IMPACT OF EMISSIONS OF MARINE DIESEL ENGINES TO AIR POLLUTION ON THE EXAMPLE OF THE YUGOSLAV RIVER SHIPPING

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Abstract: The subject of this paper is the impact which marine diesel engines have on air pollution. The combustion of fossil fuels for marine diesel engines produces emission of various greenhouse gases; including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO_2). Gas emission calculation is shown on the example of the Yugoslav river shipping with two methods for calculating harmful emissions of the marine diesel engines. Technologies for reduction of harmful emissions of marine diesel engines and other engines are also presented, as well as the implementation of those technologies, using the example of the Yugoslav river shipping. One of the objectives of this paper is to determine the actual condition of the fleet, as well as the impact it has on air pollution in Serbia, as a country which plans to become a member of the European Union. A measurement on diesel engines of different production date was done with a special device, in order to get the results that represent reality (about harmful emissions) in Serbia. Final task of this paper is to collect information in order to reduce harmful emissions of the marine diesel engines, along with preservation of the environment.

Keywords: emissions from marine diesel engines, climate changes, Yugoslav River Shipping (JRB).

1. Introduction

Over the course of several past years, the attention has been turned to a potential consequences of climate change on the global transport infrastructure and operations e.g. rising of superior sea-level, flooding and storm waves overwhelming port transportation facilities, runways at airport near the coast, sub-ways, and railways entering the tunnels and roads and bridges in low-lying coastal areas.

Consequences which these impacts can have on the transportation sector are not fully studied, nor considered by transportation planners and decision makers in the processes of planning, decision making and management of transport infrastructure. Many experts are not aware of the traffic problems that can lead to the climate change. Others are reluctant to take action because of the uncertain outcome, long-term framework and lack of clear guidelines and standards for classifying the effects of climate change.

The purpose of this study is to gain knowledge of substances that come from marine diesel engines and their quantity, as well as to help in recognizing the need of developing technologies which can reduce these substances, enhanced by the operation of ship diesel engine - as the best mode of transport in an ecological sense.

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Marine diesel engines will be used certainly for many years so that research should focus in improvement of their ecological efficiency (National research council of the national academies, 2008).

2. Advantages of River Transport

In comparison to other pollutants (heating, industry, road transport), river transport has a low level of fuel consumption and consequently a relatively low level of polluting the environment. The total amount of air pollution by the waterways is only 0.5 %.

It is expected that by year 2030 the effectiveness of river transport is going to increase by approximately 30%, while fuel consumption will decrease by 15% (compared to year 1990).

In terms of growth, river transport has virtually no limitations, e.g. the river Rhine which has the possibility to increase the volume of transport by 4 times, and the Danube by 10 times. Moreover, only the river transport is able to clear the road congestion.

3. Marine Engines

Ships are way different from other means of transportation, such as trucks or rail. In addition to the transportation of various goods and passengers, ships must include accommodation and other necessary facilities for the crew. In many cases must be able to handle different types of cargo in ports, as well. In order to secure this, ships must be able to provide energy in various conditions. Therefore, the ships are equipped with different types of "producers" of energy (Adamkiewicz and Kołwzan, 2007).

Marine engines are presented as the main engine and auxiliary engines. The main sources of emissions are as follows:

- Main engine - used for ships movement;
- Auxiliary engine - used to generate electricity (current).

The most commonly used engine in the ship is diesel engine. The diesel engine has undergone a powerful development process resulting in a completely new generation of engines with considerably improved performance. The specific fuel consumption of a modern two-stroke diesel engine may be in the order of 160g/kWh, as compared to 210g/kWh for older engines. Today, the largest two-stroke diesel engines have an output of over 80 MW, which should be sufficient even for future proposed high-speed container ships. Owing to the high efficiency of diesel engines, the emissions of CO_2, CO and hydrocarbons are relatively low; however, they have high emissions of NO_x. The same high combustion temperatures that give a high thermal efficiency in the diesel engine are also most conducive to NO_x formation. By running on low quality fuels with a low fuel consumption, large diesel engines offer enormous savings in fuel costs compared with those of alternative prime movers.

However, the ship's engines produce various emissions of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOCs) and sulfur dioxide (SO_2), (Adamkiewicz and Kołwzan, 2007). Primary goal is maximum reduction of harmful emissions.

