journal of Rotating Machinery*, Volume 2012, Article number 321306: 1–12.

Balzani Lööv, J. M., Alfoldy, B., Gast, L. F. L., Hjorth, J., Lagler, F., Mellqvist, J., Swart, D. P. J. 2014. Field test of available methods to measure remotely SOx and NOx emissions from ships. *Atmospheric Measurement Techniques*, 8, 7, 2597–2613.

Battistelli, L., Fantauzzi, M., Coppola, T., Quaranta, F. 2012. Evaluation of the environmental impact of harbour activities: Problem analysis and possible solutions. In Carlos Guedes Soares and Enrico Rizzuto (eds.), *Sustainable Maritime Transportation and Exploitation of Sea Resources, Proc. intern. Symp*.

Brettschneider, J. 1997. Extension of the equation for calculation of the air-fuel equivalence ratio (No. 972989). *SAE Technical Paper*.

Cooper, D. A. 2001. Exhaust emissions from high speed passenger ferries. *Atmospheric Environment*, 35(24), 4189–4200.

Coppola, T., Mocerino, L., Rizzuto, E., Viscardi, M., Siano, D. 2018. Airborne noise prediction of a Ro/Ro pax ferry in the port of Naples. In Alberto Marinò and Vittorio Bucci (eds.), *NAV International Conference on Ship and Shipping Research, Proc. intern. symp., Trieste*.

Corbett, J. J., Wang, H., Winebrake, J. J. 2009. The effectiveness and costs of speed reductions on emissions from international shipping. *Transportation Research Part D: Transport and Environment*, 14(8), 593–598.

Corbett, J. J., Lack, D. A., Winebrake, J. J., Harder, S., Silberman, J. A., Gold, M. 2010. Arctic shipping emissions inventories and future scenarios. *Atmospheric chemistry & Physics discussions*, 10(4).

Heywood, J. B. 1988. *Combustion engine fundamentals*. 1ª Edição. Estados Unidos.

IMO 2014, MEPC, Guidelines On The Method Of Calculation Of The Attained Energy Efficiency Design Index (Eedi) For New Ships, As Amended (*Resolution Mepc.245(66), As Amended By Resolutions Mepc.263-(68) And Mepc.281(70))*

Iodice, P., & Senatore, A. 2015. Industrial and urban sources in Campania, Italy: The air pollution emission inventory. *Energy & Environment*, 26(8), 1305–1317.

Iodice, P., Langella, G., & Amoresano, A. 2017. A numerical approach to assess air pollution by ship engines in manoeuvring mode and fuel switch conditions. *Energy & Environment*, 28(8), 827–845.

Karl, M., Jonson, J. E., Uppstu, A., Aulinger, A., Prank, M., Sofiev, M., … & Matthias, V. 2019. Effects of ship emissions on air quality in the Baltic Sea region simulated with three different chemistry transport models. *Atmospheric Chemistry and Physics*, 19(10), 7019–7053.

Mocerino, L., Murena, F., Quaranta, F., Toscano, D. 2020. A methodology for the design of an effective air quality monitoring network in port areas. *Scientific Reports*, 10 (1), 1–10.

Murena, F., Mocerino, L., Quaranta, F., Toscano, D. 2018. Impact on air quality of cruise ship emissions in Naples, Italy. *Atmospheric Environment*, 187, 70–83.

Nunes, R. A. O., Alvim-Ferraz, M. C. M., Martins, F. G., & Sousa, S. I. V. (2017). Assessment of shipping emissions on four ports of Portugal. *Environmental Pollution*, 231, 1370–1379.

Peng, Z., Ge, Y., Tan, J., Fu, M., Wang, X., Chen, M., … & Ji, Z. 2016. Emissions from several in-use ships tested by portable emission measurement system. *Ocean Engineering*, 116, 260–267.

Quaranta, F., Fantauzzi, M., Coppola, T., Battistelli, L. 2012. The environmental impact of cruise ships in the port of Naples: analysis of the pollution level and possible solutions. *Journal of Maritime Research*, 9(3): 81–86.

Rodríguez, G. D. M., Martin-Alcalde, E., Murcia-González, J. C., & Saurí, S. 2017. Evaluating air emission inventories and indicators from cruise vessels at ports. *WMU Journal of Maritime Affairs*, 16(3): 405–420.

Toscano, D., & Murena, F. 2019. Atmospheric ship emissions in ports: A review. Correlation with data of ship traffic. *Atmospheric Environment: X*, 4, 100050.

Trozzi, C., & De Lauretis, R. 2016. EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016 (Technical guidance to prepare national emission inventory), ISBN 978-92-9213-806-6, *European Environment Agency.*