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SHIPS MOORING IN THE PORT AS A THREAT TO OUR NATURAL ENVIRONMENT

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Abstract:
An increase in the marine transportation with growing requirement for electricity by the ships both result in is the increased pollution of the air generated by the ships. This is important for the ports.
A comparison among different sources of air pollution produced by the ships in the ports is presented in this article. The estimation of the magnitude of air pollutants emitted by the ships in ports is necessary for the proper economic activity of the port. It also creates the basis to determine the impact of the port work on the environment. The authors present a methodology of calculating emissions from ships at berth in ports.

Key words: *emission of air pollutants, emission sources, emission factor*

INTRODUCTION

Sea freight plays an essentials role in the world wide transport. 90% of goods of the EU coming from the trade with the non-EU countries is transported via ships, while 40% within the EU borders. In the last few years regardless of world economic crisis, the number of ships has increased worldwide. 40% of the world float belongs to the EU.

As the sea freight develops, ships' demand on the power increases, what in turn generates the greater air pollution emission to the atmosphere. This pollution may contribute to threatening people's health.

Anthropogenic emission is a side effect of the economic human activity. Among the anthropogenic sources of pollution emission, sources producing electric and mechanical energy based on the conventional fuels are of paramount importance.

Damages done by the air pollutions to the environment generate the economic loss that is not included in the electric energy costs. These costs are called ExternE – External Electricity Costs. They include health costs, environmental damage costs, greenhouse effect costs, and the costs of possible break-downs. Health costs and environmental damage costs, being 98% of all external costs, dominate other effects [1].

Figure 1 presents the collation of the external costs of air pollution for different means of transport expressed in TEU-km (Twenty feet Equivalent Unit) [2].

The highest external air pollution costs are generated by the sea freight. This is caused mainly by the high emission of the nitrogen oxides what is discussed in detail in subsequent parts of the article.

CO_2 emitted by the ships makes about 3% of the CO_2 world emission. It is crucial in ports where ships are at berth because these are located near the densely populated agglomerations. Carbon oxides are formed as a result of imperfect combustion of fuels. Big power distribution companies strictly control the combustion processes, hence carbon oxides emission is limited. The road transport is becoming the main source of this emission in the cities except for port cities where the pollution is generated by the sea freight.

It is estimated that by the year 2020 sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emission will have exceeded the emission generated by all ground sources in the EU [3].

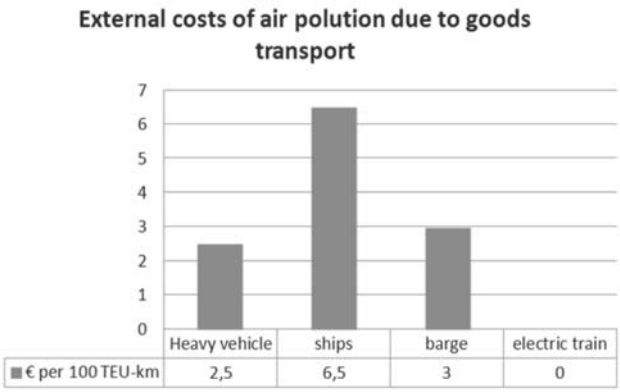

Fig. 1. External costs of air pollution for different means of transport [2]

