THE ENVIRONMENTAL IMPACT OF CRUISE SHIPS IN THE PORT OF NAPLES: ANALYSIS OF THE POLLUTION LEVEL AND POSSIBLE SOLUTIONS

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ABSTRACT

The environmental problem in land activity has created a great alarm especially close to highly inhabited zones; for harbours the main problem consists in the contemporaneous presence of a number of ships releasing large amounts of substances noxious in the air and the water. New regulations and limits to these elements have been set up in order to limit the impact on human activities. This problem should be urgently faced in order to avoid very dangerous consequences in such critical zones. One of the ports closer to the centre of the town with a significant influence on its life, lies in Naples, in the core of the urban activities with thousands of people living and working nearby.
In this paper the case study of the port of Naples is developed with particular regard to the exhaust emissions from the cruise ships which frequently berth in Neapolitan bollards, keeping most of their engines on in order to produce the electric energy needed for the auxiliary services onboard. In fact, the contemporaneous presence of four or five cruise ships may create a very dangerous environment, especially for people living close to the harbour.
In the frame of a research program which involves the CNR Istituto Motori and the University of Naples "Federico II", tests on the quality of the air were recently done; first results of this research are reported together with the analysis of the possible solutions to the problem. In this phase, the most important components of pollutants were analyzed: NOx and SO_2.

KEYWORDS: Environment, emissions, cruise ships, ports, cold ironing

INTRODUCTION

It is well known that the environmental question worries all the communities exposed to risks coming from the effects of human activities in terms of pollution of soil, air, water and whatever may have a significant impact with human life.

More recently this concern has been extended to the water cities for their continuous and close contact with several sources of environmental risk. Indeed, in some cases, the operations of ships involves very inhabited zones, where relatively large amounts of risky substances flood the environment.

Lets consider Venice, for example, where thousands of people (and thousands of very important masterpieces) are daily in contact with the exhausts from a multitude of ships operating in the lagoon and in the centre of the town and where the banks of the canals are exposed to the decay due to the wash effect generated by a very intense marine traffic along the Venetian waterways.

Naples, with its port occupying a large part of the coast, is one of the watercities where the industrial activity connected with ship operations has the largest impact on urban life; and such impact is evidently worsened by the position of the mooring points destined to cruise ships which is located close to the main square of the city, in the very centre of it. In some periods, even five or six cruise are contemporaneously berthed in Naples; since many people live and work there, it is very hard to ignore the high impact on the exhaust emissions from the engines of such a ships on the human life in a relatively small but very important area.

THE PORT OF NAPLES

The port of Naples must be considered a particularly interesting case where several industrial activities (passenger moving, fuels and products treatment, containers and merchandise transportation and so on) are carried out with a very important impact on the surrounding areas. Its main characteristics are reported in tab. 1

Table 1 – main characteristics of the Port of Naples

coordinates		40°51'19" N - 14°15'36" E	
coast occupation	> 5 km	containers moved (number)	> 300'000
bank available length	> 11 km	containers moved (TEU)	~ 500'000
berths	75	passengers (general)	~ 7'000'000
inner street available length	> 3 km	passengers (cruise)	~ 2'500'000
inner railway available length	2 km	number of cruise ships (per year)	~ 700

RULES AND EFFECTS ON THE HEALTH

Among the noxious contents emitted by marine engines, relevant attention is paid to SOx and NOx emissions; this is due mainly to the relatively large amount of this substances in the exhausts. Other components are either emitted in smaller quantities by diesel engines (NO) or unavoidable for the correct working cycle of engines (CO_2) or their emission is connected with other substances (i.e. PM, whose presence in the exhaust strictly depends on the content of SOx in them).

The only way to contain the NOx emissions is to set the engine with this goal; the IAPP certificate assesses the capability of the engine to respect the imposed limits. Table 2 shows the present limits for engines running at given rpm and those that will be applied after 1/1/2016.

