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AIR POLLUTANT EMISSION MEASUREMENT

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Abstract. One of the main methods for estimating air pollutant emissions from ships is the method developed by Carlo Trozzi, which was later accepted and recommended by the European Environment Agency in its air pollutant emission inventory guidebooks. Consequently, it has become the most commonly used methods for making inventories of air emissions in the shipping industry and for predicting future trends. The method and its equations use emission factors to calculate the emission of air pollutants from ships. Emission factors are calculated depending on fuel consumption or main engine power; results are given for different year of manufacture and engine speed. This paper presents the measurement of air pollutant emissions and some other parameters on marine engines operating in different conditions. The measured values are calculated to obtain values which will enable the next step, the comparison with the emission factors in the latest guide of the European Environment Agency on the inventory of pollutant emissions.

Keywords: air pollutants estimating; emission; shipping

Introduction

One of the main methods for estimating air pollutant emissions from ships is the method developed by Carlo Trozzi (Trozzi 2010), which was later accepted and recommended by the European Environment Agency in its air pollutant emission inventory guidebooks[1,2)]. Consequently, it has become the most commonly used method for making inventories of air emissions in the shipping industry and for predicting future trends or for estimating the potential benefits of the introduction of green propulsion systems which is one of the goals planned by European Commission[3)]. The method in its equations uses emission factors to calculate the emission of air pollutants from ships. Emission factors are calculated depending on fuel consumption or main engine power; results are given for different year of manufacture and engine speed.

Even during the research resulting in the creation of the method it was noted by the author that the method has some potential uncertainties, which can lead to differences in the results (Trozzi et al. 2004). This conclusion was followed by some additional research into the uncertainties of the air pollution estimate (Zhao et al. 2011; Insel 2008; Moreno-Gutiérrez et al. 2021).

Differences discovered in the mentioned research were significant, varying from some 50% in (Moreno-Gutiérrez et al. 2021) up to 300% in some cases listed by (Trozzi et al. 2004) and (Insel 2008).

An article with the estimate of the air pollutant emissions on the route between Korčula and Orebić and potential benefits of the future introduction of the electrically powered ferry on that route is in process of publication (Perić et al. 2021). All these calculations and analyses are performed in order to determine the effects of the progressive reduction in emissions as stipulated in some aspects of MARPOL[4)].

If applying the assumption of the uncertainties published by Trozzi (300 %!), the question remains how far from the target that estimate is.

Similar ferry, with a slightly more powerful propulsion, is operating locally, on a slightly longer route. An air emission estimate for that ferry has been performed and presented in this article. Air pollutant emission is measured twice on board the same vessel on the route, once on the way from Split to the port of Supetar and the other back. Measured air pollution quantities are compared with the calculated estimate to recheck the accuracy of the estimate and to determine uncertainty factor for this route and the type of vessel. That uncertainty factor might also be applicable for the new calculation of the estimate (Perić et al. 2021).

Additional Information

The measurement is carried out using the testo 350 MARITIME – Exhaust gas analyser for diesel ship engines (Figure 1) which can measure multiple gases: NO, NO_2, SO_2, CO, CO_2.

Figure 1. Flue gas analyser[5)]

The vessel where the measurement has been performed is M/T Juraj Dalmatinac, ferry data is shown in Table 1.

Table 1. Vessel data[6]

Loa	87.6 m
B(moulded)	17.5 m
Draught max.	2.4 m
Max speed	13 knots

Air emission estimate

Ship air pollutant emission estimate has been calculated using the methodology published by Trozzi (2010). For the use of the methodology, it is mandatory to know either the ship's fuel consumption or the ship's installed power. Most estimations, this as well, use engine power, which is information much easier to obtain. The total air pollutant emission in this case consists of two parts:

$$E_{total} = E_{cruising} + E_{maneuvering} \quad (1)$$

Each of those two parts can be calculated using the Equation:

$$E = T * P * LF * EF \quad (2)$$

where:
E – emission [kg]
T – time [h]
P – engine nominal power [kW]
LF – engine load factor [%]
EF – emission factor [kg/kW]

The vessel has four Caterpillar C3412 engines, each driving its own propeller. Two engines are forward and two aft. Engine details are presented in Table 2., each driving one propeller, during manoeuvring and navigation all four engines are in operation.

Table 2. Vessel main machinery[6]

Main engines type	Caterpillar 3412 E DITA
Main engines	4 pcs
Engine design	V 12
Engine power	492 kW

Bore/Stroke	137 / 152 mm
Electric power plant	2 x 240 kVA
Emgcy el. power plant	1 x 90 kVA

Emission estimate is calculated according to the Equation 2. Manoeuvring time is the time needed for a ship to perform manoeuvring on departure and on arrival. The time may vary slightly depending on various factors, duration of arrival and departure manoeuvring for this calculation is noted during the measurement of the emissions and it amounts to 15 minutes in total. The cruising distance is 8.1 Nm, and the cruising time is affected by various external and internal inputs, it can vary significantly. During analyzed trip cruising time was 40 minutes.

