Experimental Method for Marine Engine's Emissions Analysis

Eksperimentalne metode analize emisija brodskog stroja

Tomislav Jurić
Brodosplit - Shipbuilding industry Split

Gojmir Radica
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
University of Split
e-mail: gojmir.radica@fesb.hr

Maro Jelić
Maritime Department
University of Dubrovnik
e-mail: maro.jelic@unidu.hr

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Summary

The world is considering various solutions to reduce exhaust emissions, the use of alternative fuels and the development of more efficient marine engines. IMO the company gave guidance for future borders of individual exhaust components, taking into account a variety of applications and conditions for the operation of marine engines. Engine manufacturers have been forced to develop new technologies, to meet the existing IMO rules and regulations that are yet to come, for the emission of harmful exhaust emissions.This paper describes the experimental procedure that support the modeling of the operating parameters of marine internal combustion engines in order to diagnose the condition, optimization of engine and reduce exhaust emissions. Special attention was given to verify the adequacy of the investigation, its accuracy and relevance. It outlines experiments that support the selection procedure tests during sea trials and later in the exploitation of the ship.

KEY WORDS
exhaust emissions
marine engine
experimental method

Sažetak

Svijet razmišlja o raznovrsnim rješenjima kojima bi se smanjile emisije ispušnih plinova, o uporabi zamjenskih goriva i razvoju djelotvornijih brodskih strojeva. Svjetska pomorska organizacija dala je smjernice za buduće granice individualnih ispušnih komponenata, uzimajući u obzir različite primjene i uvjete za rad brodskog stroja. Proizvođači strojeva bili su prisiljeni razvijati i nove tehnologije kojima bi se udovoljilo postojećim MPO propisima što će još biti doneseni u vezi s emisijom štetnih ispušnih plinova. U članku se opisuju one eksperimentalne procedure kojima se ostvaruje modeliranje parametara brodskih strojeva s unutarnjim izgaranjem da bi se ustanovii uvjeti, optimizacija stroja i smanjile nepoželjne emisije ispuha. Posebna se pozornost posvećuje verifikaciji adekvatnosti istraživanja, njezinoj preciznosti i relevantnosti. Prikazuju se i eksperimenti kojima se omogućuje procedura pri odabiru testova za vrijeme probnih putovanja i budućeg iskorištavanja broda.

KLJUČNE RIJEČI
ispušne emisije
brodski stroj
eksperimentalna metoda

1. INTRODUCTION / *Uvod*

Pollution of the environment is largely applied to the shipping industry in general and on the boat as transportation for navigation at sea. The ship in the fleet, is a major polluter of the environment, namely the atmosphere, which is saturated with harmful gases acting at their releasing. The combustion of fuel in the ship's engine creates exhaust gases that contain harmful compounds such as nitrogen oxides, carbon dioxide and monoxide, and sulfur oxides and soot (Figure 1).

According to the provisions of the Protocol of 1997, which is added to the International Convention for the Prevention of Pollution from Ships (ICPPS 1973), to any new type of marine engine, with standard test bench is dedicated to testing exhaust emissions, carried out by qualified companies, according to the order and the way that is given and approved according to IMO NOx Technical Code. These data and protocol tests are entered in the ''technical document" boat engine (*Technical File*, IMO TF *Supportive document*) which must meet the IMO requirements for greater reduction of exhaust emissions. If the ship's engine meets the IMO criteria, issued by the authority: international certificate for prevention of air pollution from marine engines, or ''International Air Pollution Prevention Certificate" (*IAPP Certificate*) [1].

Tests were performed according to standard procedures, tests reduced data using this calculation codes for exhaust emissions, engine manufacturer's approved method notified to IMO [1]. Data emissions were corrected according to the

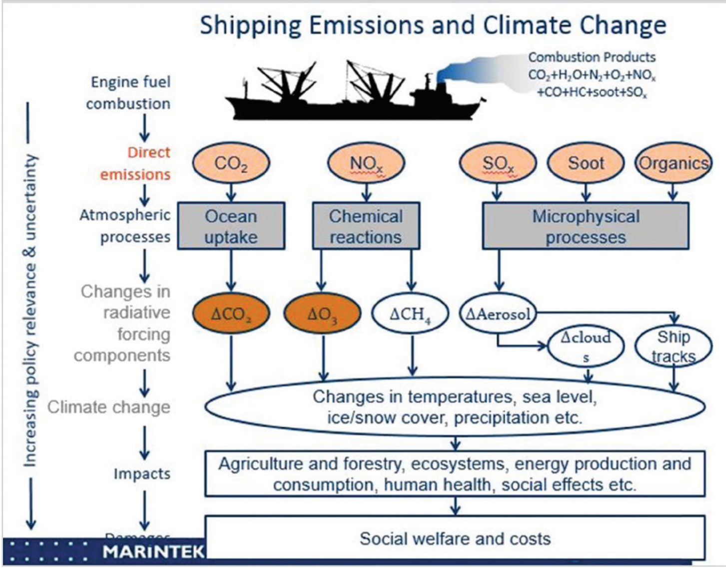

Figure 1 The impact of emissions on climate change and the environment [1]
Slika 1. Utjecaj emisija na izmjenu klime i okoliš

standard ISO environmental conditions, using the formula developed for ambient corrections. Report is submitted to an authorized company that issues EIAPP Certificate. Also, this report contains the necessary documentation for the method of performance measurement of exhaust emissions of boat engine on the test bed.