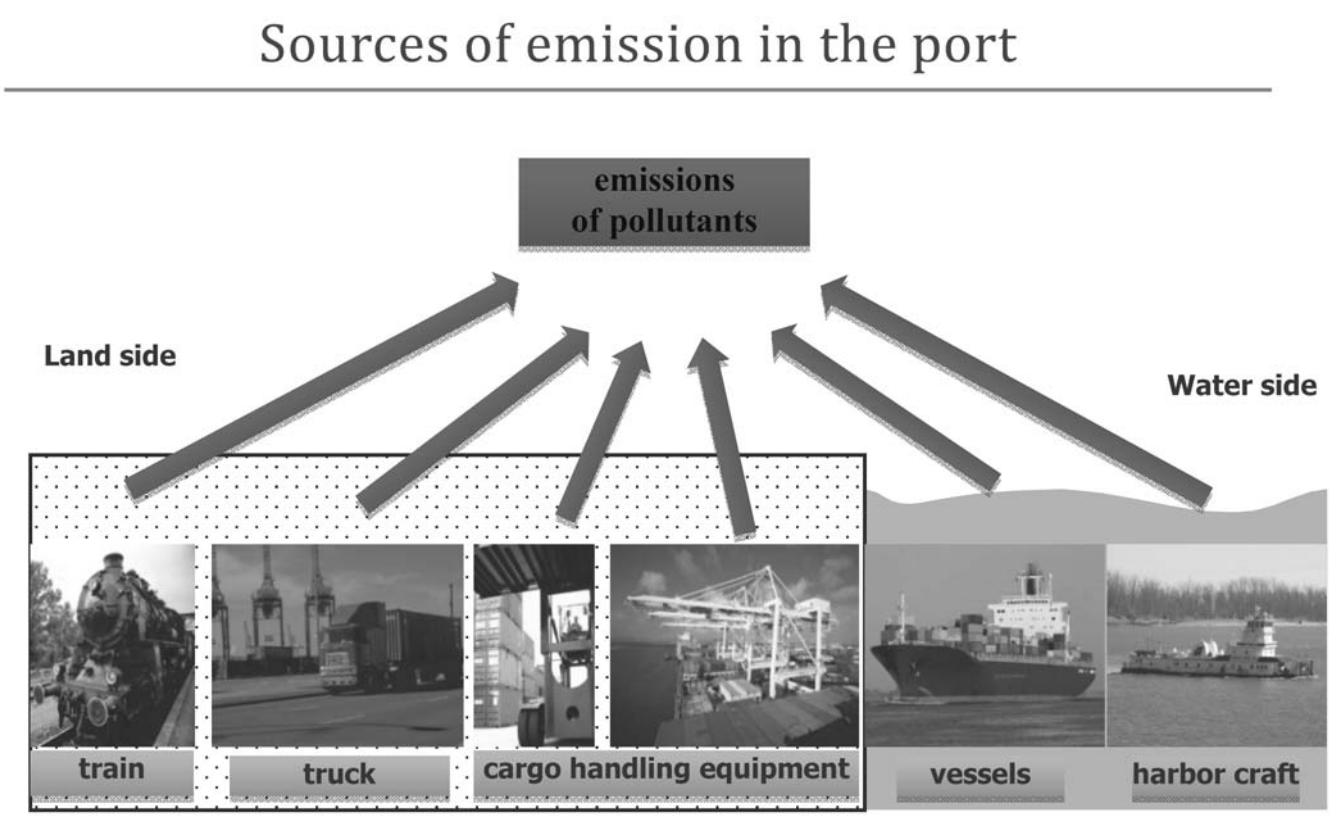

Fig. 2. Sources of emission in the port

THE SOURCES OF AIR POLLUTIONS IN PORTS

The processes of the energetic fuels' combustion are the main source of the anthropogenic air pollution emission. Over 75% of NO_x and SO_2 emission and over 90% of CO_2 emission is connected with the fuels' combustion processes.

The quantity and the quality of pollution depends mainly on the type and condition of the combusted fuel, the conditions of combustion, and the capacity of equipment as well as the efficiency of the devices that purify the exhaust fumes before they reach the atmosphere.

The pollution emission in ports comes from the sea and the land.

The main source of this emission are combustion engines of the marine ships, haulers, and other types of watercraft in the docks. Another source of the pollution emission is cargo handling equipment (terminal tractors, cranes, containers' transporters, forklifts), tracks and railway engines in the port – Fig. 2.

The sources of CO_2 emission in the port

Carbon oxides are formed in the process of imperfect fuels' combustion. On-land power distribution companies currently emit small amount of CO_2 because the combustion process there is strictly controlled and run in the optimal conditions.

The main source of the CO_2 is transportation. Regulations applied lately on-land have limited, to the great extent, the CO_2 emission by the road transport. Since 2012 there has been a norm according to which all cars being sold in the EU cannot emit more than 120 g of CO_2 for every kilometre.