Table 2 - ANNEX VI to MARPOL (TIER I & II), rule 13

ENGINE SPEED	TIER II (< 1/1/2016)	TIER III (> 1/1/2016)
rpm < 130	14.4	3.4
130 < rpm < 2000	$44 / rpm^{0.23}$	$9 / rpm^{0.2}$
2000 > rpm	7.7	2.0

As regards the SOx emissions, they are limited by imposing a max content of sulphur in the bunkered fuel. As an alternative to this, it is allowed to use normal sulphured fuels as long as the content of SOx in the exhaust doesn't exceed 6.0 g/kWh (this can be achieved by installing an efficient scrubber). As a comment to this situation, a severe control of real emissions from ships should be performed in order to asses the environment - friendly quality of energetic systems accepted in ports.
Excessive emissions of noxious elements may lead to serious damages to human health and to environment in general. Consequences of the intake of such substances have been well known for some time to WHO that indicates the maximum exposure to each of them together with possible effects on the human organism.
Table 3 reports these conclusions together with a prediction of possible disease to human health.

Table 3 – main effects of the exposure to SOx and Nox

Sulphur oxides	
Concentration	*Effects on the health*
Exposure with limited injury	
0,06 mg/m^3	possible bronchitis episodes and chest infections
0,3 mg/m^3	possible damages to the respiratory system (especially for children and elderly)
0,8-2,6 mg/m^3	olfactory sensing of the substance (stimulates search for gas mask and refuge)
Exposure with serious injury	
0,06 mg/m^3	possible bronchitis episodes and chest infections
0,3 mg/m^3	possible damages to the respiratory system (especially for children and elderly)
0,8-2,6 mg/m^3	olfactory sensing of the substance (stimulates search for gas mask and refuge)
Nitrogen oxides	
Concentration	*Effects on the health*
50-150 mg/m^3	(for short periods of time) possible harm to lungs
100 mg/m^3	serious damages to the breathing apparatus
300-400 mg/m^3	lethal

From the point of view of the maximum acceptable limit for the concentration of NOx and SO_2 in the air, the reference rule now in force is the # 155/10: "accomplishment of the DIRECTIVE 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe" table 4 reports these limits.

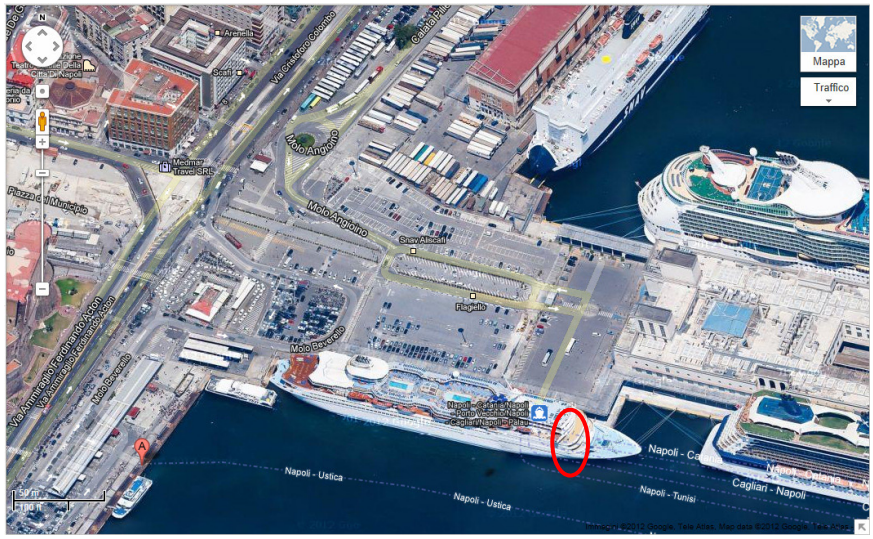
Table 4 – allowable limits for the concentration of NOx and SO_2 in the air

substance	***kind of average***	***maximum acceptable limit***
NOx	1h	200 μg/m^3
	civil year	40 μg/m^3
SO_2	24 h	125 μg/m^3
	1 h	350 μg/m^3

THE DATA LOGGING CAMPAIGN IN THE NEAPOLITAN HARBOUR

The first data logging campaign was carried out in the period March 25th - April 10th, 2012. The site is indicated in figure 1. To evaluate and register the composition of the air we used an equipped van with some precision instruments onboard for the monitoring of the main contents in the air. The exact position of the van is given in figure α where it is possible to notice how close to the mooring site of the cruise ships the measurement point was. The sampling rate was about one minute but, for the moment, only hourly averages are available for each component logged.
Beyond the quality of air, also weather - wind characteristics were logged: direction and intensity of the wind, pressure, temperature and humidity of the air. These elaborations (the first on this set of data) could not take into account these conditions whose influence on the quality of the air will be assessed in following phases.