4. Methods for Calculating Emissions

The IPCC methods provide a general approach to estimate emissions from the combustion of fossil fuels for navigation. The activity data used is generally fuel consumption. The emission factor may be fuel type and/or technology type specific. The basic equation, Eq. (1) is:

$$Emissions = Fuel\ Consumption \cdot Emission\ Factor \quad (1)$$

The IPCC method provides two approaches, Tier 1 and 2. Both tiers use fuel consumption data. The Tier 1 approach does not use fuel type or engine type specificity for the non-CO_2 gases (although it does for CO_2), and therefore is assumed to be less accurate for the non-CO_2 gases. The Tier 2 approach requires that the calculations are to be performed with some fuel or vehicle type specificity and in some cases discusses engine type specificity.

Method I

Carbon Dioxide (CO_2)

The IPCC Tier 1 or Reference approach for estimating CO_2 emissions from the combustion of fossil fuels used for navigation is the same approach used for other energy sources. It is a "top-down" method that estimates emissions based on the consumption of fuels.

The steps in the methodology are as follows:

Step 1 - Estimate consumption of fuel

Fuel consumption data is generally collected and published by national or international agencies. The amount of fuel consumed in ships, boats and other vessels for navigation may have to be approximated using proxy data on the marine shipping industry or other metric.

Step 2 - Convert the fuel data to a common energy unit (TJ), if necessary

The fuel consumption data may not be reported in common units.

Step 3 - Select the carbon content factor for the fuel and estimate the total carbon content of the fuel

Although default IPCC carbon emission factors are available, country-specific values should be used if possible.

Step 4 - Estimate the amount of carbon stored in products for long periods of time

If lubricants have been included in the estimates of fuel consumption, then the fraction of those lubricants which remain un-combusted should be subtracted from the consumption total. The oxidation of lubricants in ships is expected to be an extremely minor source of CO_2 emissions.

Step 5 - Account for carbon not oxidized during combustion

The fraction un-oxidized is a function of the type of fuel, the combustion technology, and the operation and maintenance practices. The default value for most common petroleum fuels combusted in typical engines is near 1 percent (Jun et al., 2001).

Method II

The Tier 2 IPCC approach requires only minor additional specificity. The IPCC methods do not currently provide Tier 2 default emission factors by fuel type and engine type. In theory, the IPCC approach would use the equation below to estimate emissions of non-CO_2 gases, Eq. (2):

$$Emissions = \Sigma\ (EF_{ij} \cdot Activity_{ij}) \quad (2)$$

Where:

EF - Emission Factor (g/MJ or g/kg fuel)

Activity - Fuel Consumption (MJ or kg)

i - Fuel type

j - Engine type

Estimates for CO_2 using the Tier 1 methodology already requires fuel type specificity, and the accuracy of those estimates is unlikely to be improved by the addition of engine type specificity. Emissions of non-CO_2 gases are far more dependent upon the engine characteristics and technology than CO_2 emissions. In the case of SO_2, the sulphur content of the fuel is the primary factor (Radojčić, 2006). It is important to note that the existing default emission factors presented in the IPCC methods are currently inaccurate to estimate emissions of non-CO_2 gases using well characterized activity data by fuel and engine type.

5. Fleet Sample

Detailed monitoring and records of vessels on field, it was found that in April 2005, the following ships were in service (Table 1), (Sladojević, 2006).

Table 1
Ships in Service (April 2005)

Ships at Service		Power (kW)	Fuel Consumption (l)	Working Hours (h)
1.	"Karlovac"	3091	181384	471
2.	"Karadjordje"	2060	110630	441
3.	"Kadinjaca"	1620	68738	268
4.	"Kajmakcalan"	1552	59738	368
5.	"Velebit"	1552	92370	348
6.	"Bihac"	1104	95065	477
7.	"Orasac"	1103	63512	328
8.	"Deligrad"	1276	59887	237
9.	"Kosmaj"	736	4380	29
10..	"Birac"	442	19095	278
11.	"Stig"	368	13260	169
12.	"Modrica"	592	22934	298
13.	"Kalemegdan"	109	22353	251
14.	"Gavran"	64	0	0
15.	"Radan"	40	0	0
16.	"Mc-20"	6	0	0
17.	"Miljacka"	88	0	0
18.	"Sarajevo"	736	0	0

Detailed tracking of the vessels in April 2005 helped in gathering the data on fuel consumption and hours of work for each of these ships. This data is essential for the calculation of emission which is made for all of the above mentioned ships. The Table 2 shows the total emissions of harmful substances for the month of April of all the ships that were in use. Calculation was made according to the methods which are briefly presented above.