Figure 3 presents the percentage comparison of CO_2 emission sources giving the port of Montreal as an example. Such percentage distribution of CO_2 emission sources can be attributed to the local conditions typical to the port. In the port cities the ships at berth are the significant source of CO_2 emission.

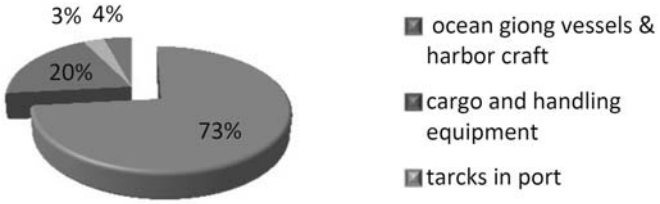

Fig. 3. Comparison of sources of CO_2 emissions in the port of Montreal [4]

The sources of SO_2 emission in the port

Sulphur dioxide (SO_2) can be considered one of the most dangerous atmosphere pollutants. The source of its emission are mainly fuels' combustion processes for the energetic needs. Sulphur dioxide can be transported via wind over a long distance up to one thousand kilometres.

In the fuels used in the self-ignition engines there is usually certain amount of sulphur. The bigger the mass content of the sulphur, the higher the density of the fuel. Sulphur occurring in the fuels, be it in a free state or in compounds, is always an undesirable element despite the well-known lubricating properties.

In fuels used to supply marine engines the amount of sulphur can reach up to 1,5% for Marine Diesel Oil and 5% for Heavy Fuel Oil according to the ISO norm 8217 of fuel classification.

The problem of sulphur dioxide emission is especially significant for the plants whose energetic policy is based

upon carbon. In the recent years energy distribution plants have significantly reduced the SO_2 emission. In the port cities ships at berth remain the main source of sulphur oxides emission (Fig. 4).

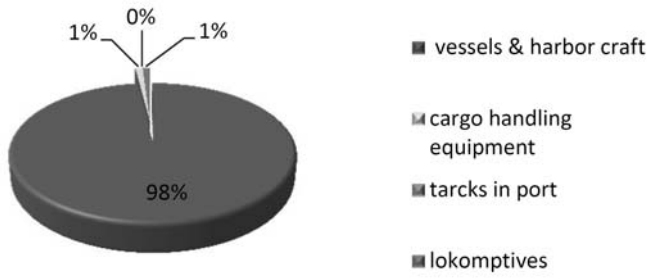

Fig. 4. Comparison of sources of SO_2 emissions in the port of Montreal [4]

The sources of nitrogen oxides in ports

Nitrogen oxides are one of the most dangerous substances polluting the atmosphere, being almost ten times as harmful as carbon oxide and few times as harmful as sulphur dioxide.

Nitrogen oxides are a side product in the combustion process. As a result of this process NO-nitrogen monoxide and NO_2 - nitrogen dioxide are produced. NO is an unstable compound that either decomposes or creates a stable NO_2 depending on the conditions. Nitrogen oxides emission can significantly upset the balance of the natural chemical changes in the atmosphere.

Nitrogen oxides constitute the group of two-componential composition of nitrogen and oxygen in which nitrogen obtains 1.,2.,3.,4. and 5. oxdation state. NOx symbol is the composition of two gases: NO-nitrogen monoxide and NO_2 - nitrogen dioxide. Other nitrogen oxides are also known to us yet, aforementioned compounds are considered primary pollutants of the atmospheric air that are a direct effect of the combustion process in the piston engines. Figure 5 presents the NO_X emission level for different emission sources in the port of Montreal.