Figure 1 – The site were the data logging campaign was done

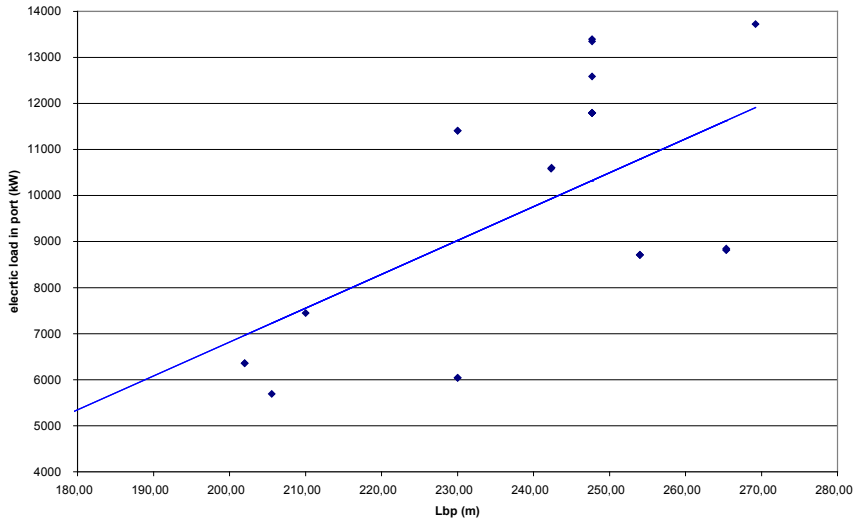


THE RESULTS AND A FIRST CORRELATION BETWEEN THE EMISSIONS FORM SHIPS AND THE NOXIOUS CONTENTS IN THE AIR

The final goal of the present experimentation is to build a reliable routine able to correlate the presence of ships in port with the quality of the air in terms of level of main noxious substances in it.
The present step was carried out by setting up a mobile laboratory with various analyzers and leaving it in a given (and strategic) zone of the port for more than 10 days. During this period NOx and SO2 concentrations in the air were measured; the former with the chemiluminescence method, the latter with the fluorescence.
In order to improve the accuracy of the level of the correlation, also weather, wind and rain conditions were logged (local and general). Of course, also the attendance of ships was registered in the observed period.
A reasonable nexus between the emissions from ships and the quality of the air in the zones close to berths is very difficult to built; to achieve a good correlation, the incidence of weather factors, the diffusion of compounds in the air, the exact positions of ships and many other factors having some incidence on the quality of air, must be analyzed with very accurate methods capable of mapping the emissions from engines (together with all other sources of pollution); it is also important to reveal

the real distribution of the noxious substances in the various zones involved in this particular and complex kind of pollution.
In this first application phase of the research program, a series of elaborations were carried out in order to initialize such a challenging operation with present instruments and data.
In the following, the main criteria used for the experimentation will be detailed.
After the results of the pollutant emissions campaign came in, a first level appreciation of the pollutant really emitted by the engines of ships at berth was required. Unfortunately, apart from the very difficult determination of the real state of the load of engines operating during the campaign (and related emissions), for several reasons, it is always very hard to obtain reliable data of the operations of ships.
As a first approach, we got over such a difficult problem by using a database kindly offered by Fincantieri, the Italian national Shipyard Company.
This database contains the values of the main characteristics of the cruise ships built by Fincantieri; among them, overall length, overall power installed onboard, electric motors overall power, summer and winter electric loads for hull and hotel devices.
A quick research on the ships present in the Neapolitan port during the acquisition could reveal only few reliable data; practically, only overall length and ship speed are available for (almost) all of them, other variables are spread in a very non-homogeneous manner and are definitively not usable for a decent statistic elaboration.
Mainly, the most important value to determine was the electric load on the engines acting during the observation period because the emissions of the noxious gases from engines are evidently connected with this parameter. But this was not the only problem to solve: even knowing (or evaluating) the level of the load from engines, how to realize the level of NOx and SOx coming from the exhausts?
Thus, by using the Fincantieri database, a linear regression was carried out to correlate the only available variable – the overall length of the ships – to the winter load in port, the most significant for the spring period when the acquisition was done.
Such correlation gave the results shown in figure 2; the correct value of squared R was about 0.20, the standard error of about 2100 kW.

