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Evaluation of the environmental impact of harbour activities: Problem analysis and possible solutions

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ABSTRACT: The environmental problem involves all aspects of the human activities and is leading to a severe decisions in order to avoid dramatic consequences on human health. In the marine field, after a very long period of stand by, now the problem is felt mainly in the big water cities where, close to the harbours, a heavy microclimate can be dangerous for those who live nearby. This work aims at analysing the present rules operating in port areas, and at presenting the sustainable actions to cope with the problem of the environmental impact of naval activity.

1 INTRODUCTION

In the marine activity, harbour operations have a dramatic environmental impact because of logistics, energy supply, traffic congestion, etc. The alarm of institutions studying the environmental problem focus on the densely inhabited areas where pollution may cause major damage to the people living close by. Regulations have been adopted in order to reduce the noxious effects of port activities. The marine field has been less touched by this problem, probably because most part of the noxious elements is released by engines far away from inhabited zones and it is not "felt" as dangerous as other fields of human activity (industrial, services, road traffic, etc.).

But, aside from the evident need to save the planet as a whole and release the least possible waste—although in "desert" zones—, there are particular areas where the simultaneous operations of a number of ships may create a heavy impact. Typically, very busy harbours, "water cities" and other contexts where the human life develops close to the sea or the aquatic environment, expose people to major risks of serious damages for their health.

Therefore, it is very important to analyse the complex scenes of the maritime harbour operations and find efficient solutions that should be logistically and economically sustainable, in compliance with the present rules on exhaust emissions from ships.

2 ENVIRONMENT CHARACTERISATION—POLLUTION FACTORS IN PORT AREA

The environmental pollution in the harbours has three main aspects; air, water and acoustic [1,2,3].

The air pollution is due mainly to dusts in the form of suspended particles and gaseous elements that are often very dangerous for the human health.

In the port areas, dusts are mainly due to load/unload phases of bulk carriers; the noxious gases, on the other hand, are emitted by diesel engines onboard ships and by technical vehicles working in the port area or in the surroundings.

Among the gaseous pollutants, the most important are:

a. the nitrogen oxides NOx and sulphur oxides SOx;
b. the Carbon Monoxide (CO) and Carbon Dioxide (CO2);
c. particulate matters PM (in particular PM_{10});
d. the volatile organic compounds (VOCs—benzene, formaldehyde, toluene, etc.).

Apart from the presence of these substances, their combinations may create further noxious elements. For example, the interaction between VOCs, NOx and the sunlight produces ozone; sulphur oxides, combined with water steam, cause the so called "acid rain" which can cause serious damages even in zones far away from the pollution source.

Water pollution is mainly due to oil products and to sewage disposals in harbours. Often accidents involving oil carriers cause severe pollution; this risk is directly proportional to the overall amount of carried oil and to the number of manoeuvres carried out.

Also some maintenance operations normally carried out onboard (for example: painting) can cause pollution; in such cases, antifouling additives may have seriously negative effects on the marine environment.

Finally, there are sources of acoustic pollution both on ships and in port areas; the latter are due to the vehicles moving goods and people and to daily activities developed close to the harbour, especially in inhabited zones.

3 HOW TO COPE WITH THIS PROBLEM: FIRST FUELS AND SETTINGS

As regards the air pollution—the more urgent problem—fuels are at the core of the problem: indeed, emissions certainly depend mainly—but not exclusively—on the quality of fuels burned in the harbours.

First of all, a reduction of the fuel consumption involves the reduction of all emissions from the engine. This means that new generation fuel-saving engines should be preferred to old and "dirty" ones. But, in order to obtain a serious decrease in emissions, also the fuel characteristics must also be changed and adapted to a cleaner use.

Doubtless, problems due to a change in fuels are many and difficult to solve. Ships that have to burn relevant quantities of fuel close to inhabited zones are forced to store different kinds of fuels (dirtier for use in open sea, clearer in ports); and this involves problems of storage, division of thanks for each kind of fuels and so on.

Moreover, the availability of various fuels is not granted everywhere in the world and difficulties could arise in case a ship has not supplies on board of the fuel required for the admission to a port: for example, the low sulphured fuels, required almost in all ports today, are not universally available.

In a next future, probably, the use of non conventional fuels will be more enlarged; the methane added with hydrogen, for example, seems to be able to reduce the NOx emissions from diesel engines; but the arrangement of engines is very invasive and predictably, a long time will pass before such technologies are applied.

However, some emissions are strictly connected with fuels and the most reasonable approach seemed to be limiting the related content of the substance in it. This is the case of sulphur oxides SOx which can be limited by reducing the content of sulphur in fuels.