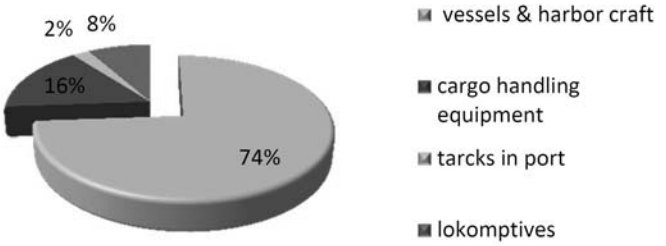

Fig. 5. Comparison of sources of NO_X emission in the port of Montreal [4]

In the last years the emission of NO_X by the road transport has been significantly limited (i.e. by using catalytic converter systems). It is still ships and other port watercraft that remain the main source of NO_X emission in ports. The pollution emission studies of other ports, both Europe and America show similar dependences for the port in Montreal, which means that the ships are the main source of pollution emission.

THE LEVEL OF POLLUTION EMISSION BY THE SHIPS IN PORTS

For the economic activity of the port it is crucial to estimate the level of air pollution emission by the ships in ports. This is essential to determine how high the influence of the port activity on the environment is. The emission level is crucial for the potential expansion of ports, and for the growth of their economic activity.

The detailed research of the pollution emission is a point of reference in implementing the strategies allowing for emission limitation and its control.

In the previous chapter it has been pointed out that ships are one of the crucial sources of pollution emission in ports. Having others mobile emission sources (tugboats, trans-shipment equipment, trucks and train engines) in mind, this article focuses on the pollution emission by the ships. Other pollution sources must be taken into account for estimating the total pollution emission in the port yet, they are not considered here.

The pollution emission from the ships comes mainly from the ships' diesel engines that are used as a main drive and for producing the energy necessary for the ship's exploitation.

The sources of the data for calculating the pollution emission by the ships in ports

The data necessary to calculate the pollution emission by the ships comes from many sources (Fig. 6):

- **The data of the port authorities and the pilot stations** – such information includes mainly necessary data for calculating the time of the given working stage of the ship. On the basis of this data the velocity of the ships during transit and manoeuvring can be stipulated.
- **The data from AIS** (Automatic Identification System) – system of the automatic communication ensuring the automatic exchange of data necessary for avoiding the ships' collision and identifying the ship for the on-shore Vessel Traffic Services (VTS).
- **Ships' register** – the data from the ships' registers are very useful for providing the detailed description of the ship, determining the power of its main and auxiliary engines. Depending on the ship's register, the provided data describing the ship differ, being more or less detailed. The most detailed database is provided by Lloyd Register of Ships including nearly 200,000 ships.
- **Reports from the ships** – Reports from the ships are the most reliable source of information, especially as for the load of the main and auxiliary engines. Such reports can be done by the crew of the ship on command of the ship-owner or the ship authorities. On the older or less-automated ships the crew notes the ship's operating condition, time and engines' load. On the modern, computerized ships it is possible to do such reports in an automatic way. So called "loads' trends" are compiled and engines' loads are reported for a certain period of time.