Table 2
Total Emissions of Harmful Substances Estimated by Methods I and II (April 2005)

		(kW)	Total Emissions Method I (t)	Total Emissions Method II (t)
1.	"Bihać"	1104	70.24	73.7
2.	"Birač"	442	16.69	17.38
3.	"Deligrad"	1276	44.96	46.72
4.	"Kadinjača"	1619	51.07	53.6
5.	"Kajmakčalan"	1552	44.4	46.5
6.	"Karađorđe"	2060	82.24	86.1
7.	"Karlovac"	3091	134.81	142.44
8.	"Kosmaj"	736	3.25	3.4
9.	"Modriča"	592	16.12	126.8
10.	"Orašac"	1103	47.2	49.4
11.	"Raška"	368	2.4	2.6
12.	"Stig"	368	9.85	10.3
13.	"Stig"-II	368	10.62	11.04
14.	"Velebit"	776	71.61	75.12
	Total	15455	605.46	745.1

From Table 2 can be seen that the total emissions for each vessel has a higher value when calculated by method II. This is because the calculation does not include CO_2 gases. That is why it cannot be always used for certain engines and certain fuel types but should have been properly modified.

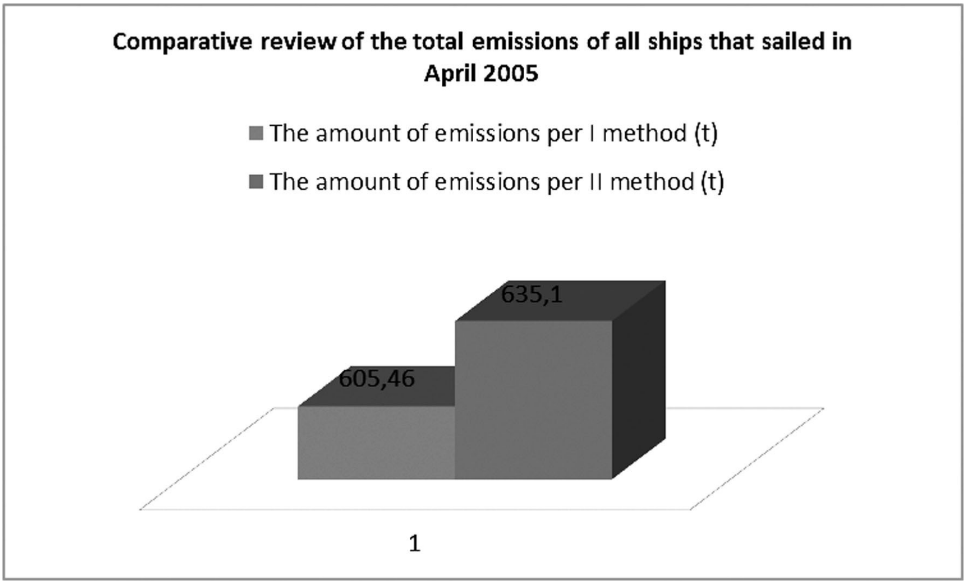

Fig. 1.
Comparative Review of the Total Emissions per Methods I and II of all Sailed Ships (April 2005)

Table 3
Estimated Reductions of Pollutants

Types of Technology	**NO_x**	**PM**	**FC**	**CO_2**	**SO_x**
Tempomat (ATM)	-7%	-7%	7%	-7%	-7%
Fuel with less sulfur	-	17%	-	-	99,50%
Catalizator (SCR)	85%	-	-	-	-
Particulate filter (PMF filter)	-	95%	2%	2%	2%
Total emission reduction	86%	96%	5%	-5%	-99.5%

6. Technology for Reduction of Harmful Emissions

There are four basic technologies to reduce harmful emissions that are used today: the use of selective catalytic reduction (SCR catalyst) using a filter to remove soot (PMF filter), using fuel with ultra low sulfur content, the same standard diesel fuel used by road vehicles; Cruise control (ATM), a computer program for advising the captain on the most cost-effective combination of distance and speed (Table 3), (Graham, 2010).