Engine load factor for the manoeuvring is set to 20% and during cruising to 80% according to Table 11 by Trozzi (2010).

Emission factors vary according to the type of fuel, the type of engine and the manufacturing year of the engine. Emission factors are taken from two sources depending on the availability of data. Those sources are Trozzi (2010) and Van der Gon & Hulskotte (2010). Emission factors for the manoeuvring are shown in Table 3.

Table 3. Emission factors (Trozzi 2010; Van der Gon 2010)

	Manoeuvring	Cruising
NOx	10.2 g/kWh	12.8 g/kWh
CO	1.5 g/kWh	1.5 g/kWh
CO_2	677 g/kWh	677 g/kWh

Air pollution emission estimate for one passage is calculated using the presented data and shown in table 4.

Table 4. Emission estimate

	Manoeuvring	Cruising	Total
NOx	1.00kg	13.43 kg	14.44 kg
CO	0.15kg	1.57 kg	1.72 kg
CO2	66.62kg	710.58 kg	777.20 kg

Air pollution measurement

Air pollution measurements (Figure 2) are taken on board on one forward engine and one aft engine.

Figure 2. Air pollution measurement

Measured values can be displayed as a graph (Figure 3) which allows faster overview or a data table.

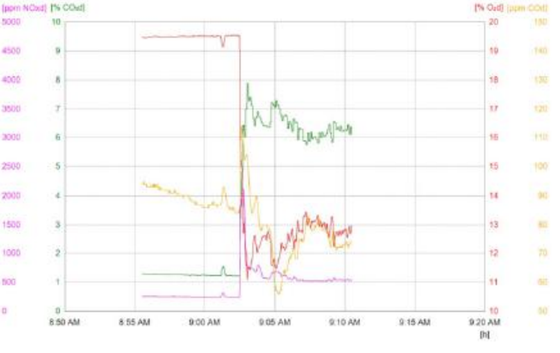

Figure 3. Split departure measurement

Data table is used to calculate the average value for each specific part of the passage, average values are shown in Table 5.

Table 5. Measured emissions

	Manoeuvring	Cruising
NOx	605 ppm	538 ppm
CO	97 ppm	77 ppm
CO2	6.14%	5.69%

Calculation with measured values

Presented data, together with the measured exhaust gas flow, is used to calculate total air pollutant emission.

Calculation is also divided into two separate columns to enable comparison with emission estimate presented in the Chapter 3. Calculation of air pollutant emissions using measured values is presented in Table 6.

Table 6. Calculation with measured values

	Manoeuvring	Cruising	Total
NOx	0.63 kg	6,79 kg	7.42 kg
CO	0.10 kg	0.97kg	1.07 kg
CO_2	52.83 kg	578.98 kg	631.81 kg

Discussion

Significant differences can be spotted if comparing Tables 4 and 6. Difference of values goes from 123% to 198% as shown in Table 7, depending on measured item.

Table 7. Differences of values

	Manoeuvring	Cruising	Total
NOx	159%	198%	195%
CO	150%	162%	161%
CO_2	126%	123%	123%

Largest differences are noted in the emission of NOx during cruising, calculation based on measured values gave almost two times smaller quantity than with the estimate. At the same time, quantities of released CO_2 do not differ significantly. As there are only two complete measurements analyzed at the moment, results shown should be taken with a dose of caution because nobody "gambles his research hypotheses on small samples without realizing that the odds against him are unreasonably high" (Tversky et al. 1971).

During this measurement another uncertainty was noted. Due to wind and sea conditions, measured air pollutant emissions values were different on the way to Supetar than on the return trip, measured values differed up to 25%. This fact supports the claim that many more measurements must be performed in order to establish real values.

Conclusions

Determination of the uncertainty in this example brought a value of uncertainty factor of 1.55 (median of all uncertainty factors). Although there is a measurement and calculation behind this number, the whole body of research showed that it is influenced by a multitude of internal and external factors. This uncertainty leads to significant differences in the comparison of air pollutant emissions using the methodology recommended by the European Environment Agency (EEA) or calculated with measured values for this route and vessel type. During the measurement of air pollutant emissions on this ship, another impact factor was observed, namely weather conditions, sea current and sea state have a respectable impact on the differences of measured values and determination of the uncertainty factor. Considering all listed, calculated average uncertainty factor of 1.55 cannot be taken as a true value, it represents only the value measured and calculated on this trip and on this vessel. Further measurements will either confirm these values or disprove them, but in both cases, there will be many more measurements and calculations to back up the conclusion.

Together with the method based on engine power, Trozzi developed the method based on the actual fuel consumption which should bring much more accurate values. Due to the lack of that data, comparison based on that aspect was not performed and remains for some future calculations.

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