As for NOx, it can be kept under control either by setting the engine properly, or retrofitting the engine with a system capable of lowering the content of nitrogen oxides in the exhausts.

4 RULES

The awareness of the problem of the environmental pollution dates back to some decades ago: thus, the famous ANNEX VI of the MARPOL 73/78 (and its amendments) created the so called SECA (Sulphur Emission Control Area) where the use of fuels with a controlled level of sulphur was introduced.

The first SECA entered into force in 2006 and involved the English Channel and the Baltic Area.

Sometime later, in order to meet the dramatic conditions of ports located close to big towns, the ECA (Emission Control Area) were introduced as zones where more stringent fuel sulphur and engine NOx limits were imposed. In all European ports, for example, the maximum sulphur contents in the fuels was fixed in the 0.1% (since 2008/1/1).

As regards the air pollution, in particular, the production of NOx, SOx, PM (depending on the sulphur oxides) and CO2 are under observation in order to contain the noxious effects of these substances on the environment.

The ways to handle NOx and SOx in order to clean the exhausts are considerably different: the limitation in SOx is achieved by a reduction of the sulphur in the fuel. The synthesis of present and future limits is given in Table 1.

In addition to these limits, the "EU DIRECTIVE 2005/33/EC", emending "MARPOL Annex VI Air Pollution", limits the sulphur contents of marine fuel in many areas (including all European ports) to 0.1% [4,5].

If low sulphured fuels are not available onboard, the Annex VI permits the use of retrofits that must reduce the maximum value of SOx to 6 g/kWh.

Table 1. Maximum admissible content of sulphur allowed in the fuel (%).

TERMS	NON SECA areas	SECA areas
<1/1/2012	4.5	
>1/1/2012	3.5	
>1/1/2020	0.5	
<1/1/2015		1.0
>1/1/2015		0.1

Table 2. Maximum admissible emissions of NOx (g/kWh).

ENG 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

Table 3. Sulphur oxides: 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)

Table 4. Sulphur oxides: Exposure with serious injury.

3 mg/m^3	Increase of the breathing rhythm and heart pulsation
25 mg/m^3	Irritations to eyes, nose and throat, increase of the heart rate
5 g/m^3	Toxic asphyxia, cardiovascular collapse

Table 5. Nitrogen oxides.

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

The emission of NOx depends on the temperature of combustion and the only way to contain it in the exhaust emissions is to set the engine (pumps, turbochargers, ignition timing etc).

Table 2 presents limits in NOx contents in the exhausts from marine engines; in the field between 130 and 2000 rpm (practically, all the engines destined to the production of electric energy onboard), the limitation are fixed as a function of the engine rpm.

5 AND THE EFFECTS ON THE HEALTH?

All these emissions may have direct effect on the human health and on the vegetal life.

Synthetically, the main effects—identified by WHO—are reported in Tables 3 to 5 [6].

6 MANY SHIPS IN PORT: IS IT A PROBLEM?

Passing through a large European harbour it is possible to count many ships at berth at the same time and "in full activity". Of course cruise ships are only part of the port activity, but they require a large amount of electric energy in order to make the life onboard possible (and pleasant!).

The ships generate electric energy onboard for many applications, from simply feeding lights and air conditioners to more sophisticated systems of control and steering. In order to grant a correct ship management, other systems require electric power such as hull systems (bilge, ballast, balancing, etc.) safety systems, engine room devices, and all tools for the movement of loads and/or the management of passengers.

To produce the electric power needed for services oboard, conventional ships have diesel electric groups that feed only the abovementioned users; the "all electric" systems, more and more widespread nowadays in the cruise ships, feed both the propulsion plants and all electric auxiliary users.

The evaluation of the electric power required onboard must certainly take into account the overall power installed with auxiliary diesel engines; this datum is normally (but not always [7]) available in the case of conventional ships, while it must be derived for all electric ships.

On the other hand, determining of the value of the electric energy required onboard depends on the variability of the electric loads during the berthing period.

The electric power during the berth periods can be evaluated by using the so called "load factor", a coefficient which gives the mean power used onboard with the overall electric power installed onboard as reference. This factor obviously may vary greatly from ship to ship.

Table 6. Load factors for various kinds of ship.

Car carrier	0.24
Bulk carrier	0.22
Container	0.17
Cruise	0.64
General cargo	0.22
Ocean tug/tow	0.22
Reefer	0.30
RoRo	0.34
Tanker	0.67
Others	0.22

The following table reports these coefficients determined in [8].

