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THE EVALUATION OF THE CHANGES IN THE EMISSION OF TOXIC COMPOUNDS RESULTING FROM THE POWER SUPPLY FOR THE SHIPS IN PORTS EFFECTED BY MEANS OF THE SHORE POWER

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Abstract

During their stay in harbours the ships generate the electric energy for their needs most frequently by ship's power plant through Diesel generating sets. In many ports, however, there is also a possibility to supply the ship with electric power by use of the shore power connection. Using such sources in some cases may contribute to reduce the emissions of toxic compounds. This article presents the results of the comparative analysis of the emission levels in both cases of electric supply basing on the measurements conducted on two ferries and Dolna Odra power plant nearby Szczecin.

Key words: *ship's power plant, environment protection, emission of toxic compounds, power plant*

1. Introduction

The implementation of the Emission Control Areas (ECA) as well as the requirements for the reduction of the emission of toxic compounds in ports, both constitute one of the major challenges for the navigation [4]. Since 1.01.2011 the International Maritime Organisation (IMO) regulations determine the new limit for the NO_x emission(standard Tier II), whereas for 2016 they predict very strict limits in relation to the NO_x emission control areas (Tier III). The permissible limits of NO_x emission – Tier II and Tier III standards are presented in the table 1 below.

Tab. 1. The permissible NO_x emission limits according to MARPOL convention Annex VI [3]

Engine rpm [min^{-1}]	**NO_x [g/kWh] emission limit**	
	Tier II	**Tier III ***
Implementation date	1.01.2011	1.01.2016
n<130	14,4	3,4
130 ≤n<2000	$44 \cdot n^{(-0,23)}$	$9 \cdot n^{(-0,2)}$
n≥2000	7,7	1,96

* applicable only to NO_x emission control areas (ECA)

On the other hand, in relation to the sulphur oxides their permissible emission is limited by the introduction of the sulphur content limit in fuel. The permissible limits of the sulphur content in fuel in global terms as well as within the SO_x emission control areas (SECA - SO_x Emissions Control Areas), and also the dates of their implementation are presented in the table 2 below. It is allowed alternatively to apply, in the control areas and globally, the SO_x content permanent reduction and monitoring in the exhaust gas, at least down to the level resulting from the application of fuel of the sulphur content as permitted in the given area.

Tab. 2. The permissible sulphur contents in fuel according to MARPOL convention Annex VI [3]

Date of the limit implementation	**Sulphur content in fuel (%)**	
	SECA	**Globally**
since July 2010	1,0	4,5
2012		3,5
2015	0,1	
2020 or 2025		0,5

The European Union countries mostly follow IMO regulations, however, the stricter regulations concerning the sulphur oxide contents have come in force earlier, because already as of 1 January 2010. They are in force within the areas of ports of the entire Community and order the application of fuels with sulphur content not exceeding 0.1% for the mass unit for the sea-going and inland navigation vessels during their stay in harbour. In terms of the regulations the ship staying in port is the ship that is safely moored or at anchor in port during its cargo handling operations as well as during the operations not related with the cargo itself. The regulations cover also the period of the ship's stay in the shipyard, both alongside and during dry-docking. Meeting of the requirements is not obligatory while manoeuvring; nevertheless they should be met as soon as possible after calling-in the port as well as the latest prior to the departure from the port.

In the effect of these restrictions in the shipbuilding industry there appeared various concepts of the solutions and arrangements aiming to reduce the emissions. One of the possibilities is the use of the shore power. This alternative makes one consider a question what the actual effect on the environment is. The problem takes a special significance in case of power engineering of the country like Poland which is based on coal.

2. The Determination of the Emissions from a Ships Supplied by Their Own Power Plant Whilst in Port

In order to get an answer to the question asked in the introduction and for the purpose of the evaluation of toxic compound emissions from the ship staying in port a simplified analysis has been made basing on the example of two passenger-car ferries. These are more than twenty years old vessels owned by Żegluga Polska SA and operated by UNITY LINE. Their basic data are presented in the table 3 below. In both cases for the electric power generation there are used the ship's power plants consisting of Diesel generating sets.