Figure 2 – Correlation between the overall length and the electric load in winter conditions for cruise ships



As for the values of the NOx and SOx really emitted by engines, we also had a complete lack of data; the evaluation of such figures was carried out by assuming the maximum value of the emission permitted by the present reference rule (ANNEX VI to MARPOL, rule 13 which imposes a max value of NOx as a function of the load on the engines); such maximum value, for engines running @ 600 rpm, is 10.10 gNOx/kWh.
This method can be deemed adequate for the evaluation of NOx that is certified by the IAPP document (everyone attempts to set the engine at the most advantageous conditions which, more or less, means the maximum allowable emission of NOx); since the reduction of sulphur oxides is achieved by reducing sulphur in the bunkers, it is very difficult to predict the real emission in SOx.
In this case, the value of 6.0 gSOx/kWh allowed by ANNEX VI has been deemed acceptable for these cases where no low-sulphured fuels are available onboard and such emission can be achieved by using a retrofit (generally, a scrubber device).
With this method, it is possible to obtain the following graphs where, as a function of the time, the measured concentration of NOx is reported together with the predicted value of the emissions from engines of ships present in port. The same was done for the SO_2 emissions.

Figure 3 – NOx predicted emission and concentration in the air

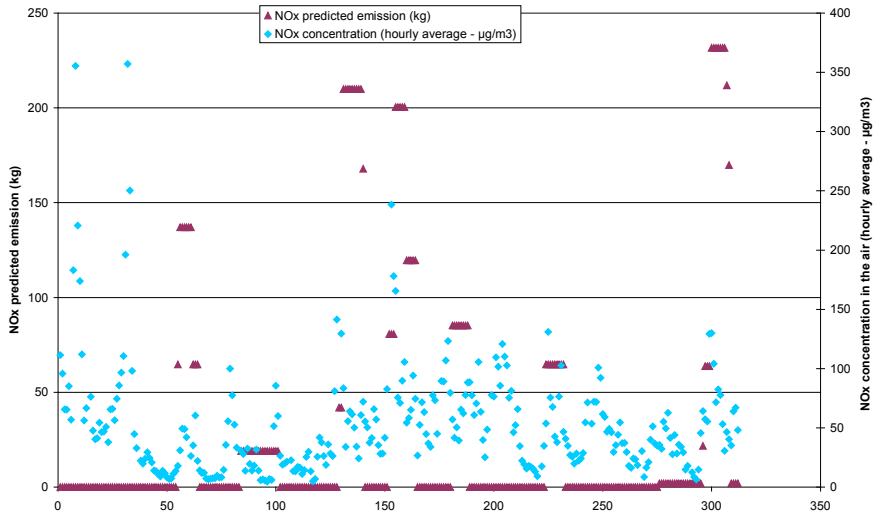
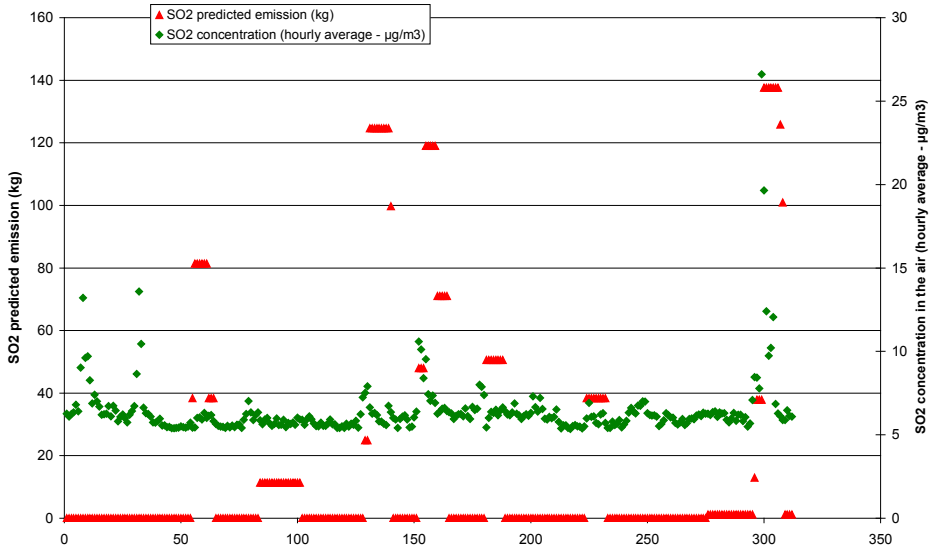