Tipically, cruise ships and tankers are the vessels that use major rates of electric power when at berth. In order to evaluate the environmental impact of many cruise ships simultaneously at berth in a single harbour, on first approximation, it's enough to evaluate a reasonable value of the electric energy needed for services onboard.

Thus, supposing that 6 large ships are berthed together in a same mooring area (many European ports have a similar situation), and each of them reserves 10–15 MW for the onboard services, according with a given datum (load factor = 0.64, supposed value of power: 11 MW), the overall power delivered by generators will be about 45 MW.

So, while supposing that all of these ships fully respect the present limits for NOx and SOx, an easy calculation permits to determine the amount of emissions released in a small area close to the berthing point:

for NOx (if generators work @ ~ 900 rpm) max 9.20 g/kWh;
for SOx max 6 g/kWh (permitted value as alternative to low sulphur fuels).
If the overall power released is about 45 MW, the correspondent emissions are:
NOx emission: 0.41 t/h
SOx emission: 0.27 t/h

discharged in a relatively limited zone (berthing points are often close to each other) with a possible (probable!) huge concentration of noxious substances in such areas.

7 WHAT CAN (MUST) BE DONE?

The solution to a big problem cannot be easy.

And, most of all, a definitive solution for the limitation of emissions close to the big harbours can be achieved only with a strong cooperation among politicians, technicians and operators in the marine sector.

Thus, intermediate solutions are to be devised and tested, with the risk that partial solutions became definitive in time.

But, in some cases, the environmental situation of areas around large harbours cannot wait for global solutions that could take a long time; improvements in the management of shipping should be achieved right now, the rules introduced—at what cost!—are an example of the action to be taken.

Beside cold ironing—the subject of the following discussion—and the other mentioned systems, some palliative could be considered. Among them, a better distribution of berths separating the largest ships and, when possible, moving some mooring quays offshore; electric energy supply directly from shore with system composed by an electric generators (in a trailer truck size a power of about 7–8 MW is available with current technology) fed by very clean fuels (hydrogen, methane, hydromethane, etc.) provided by a tank self-moved like the generator; restrictions to the access to the port area of old (and polluting) vehicles, reduction in the speed of ships close to shore and of land vehicles in port area, etc.

Table 7 summarises the main causes of the air pollution in port areas together with the possible remedies.

Table 7. Causes and remedies to the air pollution in ports.

Pollutants
– Particulate matter PM (PM10 in particular);
– VOCs (Volatile Organic Compounds—benzene, formaldehyde, toluene and others);
– Nitrogen Compounds (NOx);
– Sulphur Oxides (SOx);
– Carbon Monoxide (CO);
– Carbon Dioxide (CO2).
Main pollution causes
– Propulsion and auxiliaries diesel engines onboard ships;
– Diesel engines onboard the vehicles destined to the handling of merchandise inside harbours
Possible solutions
– Low sulphured, ecologic fuels;
– Use of new engines with lower SFOC and capable to use cleaner fuels;
– Retrofit (NOx and SOx);
– Cold ironing;
– Restrictions to the access in ports for old pollutant vehicles;
– Restrictions to the speed of ships and road vehicles in port areas;
– Electric energy supply to berthed ships from shore mobile systems fed by ecologic fuels

8 ECOSUSTAINABLE PROCESSES: THE COLD IRONING

Cold ironing (or "shore connection") means to supply ships at berth in feeding points close to the mooring sites so that the diesel electric generators can be switched off and no exhausts are delivered during ship stay. In these conditions, the shore electric system can feed the ship in "plug-in" mode.

This technique is not to be considered an absolute innovation since applications of electrified banks have been known for many years and, starting from the 80s, even ferries could use such a technology because, as they have a stable mooring point, the connection with an electric network is very easy.

Table 8. Cold-ironing installations in Europe and USA.

	Connection voltage (kV)	Frequency (Hz)
European ports		
Goteborg (Sweden)	0.4	50
	6.6	
	10	
Stockholm (Sweden)	0.4	50
	0.69	
Helsingborg (Sweden)	0.4	50
	0.44	
Piteå (Sweden)	6	50
Antwerpen (Belgium)	6.6	50/60
Zeebrugge (Belgium)	6.6	50
Lubeck (Germany)	6	50
Kotka (Finland)	6.6	50
Oulu (Finland)	6.6	50
Kemi (Finland)	6.6	50
USA ports		
Los Angeles	0.44	60
	6.6	
Seattle	6.6	60
Washington	11	60
Pittsburg (California)	0.44	60
Juneau (Alaska)	6.6	60
	11	

Anyway, this approach is nowadays particularly appreciated in the case of larger ships—first of all, cruise ship—in order to lower the air pollution in ports.