The choice of these two vessels which are ferries for the purpose of the analysis is subject to the special characteristics of their operation. Since they are the ships calling-in cyclically and in strictly determined periods of time to the same ports (repeatability of exploitation states), they provide very good material for research [5].

The estimation of the amounts of the emission during ship's stay in port has been made on the basis of the measurement readouts of fuel consumption and the load of the generating sets. The measurements have been made while the ships were moored at the terminal during the unloading and loading operations. The time of measurements taking may theoretically coincide with and overlap the period when the given vessel could have used the shore power.

The estimation of the emission amounts of the individual toxic compounds which are harmful for the environment during ship's stay in port has been made in two manners. The first manner allows to estimate the composition of the humid exhaust gas obtained in the effect of burning of stechiometric one kilogram of fuel.

Tab. 3. Technical data and operation measurements during port operations for the ferries Gryf and Wolin [2, 9]

Item	**Ship's parameters**	**Unit**	**Technical data**	
1	Ferry name	-	Gryf	Wolin
2	Year built	-	1990	1986
3	Type	-	RO – PAX	COMBI
4	Register size	GT	18653	22874
5	Length o a	m	157,90	188,90
6	Breadth	m	24,00	23,10
7	Draught	m	5,90	5,90
8	Maximum speed	w	17	18
9	Service speed	w	16	-
10	Passsengers	-	180	370
11	Vehicle lanes length	m	1880	1720
12	Auxiliary engine type	-	Mitsubishi S6R2 MPTK	Wärtsilä – Sulzer 6R 32 BC
13	Auxiliary engine power output	kW	610	2045
14	Generator type	-	LEROY SOMER LSA 49 L9	WAB 800 F8W
15	Generator power output	kVA	700	2430
16	Average fuel consumption by the generating sets while in port	kg/h	77,65	165
17	Average load of generating sets while in port	kW	350	650

To calculate the mass emission of carbon dioxide (CO_2) and sulphur dioxide (SO_2) for the unit of mass of the burnt fuel the following relations have been applied [1]:

$$M_{CO_2} = 3{,}6744 \cdot C_p + 0{,}002 \cdot S_p + 0{,}0015 \cdot \left(H_p - \frac{O_p}{7{,}9364} \right) [kg / kg_{Fuel}] \tag{1}$$

$$M_{SO_2} = 1{,}9979 \cdot S_p \; [kg/kg_{Fuel}] \tag{2}$$

where:

C_p – mass fraction of carbon in fuel,
S_p – mass fraction of sulphur in fuel,
H_p – mass fraction of hydrogen in fuel,
O_p – mass fraction of oxygen in fuel.

In the latter manner for the emission determination there have been used emission coefficients of the individual compounds contained in the exhaust gas, prepared for medium-speed engines by Lloyd's Register of Shipping which are presented in the table 4 below.

For the further analysis there have been used the larger figures amongst those obtained for the individual compound emissions.

The amounts of the solids emission from the medium-speed engines has been assumed basing on the references/literature as the constant and brought down to soot emission [7].

Such simplified approach has been adopted in view of the missing detailed research concerning the emission of compounds contained in the exhaust gas for the engines used for the chosen ships.

Tab. 4. Coefficients of emission for the calculation of the exhaust gas component emission indices

Item	**Compound**	**Emission coefficients for medium-speed engine [kg/Mg], [g/kg$_{Fuel}$]**
1	CO_2	3250
2	SO_2	21·S
3	NO_x	59
4	CO	8

where:

S – sulphur percentage fraction in fuel

Basing on the measurement data of the average power consumption during stay in port and the fuel consumed at the same time the unit emission for each vessel has been determined according to the relation (3).

$$m = \frac{M \cdot \sum G}{\sum N} [g / kWh] \tag{3}$$

where:

M – mass emission of a compound, g/kg$_{Fuel}$,
G – hourly fuel consumption during stay in port, kg/h,
N – ship's power plant load, kW.