Figure 4 – SO_2 predicted emission and concentration in the air



A first analysis of these diagrams reveals some dependence of NOx and SOx emissions on the presence of ships at berth; on the other hand, it must be considered that the period of acquisition was not very busy from

the point of view of the cruise activity, although, sometimes (including Easter), two contemporaneous presences were registered.
The first evidence is that, in every moment of the day, the level of contents of noxious elements in the air is less than that the maximum one allowed by the abovementioned rule 155/10. The SOx appears always much less then the permitted emission. NOx is closer to the limit but always lower; the weak distance to the acceptable limit, reached in some moments of the acquisition period, could be exceeded when the cruise traffic will be much more intense (May - June and September – October).
By observing the development of the lines, it is evident that in that periods when there are cruise ships in port, close to the acquisition point, the levels of NOx and SOx grow; but also in some moments when no ships are berthed, significant levels of SOx and, in particular, NOx are reported. Unfortunately, apart from the presence of ships, it was impossible to log the effects of any other activity potentially able to produce pollutants; but, evidently, it is possible to assess that there could be other operations, close to port area especially in the first period of observation, producing the logged level of SOx and NOx in the air.
Since logged levels are relatively low, it is very probable that other activities (mainly, urban traffic) could affect these data having a noticeable impact on the overall acquisition. During future data logging campaigns, since the number of cruise ships in the harbour will be much higher, a more direct dependence of their presence on the quality of the air is expected. However, in some sense, this experience can be considered as an ideal “offset” of the air conditions in the harbour area, more influenced by activities in the rest of the town than by port operations.
It is evident that such a method must be improved; indeed, important enhancements must be made in order to outline a reasonable scenario of the emissions from ships in the port of Naples and its consequences on the quality of the air in those zones. On the other hand, a complete investigation involves many aspects of the phenomena taking place in that area; it is not by chance that, although the problem of having five or six ships emitting tons of noxious elements under the nose of thousands of people is very felt, no believable figures are available on this matter hitherto. However, apart from the abovementioned quality of the assessment of emissions from ship engines, other points of weakness appear in the present investigation, due to the following items.
First of all, to connect the emissions from the ship to the real content of NOx, SOx and other substances in the air, a very deep knowledge of the diffusion of such substances in the atmosphere is required; this, in turn,

strictly depends on thermal gradient and winds and it should be correlated with them to know exactly the level of possible pollution consequent to certain levels of emissions from ships.
Then, it is to be kept in mind that the Neapolitan port area is adjacent to the very centre of the town, where a great number of industrial activities are carried out; among them the city traffic and the heavy transportation activity – acting very close to the acquisition point – may have a strong impact on the air composition and it can interfere with the interpretation of the real source of the measured pollution.
Thus, in order to achieve a complete and reliable monitoring of the air quality in the Neapolitan port and of its dependence on the sources of pollution, many other elaborations and competences should be involved.