Indeed, the electrified docks have a considerable success today, especially in North America and Europe; the following tables report European and American installations in use up to 2008 together with the main electric characteristics [9].

Many other applications are in progress; the most interesting ones are in North Europe and North America but remarkable installations regard China and Japan. In Italy the ports of Civitavecchia, La Spezia and Venice have already shown their interest in cold ironing applications.

A real standard solution for cold ironing is not available yet; actually, the kind of installation depends on the specific environmental and commercial vocation of the port as well as on the kind of ship to be fed.

This means that the solution to be adopted is to be evaluated on the basis of the maritime traffic, and of environmental pollution of a particular port area, preferably in a mid long-term scene.

Furthermore, the real plant will depend both on the particular layout of the port (with constraints deriving from the arrangement and the existing electric connections), and on the particular electric power plant onboard the ships [10,11,12,13].

Nevertheless, for practical, economic and dimensional problems, there are some invariants in present installations among which, doubtless, the most important are the MV flexible cables (6÷20 kV) even if in the fed ship the inner electric distribution net is at low voltage.

Other elements almost always present in the terrestrial plant are:

– the availability of an easy connection of the port medium voltage box dedicated to the cold ironing with an adequate power;
– the installation of such a box close to the mooring area.

In Figure 1 [14] a cold ironing system type is reported schematically. The connection is grant by a mid voltage flexible cable while, in order to make them compatible the shore and ship voltages, a medium voltage socket and a transformers are fitted onboard of those ship with a low voltage internal electric distribution system.

In some cases, the shore side connection is made by flexible cables unrolled from the ship and plugged to the berth.

Cold ironing represents only the first step of the road map of eco-sustainable processes in port areas that renewable sources and electric and ICT (Information & Communication) technologies can offer nowadays. The potential of environmental sustainability of these technologies, with the goal of containing the pollution in harbour areas, is certainly very high.

It includes the use of renewable sources as sun, wind and biomasses, production of electric energy with fuel cells, innovative systems of energy storage just to name a few.

These systems should be integrated by microgrids or smart microgrids configured as a local active electrical systems with the abovementioned distributed energy resources able to supply all the electric loads normally in connection with the electric distribution utility [15].

Among the most important technological aspects of modern microgrids, it's worth

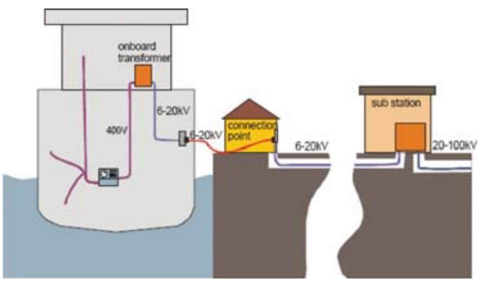

Figure 1. Scheme of cold ironing connection.

mentioning the two-way communication system with the possibility of a direct participation to the electric energy market.

9 CONCLUSIONS

The development of port activities led to evident benefits involving relevant technological resources.

But it also highlighted some important problems that haven't been solved yet.

Among them, the environmental pollution related to the maritime activity in harbours is certainly into close-up; in particular, the simultaneous presence of many ships at berth—with engines working—generates large amounts of toxic substances in limited zones. Air pollution due to the emission of noxious gases in the atmosphere by many diesel engines operating in ports is now under observation by all the Bodies in charge of the safety in such areas.

The situation has become more critical with the spread of cruise ships, actual "giants of the sea" which, although equipped with technologically advanced, high-performance engines, emit large amounts of exhaust emissions due to the high power rates required for the production of electric energy while at berth.

This problem can be faced by adopting temporary solutions, that would allow a normal development of the harbour operations without significant risks for the human health. Among them, the development of the engine technologies that could contain specific emissions, the use of ever clearer fuels—to feed external generators as alternative to those onboard—the use of efficient retrofits to reduce the exhaust emissions ad so forth.

Cold ironing requires a particular mention because it constitutes one of the most efficient (and definitive) solutions to the problem of the environmental pollution in harbours. However problems of standardization and methods of use should be evaluated by means of a dedicated R&D phase, mainly with the goal of a possible integration with electric, automatic and ICT technologies in the specific field of port applications.

In such a complex field, a very robust "system view" will be absolutely necessary in order to stimulate the cooperation of all the protagonists of this scene; apart from the benefits on the human health—that are obviously very important—it is encouraging to consider that focused and efficient operations could turn a negative situation to a condition economically convenient for all the operators involved.

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