6.1. The Application of Technology to Yugoslav River Shipping

In order to demonstrate the impact of the above technologies to reduction of harmful substances, example will be done on Yugoslav River Shipping - JRB ships, for the month of April 2005. Regarding technology - we will assume that all the ships that have sailed in April have installed catalyst and PM filter. Regarding cruise control, we needed some certain engine technologies and newer engines with computerized fuel injection system what required a complete engine replacement, and unfortunately we were not able to do so. We were not able to find fuel with a small proportion of sulfur. Good fuel quality in Serbia is difficult, almost impossible to find. So we will apply the technology catalyst and PM filter.

7. Get Results after the Installation of Technology to Reduce Emissions (April 2005)

By using the example of Yugoslav River Shipping for the month of April 2005,

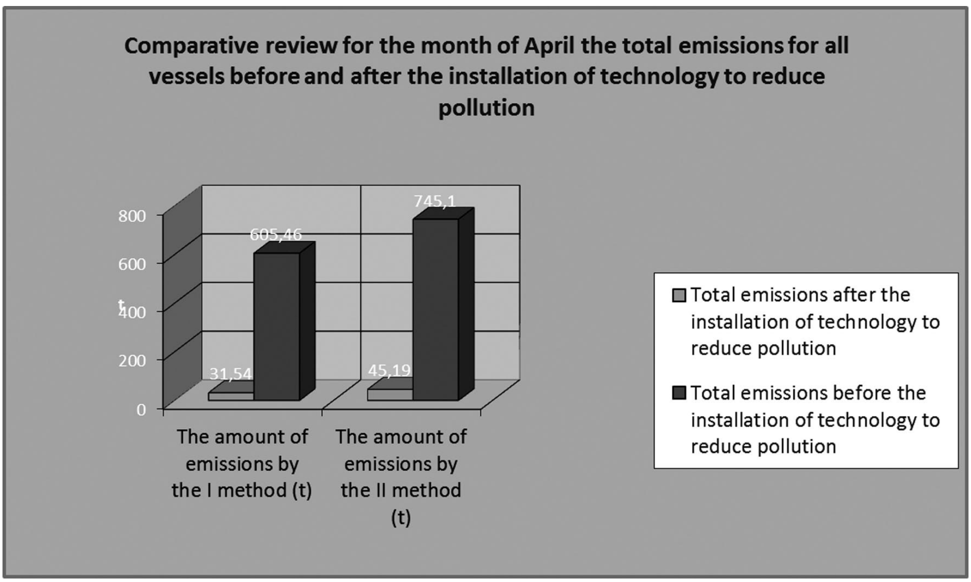

Fig. 2.
Comparative Review of Total Emissions Before and After the Installation of Technology to Reduce Pollution

we have performed a calculation of the emissions for ships that sailed, with an assumption that every ship had a catalyst and PM filter installed. Fig. 2 shows the comparison of these results (results obtained after the technology was built) and results for the same month when the ships sailed without adequate 'add-on' that reduce greenhouse gas emissions. From the Fig. 2 it can be seen that the total emissions reduced from 605.46 t to 31.54 t as per IPCC II approach method, and from 745.1 tons to 45.19 tons as per IPCC II approach method. The overall conclusion is that the first method was reduced by 19 times, while another method is reduced by about 17 times.

8. The Results of Measurements Performed on the Engines

Measurements were done on the field on diesel engines of different engine power and years of production in order to gain a real impression and carry out comparisons with the methods for calculation of emissions. Measurements were done by a device which is used to check the exhaust matter from diesel engines on technical road inspections of vehicles in the Republic of Serbia. Fig. 3 shows the emissions from diesel engine "FAP 1620BD" (year of production 1980, engine power 60 kW). This kind of truck is still used in large cases in Serbia and it is a representative type of the older diesel engines. Fig. 6 shows the emissions from diesel engine Mercedes Benz Actros (year of production the 2002nd, engine power 294 kW) with a catalyst and PM filter. We can conclude from the diagrams that the engine with the power of 294 kW has much lower level of emission. It was also interesting to find that the level of fuel consumption of the stronger engine was lower than that of the older engine type with less power. Measurements were done on 10 different kinds of engines, however-we will show only these two representative samples.

9. Conclusion

It is obvious that the fuel consumption is directly related to the emission of harmful gases and that the fuel has an important role in controlling emissions. In order for the fuel consumption to be reduced, it is necessary to move to more modern and newer engines with different fuel injection systems. This is the best solution, however it requires more investments. Moreover, replacing the old engines with new ones definitely has more advantages. Fuel consumption is lower and corresponding to the vessel owner; harmful emissions are reduced and it brings less emission factors which directly affect the emissions.