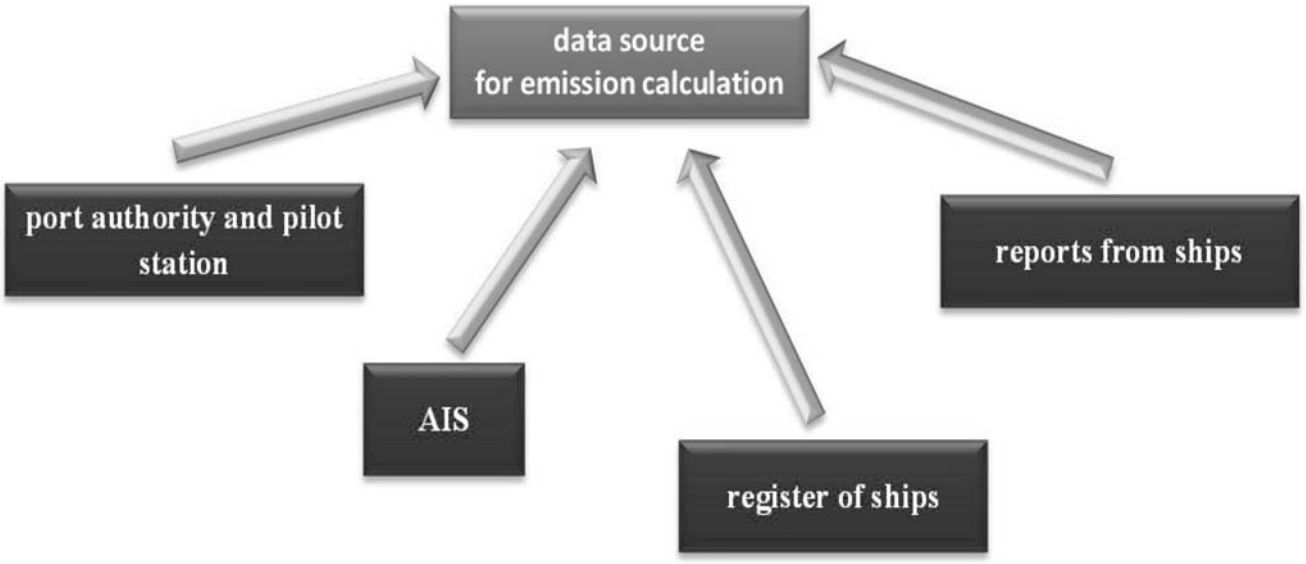

Fig. 6. Reference of data used for calculation of emission of air pollutant from the ships

Methodology of calculating pollution emission by the ships in ports

In order to prepare the detailed evaluation of the emission by the ships in ports, it has to be done separately for the different operating conditions of the ship. Every operating condition is connected to the velocity of the ship and thus, to the load of the main engine and the different use of the generators.

We can distinguish three different operating conditions of the ship in the port:

- Transit – the ship crosses the docks with the speed higher than the manoeuvring one, and lower than the maritime one (7-10 knots on average); for safety reasons there are at least two generating sets.
- Manoeuvres – the ship manoeuvres near the quay with the manoeuvring speed (5-8 knots on average or slower); for safety reasons there are at least two generating sets.
- Stay in the port – the ship moored or anchored at port; the main engine is set aside; Only auxiliary engines of the generating sets are at work for providing the ship with the electricity.

In this article much emphasis is put on the operating condition of the ship – ship's stay in the port („hoteling"). Pollution emission for "transit" and "manoeuvring" operating states are usually calculated separately.

„Hoteling" can be defined as time between the finished mooring at the quay (the main engines were set aside) and unmooring from the quay. If the stay of the ship in the port requires anchoring (i.e. river ports), this is the time between casting of the anchor and weighing it again. In this module of ship's operation, the main engines are set aside. It is only engines of the generating sets and the auxiliary boilers that are at work.

The practice of pollution emission calculation for the sea ships is based upon using the data from the ships and other sources, and is expressed by the formula:

$$E=P\cdot LF\cdot A\cdot EF \quad (1)$$

where:

E – pollution emission [g]
P – installed power of the engines [kW]
LF – load factor – use of engines expressed in per cents [%]
A – activity time in certain operating conditions [h]
EF – emission factor [g/kWh]

The reports of different organizations dealing with estimating of pollution emission can differ slightly yet, the general formula remains the basis for this estimation. EPA report [5] can serve as an example. Here the pollution emission in the port is expressed by the following relation:

$$Emissions_{hotel}=(calls)\cdot(P_{[aux]})\cdot(hrs/call_{hotel})\cdot \cdot(LF_{hotel[aux]})\cdot(EF_{[aux]})\cdot(10^{-6}tonnes/g) \quad (2)$$

where:

calls – the number of moorings
$P_{[aux]}$ – installed power of the auxiliary engines [kW]
$hrs/call_{[hotel]}$ – time spent at the quay during one mooring [h]
$LF_{hotel[aux]}$ – auxiliary engines' load factor [%]
$EF_{[aux]}$ – emission factor for the auxiliary engines [g/kWh]
10^{-6}tonnes/g – conversion factor

Pollution emission by the ships' engines – experimental research

Harmful pollutants emission by the ships' engines is a complex problem. Currently used transfer and receipt trials of ships' engines and ships' sea trials (after the ship construction is finished) do not include exhaust gases measurements. Exemplary experimental research was done on the vehicle-passenger ferry operating on the way between Poland and Sweden.