The composition of the ship's fuel assumed for the analysis is shown in table 5 below.

Tab. 5. Percentage and mass composition of fuel assumed for calculation [6, 8]

Item	**Fuel component**	**C**	**H_2**	**O_2**	**N_2**	**S**	**A**[1]	**W**[2]
1	Percentage fraction [%]	85,4	12,3	1,0	0,5	0,1	0,1	0,6
2	Mass fraction [m/m]	0,854	0,123	0,010	0,005	0,001	0,001	0,006

[1] ash;
[2] water

3. The Evaluation of the Emissions Change While the Ship is Supplied from the Shore Power Network

The change of the emission amount upon replacing the ship's power plant by the electric power from the shore has been determined by the comparison of the unit emissions from both these sources. For the comparison there has been assumed the calculated unit emission for the ship's power plants of both ships and the emission and generation data of 2009 from the coal-based shore power plant, Dolna Odra, included in the complex the Power Plants Dolna Odra owned by PGE [Polish Power Engineering Group] [10]. The results obtained are shown in the table 6 below.

Tab. 6. The specification of unit emission from various sources generating the electric power

Compound	**Unit emission [g/kWh]**		
	Ferry Gryf	**Ferry Wolin**	**Dolna Odra Power Plant**
CO_2	721,036	825,000	866,929
SO_2	0,466	0,533	1,221
NO_x	13,089	14,977	1,625
CO	1,775	2,031	0,086
Solids	0,050	0,050	0,097

The data presented in table 6 suggest that there is a significant variation of the amounts of emission in relation to the power generation manner for the ship. On the other hand, the emission level of all compounds from the power plants of both ships is very close. The substitution of the ship's power plant by the shore power provides better results in the reduction of nitrogen oxides and carbon oxide. In favour of the ship's power plant application there is the low emission of sulphur dioxide as well as the smaller emission of carbon dioxide, in particular in case of Gryf ferry.

The comparison of emission amounts suggests that the connection of the ship to the shore power is not necessarily favourable for such solution. This is caused inter alia by the very low limit of the permissible sulphur content in fuels to be used during ship's stay in port. The carbon oxide emission is, on the other hand, definitely less in case of shore power connection. Dolna Odra Power Plant demonstrates the minor emission of this compound whereas the emission from engines of both generating sets oscillate within 1.7 – 2.0 g/kWh. The case is similar with nitrogen oxide emissions, in comparison with Gryf ferry the shore power plant under consideration displays the reduction by more than 11 g/kWh and more than 13 g/kWh in relation to Wolin ferry which corresponds to the reduction by 87.6% and 89.1%, respectively. As far as the solids are concerned the comparison is in favour of the ship's power plant, but these are not the reliable factors since for the ship's engines only soot emission has been considered whilst the remaining solid components have been omitted.

4. Summary

The analysis conducted fails to provide the explicit answer as to the justifiability of the change of the power source for the ship staying in port in terms of pollution reduction in a country like Poland. The production of the electric power, both in ship's power plant and shore power plant is burdened with the emission of the toxic compounds. For the objective evaluation of this solution the harmfulness and noxiousness of the individual compounds for the environment should be carefully studied and assigned the appropriate significance degrees. However the cost should be considered.

It could be assumed that the comparison of the emission amount from each and every conventional shore power plant based on coal with the ship's power plant based on Diesel generating sets supplied with low-sulphur fuel would produce similar results. Better effects would be likely to obtain, if the power plant used pure coal technologies such as fluidised bed burning or sequestration of carbon dioxide.

Connection of the ship to the shore power is nevertheless most recommendable in the ports of the countries using the large degree of nuclear power engineering and the renewable power sources.

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