It should be kept in mind that that all emissions of greenhouse gases are not reduced in the same way. The influence of technology to reduce emissions has been presented, in order to see their actual effect on the real example. Therefore, it is shown that the installation of these technologies on ships JRB's total emissions are reduced almost 20 times, which is a significant reduction.

In respect to ecologically sustainable development strategies implemented within each country, it is considered that changes should be done in transportation sector as well. It has been recognized that the marine traffic has a potential of becoming an ecologically sustainable mean of transportation and efforts are made to lower and consequently eliminate the impact of marine traffic to the living environment.

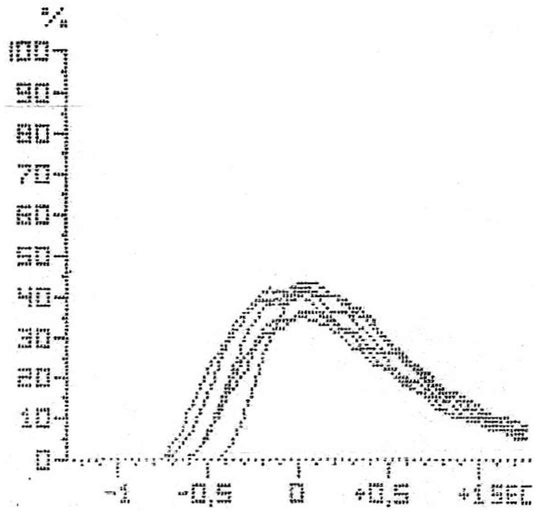

Fig. 3.
The Emissions from Motor "FAP 1620BD", Collected on the Field with Testing

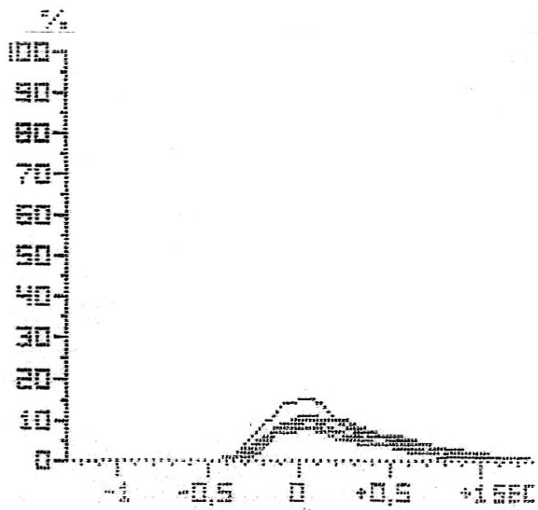

Fig. 6.
The Emissions from Motor Mercedes Benz Actros, Collected on the Field with Testing

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UTICAJ EMISIJA BRODSKIH DIZEL MOTORA NA ZAGAĐENJE VAZDUHA

Dragan Ljevaja

Sažetak: Predmet rada predstavljaju emisije iz brodskih dizel motora koje utiču na zagadjenje vazduha. Sagorevanje fosilnih goriva za brodske dizel motore proizvodi različite emisije gasova staklene baste, uključujući ugljen dioksid (CO_2), metan (CH_4), azot- suboksid (N_2O), ugljen monoksid (CO), okside azota(NO_x), isparljiva organska jedinjenja ($NMVOC_s$) i sumpor-dioksid (SO_2). U radu je izvršen proračun ovih emisija na primeru Jugoslovenskog rečnog brodarstva pomoću dve metode za proračun štetnih emisija iz brodskih dizel motora. Takodje, prikazane su tehnologije za smanjenje štetnih emisija iz brodskih dizel motora i ostalih dizel motora, kao i primene tih tehnologija na primeru Jugoslvenskog rečnog brodarstva. Jedan od ciljeva ovog rada jeste utvrdjivanje stvarnog stanja postojeće flote i njenog uticaja na zagadjenje vazduha u Srbiji, kao zemlji koja planira da postane član Evropske Unije. U tom cilju je izvršeno merenje posebnim uredjajem na dizel motorima različitih godina proizvodnje i snage. U okviru sprovedenog istraživanja prikupljeni su podaci o potrošnji goriva brodova u cilju smanjenja štetnih emisija iz brodskih dizel motora, a samim tim i očuvanja životne sredine.

Ključne reči: štetne emisije, brodski dizel motori, klimatske promene, Jugoslovensko rečno brodarstvo (JRB).