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THE MEASUREMENT OF EXHAUST GAS EMISSIONS BY TESTO 350 MARITIME – EXHAUST GAS ANALYZER

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Abstract. This paper presents the measurement process of the emissions from marine diesel engines. The emission measurement was carried out by the certified TESTO 350 Maritime exhaust gas analyzer on the Juraj Dalmatinac ferry Caterpillar C32 engines. The gas analyzer records the concentrations of nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2) and sulfur dioxide (SO_2). TESTO 350 emission sampling probe was set at the end of the exhaust pipe. A combustion emission measurement was performed during a Split – Supetar (Brač) trip and backwards with the total duration of 110 min. The emissions are estimated for two trip phases: "maneuvering" and "at sea".

Keywords: emission measurement; exhaust gas analyzer; marine ports; marine diesel engines

Introduction

The shipping industry is a growing source of transportation air pollutants and greenhouse gas emissions (GHG) with a share of 2.89% emissions in global anthropogenic emissions[1)]. Air pollutants and greenhouse gases including nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), and sulfur dioxide (SO_2), arise as fuel combustion products and have a negative impact on human health and environment. Emissions from ships are regulated by the International Maritime Organization (IMO) through Annex VI of the International Convention for the Prevention of Pollution from Ships – the Marine Pollution Convention (MARPOL)[2)]. The Fourth IMO GHG Study (2020) estimated that the greenhouse gas (GHG) emissions of total shipping, expressed in CO_2e, have increased from 2012 to 2018 by 9.6%. In 2018 CO_2 emissions accounted for 1,056 million tonnes which makes a 9.3% increase compared to the 2012 CO_2 emission amount[1].

In April 2018 the IMO agreed on a draft greenhouse gas strategy for shipping requiring the shipping sector to reduce its emissions by at least 50% by

2050 compared to 2008 emission levels[3]. The carbon intensity of international shipping should decline by at least 40% by 2030.

Until the Paris agreement was finalized in 2015, the major climate agreement in force was the Kyoto Protocol[4]. Kyoto protocol entered into force in 2005, with the task of limiting GHG emissions in developed countries according to agreed individual targets. Unlike the Kyoto protocol, which targets only developed country's emissions, the Paris agreement requires that all Parties report regularly on their emissions[5]. The European Green Deal committed in 2019 to extend the EU's emissions trading system (ETS) to the maritime sector (Mulvaney 2019).

This paper demonstrates in-vessel emissions measurements using a portable exhaust gas analyzer.

TESTO 350 maritime measurement process

Area of interest – City port of Split

The port of Split is located in the central Adriatic and is the largest port in Dalmatia with proximity to the city center (Figure 1). Port offers 27 berths for mooring of passenger and ro-ro passenger ships in national and international traffic[6]. A large percentage of the emissions from ships in the maneuvering phase and while at berth has an impact on the city residents. Due to the coast indentation, short distance between City port of Split and islands, and air emission spreading, even at sea ship phase could impact the residents. Therefore, it is of high importance to measure and quantify these emissions.

Figure 1. City port of Split[7]

TESTO 350 Maritime – exhaust gas analyzer

The concentrations of nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and sulfur dioxide (SO_2) were measured by using Testo 350 Maritime. Testo 350 Maritime is a portable exhaust gas analysis system for the measurement of exhaust gas emissions[8)]. The gas analyzer has a certificate according to MARPOL Annex VI and NOx Technical Code 2008. It consists of a control unit, analyzer box, and gas sampling probe with probe pre-filter as visible on Figures 2 – 3. It can be used for monitoring emissions on board or performing tests if engines have had some modifications. Technical information of the instrument is given in Table 1[8)].

Figure 2. Analyzer box

Figure 3. Control unit

Table 1. Testo 350 Maritime technical data

Exhaust gas	Measuring range	Tolerance
O_2	0 to 25 Vol. %	According to MARPOL Annex VI and NOx Technical Code
CO	0 to 3000 ppm	
NO	0 to 3000 ppm	
NO_2	0 to 500 ppm	
SO_2	0 to 3000 ppm	
CO_2 (IR)	0 to 40 Vol. %	

Measurement process

The onboard measurements were taken on 23 March 2021 on ro-ro passenger ship "Juraj Dalmatinac" during the trip from Port of Split to Supetar (Island Brač). The distance between Split and Supetar is shown in Figure 4.

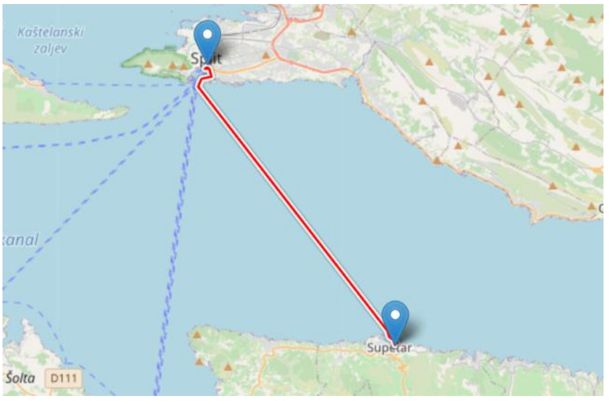

Figure 4. Split – Supetar distance[9)]

The trip started at 09:00 and ended at 09:55 hours with a total duration of 55 minutes. All measurements have been carried out for two ship phases maneuvering and at sea. The main information on Juraj Dalmatinac ship and engines can be seen in Table 2 [10)].