POSSIBLE REMEDIES

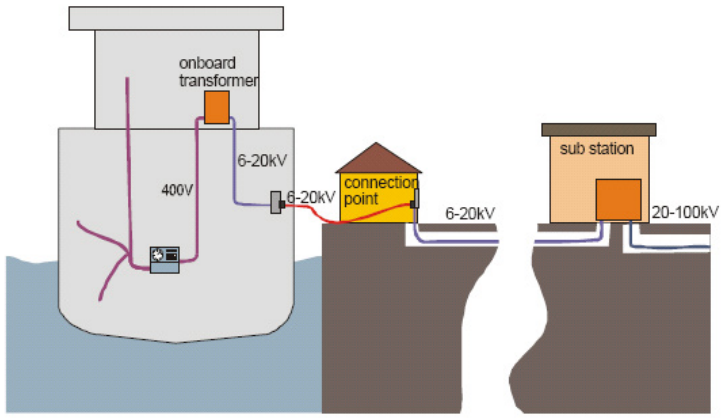
Results arising from the present experimental surveys of emissions can address possible remedies to adopt. Independently of the limitation of surveys to only some pollutants as NOx e SO_2, remedies can be best directed to reduce the entire spectrum of emissions. This involves a careful estimation of economical and environmental benefits and then the implementation of proper methodological approach to investments and interventions.
A drastic reduction of emissions can be obtained preventing ships from using on board electrical generators during berthing, by providing electric energy supply by shore-to-ship service. The used technology is known as “cold ironing”. It started in the 80s for military ships, small crafts and ferry-boats, and more recently it was extended to other types of commercial ships which need large power also for berthing, as cruise, container and tanker ships. Table 5 reports the main installations of cold ironing made in Europe end U.S.A. up to 2008.

Table 5 – cold ironing realizations in Europe and USA

Geographical area	**Ports**
Europe	Göteborg, Stockholm, Helsingborg, Piteå (Svezia), Anversa, Zeebrugge (Belgio), Kotka, Oulu, Kemi (Finlandia), Lubecca (Germania)
U.S.A.	Los Angeles, Long Beach, Pittsburgh (California), Seattle (Washington), Juneau (Alaska)

Other applications are in progress in eastern countries like China and Japan and in various parts of the world. In Italy, nearly all the most important ports are planning to apply cold ironing technology.
Frequency and voltage are main electrical parameters involved and crucial for the connection of on board electrical facilities to the shore distribution grid.
The reference frequency specifications are 50 and 60 Hz, while the voltage values are in the 0,4-11 kV range. The installed powers – both for single berth, and the whole port – depend on the number of service stations and on the ships to be supplied. The sizing criteria mainly depend on the port vocation as well as on the energy and environment policy adopted by the Port Authority. Figure 5 shows a typical scheme of cold ironing.

Figure 5 – typical cold ironing scheme



In general, we can foresee future ports with a certain number of electrified berths, equipped with interoperable supply stations for the connection with different types of ships having different electrical standards on board.
Starting from cold ironing, remedies for NOx and SO_2 pollution can be provided within wider and systemic plans addressing sustainability in both internal and external port areas, possibly integrated with metropolitan area environment.
In the near future, port areas are expected to become “smart”, with the integration of environmental monitoring to intelligent distributed energy

resources, including shore to ship facilities, renewable energy local generation, storage devices, centralized and remote control managed according to the technological "smart grid" paradigms based on active power distribution. In this way, remedies against pollution can have further considerable fallout on both local and global environment.

CONCLUSIONS

The first results of a wide research program, recently started on the quality of the air in the port of Naples, showed a certain dependence of the presence of cruise ships at berth on the concentration of the main pollutants; for the moment, only NOx and SO_2 emissions were examined. Since the first test campaign was carried out in a down time, when only few cruise ships work, the influence of other activities clearly interferes with the pollution level detected; but, by analyzing and crossing the concentration of NOx and SO_2 with the emission of these substances some correlation appears. Future investigations, planned in a busier period, will clear this aspect and, we hope, will give further tools to estimate the impact of the cruise activity. In this context, the study of a wider application of cold ironing seems to be particularly useful as the most drastic system to move away the main sources of pollution from the most inhabited zones of the watercities.

AKNOWLEDGMENTS

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