The research included the vessel with the propulsion engines characterized in the table 1.

Table 1
Characteristics of engines for the main and auxiliary propulsion of the ferry

Engine destiny	Main propulsion (propeller)	Auxiliary propulsion (generator)
Producr	Stork - Wärtsilä	Stork - Wärtsilä
Engine type	6 SW 38	6 SW 280
Power, velocity - nominal	3960 [kW], 600 [rpm]	1800 [kW], 900 [rpm]
Fuel type	IFO-380 [cSt], 989 [kg/m^3] @15°C	IFO-380 [cSt], 989 [kg/m^3] @15°C

Research methodology

Technical research on the ships run in the exploitative conditions without special conversion works lacks the possibility to set the uniform research procedure. It results from a few important conditions that finally shape individual factors of the emission of the exhaust gases' components. Test cycles required by the appendix regulations (IMO – MP/CONF.3/35) (International Maritime Organization) and included in ISO norms are directed mainly to the new engines and engines in good working order.

The conditions of running the tests should differ slightly from the standard conditions (temperature, pressure, humidity, fuel type). Then, the values of the engines' operational loads used during trials allow for appropriate use of statistical weight values with the ultimate calculation of the weight factor or certain pollutant emission. The norm allows for the engine checks on the ship taking all unfavourable circumstances of running such tests into consideration. These include: lack of possibility to measure effective engine torque, lack of possibility to measure the fuel consumption, another than required by ISO (MDO) fuel to supply the engine, inability of engine to operate in the full range of loads resulting from its partial technical aptitude. Aforementioned characteristics of the engine can be determined with the analytical methods. Such tests are considered as a simplified method of determining the rate of harmful pollutants' emission. It is run on the ship and it is designed for periodic or initial checks.

The aim of the measurements was determining the emission rate of the following harmful compounds, which are exhaust gases from the internal-combustion engines: NO_x, CO, SO_x, HC. The emission rate in this context means average weighted emission expressed in [g/kWh], related to the standard conditions. The measurement and the methodology of calculations is based on IMO recommendations mentioned in the project of Appendix VI of MARPOL 73/78 Convention [6]. The measurements were done according to the test cycles in conformity with ISO 8178 norm, part 4:

Measuring cycle for the main drive engines operating with the constant rotational speed – E2,

Measuring cycle for the auxiliary drive engines operating with the constant rotational speed – D2.

Research results

The results of the measurements from the test cycles for the individual engines were the basis for determining the final factor of every harmful component of the exhaust gases emission, which is an average weighted emission factor. Determined factors' values have been presented in the table for every engine independently.

Table 2
The values of weight factors of emission for engines of the ferry

No.	Engine	Engine destiny	NO_x	CO	SO_x	HC
			g/kWh	g/kWh	g/kWh	g/kWh
1	6 SW 38 Stork – Wärtsilä	Main engine no. 1	13.878	0.803	0.439	0.109
2	6 SW 38 Stork – Wärtsilä	Main engine no. 3	13.028	0.977	0.453	0.196
3	6 SW 280 Stork – Wärtsilä	Auxiliary engine no. 1	11.160	1.826	1.266	0.711
4	6 SW 280 Stork – Wärtsilä	Auxiliary engine no. 3	11.065	1.969	1.054	0.672

CONCLUSIONS

Among many sources of pollution emission in ports, ships remain the main one. Regulations applied on-land in the last years have limited on-land pollution emission to a great extent.

Detailed emission research mooring at ports are the point of reference to implement the strategies allowing for the emission limitation and its control. Emission rate is essential for the potential projects of ports' expansion and thus developing of their economic activity.

One of the efficient ways of pollution limitation by the ships in ports is using "shore-to-ship" system – electrical power supply of ships from the shore [7].

The authors carry detailed studies as part of the international project: "BSR InnoShip: Baltic Sea cooperation for reducing ship and port emissions through knowledge and innovation"(2011-2013).

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