Table 2. Juraj Dalmatinac main technical data

Ship type:	Ro-Ro passenger ship
Ship owner:	JADROLINIJA RIJEKA
Flag and port of registry:	Republic of Croatia, Rijeka
Hull material:	Steel

Date build:	07/2007
Length overall (m):	87,6
Breadth (m):	17,5
Draught (m):	2,400
Propulsion type:	Internal combustion engine
Type of main propulsion engines:	Diesel, four stroke, single acting
Number of main propulsion engines:	4
Builder:	CATERPILLAR Inc.
License and type:	CATERPILLAR C32 ACERT
Total power output (kW):	1968
Number and total power of generators (kW):	3,630

After selecting the location for connecting the portable gas analyzer, while the engine was switched off, a previously prepared adaptation with the appropriate ½ inch thread was placed as visible on Figures 5 – 6. The exhaust gas was measured continuously during the trip what is shown in Figure 7. The probe was removed and the plug returned when the trip was over and the engine stopped.

Figure 5. Installation of exhaust sampling probe

Figure 6. Exhaust gas sampling point

Figure 7. Exhaust gas measurement

Results

Figures 8. and 9. show diagrams with the composition of exhaust gases during the maneuvering phases of departure from the port of Split and entry into the port of Supetar.

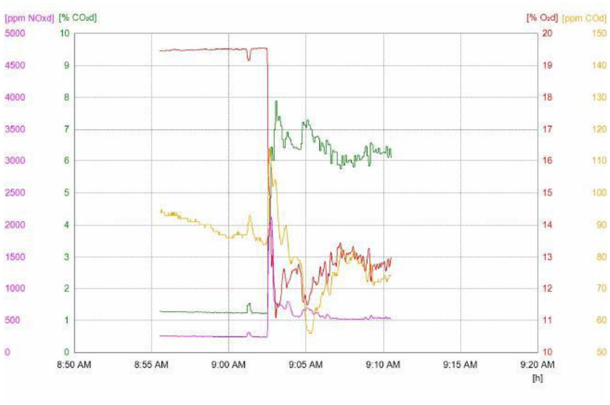

Figure 8. Departure from port of Split

Figure 9. Arrival in Supetar port

The attached diagrams show an increase in exhaust emissions at the very beginning of the maneuvering phase during the departure from the port of Split. After switching to the "at sea" navigation phase, exhaust emissions have stabilized and are declining. Switching from the "at sea" phase to the maneuvering phase when entering the port of Supetar leads to an increase in exhaust emissions.

Measurements obtained using Testo 350 Maritime indicate increased exhaust emissions during the maneuvering phase relative to the "at sea" phase. However, when summing the total amount of exhaust gases released, time spent in each phase should be taken into consideration because the maneuvering phase lasts much shorter than the "at sea" phase.

For the same ship, emissions are estimated using the "bottom-up" approach in the literature. (Bacalja 2020) Emissions are estimated for a single trip by multiplying maneuvering and hotelling time with the sum of the installed main and auxiliary engine power, the load factors for the main and auxiliary engine, the load factors for the main engine, and the operation's main engine time and emission factors. On Figure 10. are shown emissions estimated for the ship Juraj Dalmatinac maneuvering phase.

Ship	Main engine kW	Auxiliary engine kW	Main engine EF Nox g/kWh	Main engine EF NMVOC g/kWh	Main engine EF TSP PM10 PM2.5 g/kWh	Maine engine EF SO2	Maine engine EF CO2	LF main engine %	Main engine time of operation %
JURAJ DALMATINAC	1968	630	8,8	1,5	1,2	6,8	710	0,2	1

LF auxiliary engine %	Auxiliary engine EF Nox g/kWh	Auxiliary engine EF NMVOC g/kWh	Auxiliary engine EF TSP PM10 PM2.5 g/kWh	Auxiliary engine EF SO2	Auxiliary engine EF CO2	Nox	NMVOC	PM	SO2	CO2	Hours
0,5	11,5	0,4	0,4	6,5	690	2362,06	238,8	199,44	1574,66	165602	0,33

Figure 10. Juraj Dalmatinac estimated maneuvering emissions

If total maneuvering emissions are observed on an annual basis, it can be noticed that emissions depend on number of arrivals and departures. Juraj Dalmatinac maneuvering emissions in year 2017 are the lowest, following the lowest number of arrivals and departures (44). In year 2018, maneuvering emissions are the highest and so is the number of arrivals and departures (885).

Year	Ship	Number of calls	Nox	NMVOC	PM	SO2	CO2
2017	JURAJ DALMATINAC	44	103930,6	10507,2	8775,36	69285,04	7286488
2018	JURAJ DALMATINAC	885	2090423	211338	176504,4	1393574	1,47E+08
2019	JURAJ DALMATINAC	826	1951062	197248,8	164737,4	1300669	1,37E+08

Figure 11. Juraj Dalmatinac total maneuvering emissions through years

Conclusions

The reduction and control of exhaust emissions from shipping require adequate methods of measurement. This paper describes the method for analyzing exhaust emissions by the usage of the Testo 350 Maritime portable gas analyzer. These measurements enable reliable exhaust gas emission results in comparison to the emissions based on estimations and calculations. For this reason, ship emission measurements under actual operating conditions for all ship phases are of high importance. To obtain better control over the emissions of harmful gases, especially in maritime ports, it is necessary to perform the appropriate measurement directly on the engine itself, during all navigation phases. The measured results contribute to the overall measurement and monitoring of all parameters that contribute to energy efficiency and ultimately the quality of life. Measured emissions are significantly more reliable than those made based on estimates and calculations. By measuring exhaust gases, the machine itself is diagnosed, recommendations can be given for the maintenance of the machine, and exhaust gases are controlled. It is easier to measure emissions with a device like Testo 350 because the device is easy to handle and can give instantaneous values of the condition, i.e. the quality of the exhaust gases.

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NOTES

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