The documentation: A Guideline to the Unified Technical File,Regulations for the Prevention ofAir Pollution from Ships, Nov. 2004, contains the procedures that are standard for all marine engines:

- NOx functions – prediction model of NOx emissions,
- Using the NOx function to determine tolerance,
- Ambient correction factor for marine engines,
- Procedures for measuring emissions IMO certification of marine engines,
- Calculation Code for exhaust emissions' approved by IMO,
- Correction factors for marine engines,

Once the engine is tested on test bed according to the above-mentioned procedure and when the EIAPP Certificate is issued, it is considered that the engine meets the regulations on exhaust emissions, and checks are made only through the *Technical file* that must register all changes to the relevant parts of the engine, important for the combustion process. During engine life all operating parameters have to be within the permissible limits.

The problem is we do not measure the exhaust emissions, it is indirectly concluded that the emissions are within acceptable limits. This paper will analyse the possibilities of obtaining data and propose experimental analysis to support the selection procedure tests during sea trials the ship in operation in order to determine exhaust emissions and influencing parameters on the optimal engine performance, and to propose a method for future research in order to reduce exhaust emissions and optimization of marine engines.

Examining on test bed gives the access to certain operating parameters at loads of 25%, 50%, 75%, 100%. When defining the experimental method more parameters must be included, perform research and identify the most important parameters to be used for the modelling and optimization of the engine. In medium speed and slow speed marine diesel engines, modelling the working process is far more complicated in the light engine, research and measurement are more complex, more expensive and a small number of scientific papers. The experiments are difficult, and the processes are complex, because every engine is different, every single cylinder chamber in the engine has variations in the performance which gives a variety of parameters. These engines are most commonly found in commercial shipping traffic and they practically produce the majority of exhaust emissions in maritime transport [2]. It is necessary to find an effective and convenient method for the determination of emissions and optimization.

There are different programs for commercial development of the working process of the engine. Most are based on Vibe model for heat release and Woschni heat transfer model[3,11,12], but the coefficients that are proposed, have not been tested in such large engines. Also Zeldovich's starting mechanism in nitric oxide production [3], should be checked at low speed engines. A numerical-experimental method should be used to determine the relevant data for emission analysis. All parameters important for the process should be used in modelling the process and the results should be verified with obtained measurements. This paper will cover the parameters which are given by the manufacturer and the recommended literature during questioning and assessing the performance characteristics of the engine, and also recommend the procedures and parameters that are important in the experiment to determine the exhaust emisions. This paper processes sensors which are used for enabling the implementation of experiment on board during the sea trials and later in exploitation. The proposal of the experiment is given by the protocol for conducting the experiment. Finally, the results are given to preliminary experimental analysis.

2.TESTING PERFORMANCE OF MARINE DIESEL ENGINES / *Testiranje izvedbe brodskog dizelskog stroja*

Each test consists of procedure where circumstances and operating conditions are determined and included in the calculation of engine performance. This procedure is essential for correct measurements and diagnosis of engine's performance. The knowledge of methods of measurement, characteristics of measuring sensors and techniques for diagnosing are important for the design and optimal operation complex technical system in ship.

During engine operation following parameters are observed: fuel quality and viscosity, cylinder oil, circulating oil and turbine oil quality, pressure and temperature; for each cylinder: cylinder pressure, and exhaust gas temperature; Fuel pump index and VIT index, cooling water temperature, piston outlet lubrication oil temperature; cooling water temperature, inlet and outlet for main engine and air cooler; sea water temperature, turbine exhaust gas temperature on inlet and outlet; exhaust pressure in receiver and on turbine outlet; turbocharger speed, Scavenge air pressure difference through air filter and cooler, as well as in receiver; scavenge air temperature: inlet blower, before and after cooler; engine lubricating oil pressure and temperature: system oil, camshaft, turbocharger, thrust segment; fuel oil temperature and pressure before and after filter. Important parameters to be calculated and corected according to ISO conditions are: fuel consumption, indicated pressure and power, efficiency of the engine and , turbochargers. According to the observation, engine diagnostic is performed:fuel combustion conditions, the general state of the cylinder's chambers and the general condition of the engine. If there are disturbances, they can be found at an early stage and thus prevent further development and the emergence of failures.

The main parameters being monitored during engine operation and important to determine the performance of the engine [8] are: atmospheric pressure, engine speed, draft, the middle indicated pressure, compression pressure, the maximum combustion pressure, the index of fuel pumps, exhaust gas pressure, exhaust gas temperature, pressure turbocharged air temperature turbocharged air, the speed of turbochargers, exhaust gas back pressure in the exhaust pipe after the turbocharger, the air temperature before the filter turbochargers, the difference in air pressure through a filter (if installed pressure gauge), the difference in air pressure through water cooling, air temperature and cooling water before and after drilling cooler air.

During examining records will be kept and monitored whether the parameters are within the permissible limit values set by the the engine manufacturer and the classification society that accompanies the engine during the test.

3. DETERMINATION OF EXHAUST GAS EMISSIONS / *Određivanje emisija ispušnih plinova*

The most appropriate tools and principles on which the sensors converts the required physica size into the data have to be analysed and determined.

The exhaust emissions of internal combustion engines depend on the process of fuel combustion, the engine status and systems to control exhaust emissions. The products of incomplete combustion of hydrocarbon particles in the fuel make up a small portion fraction of the exhaust gas [5].

The majority of NO_x emissions comes from the high temperature reaction of atmospheric nitrogen with oxygen present in the combustion process. A secondary source of NO_x emissions comes from nitrogen-related mixture of fuel. Proces combustion produces, almost entirely, NO, that during the expansion process further oxidates to NO_2. Depending on the retention of the exhaust system (depending on the volume of the exhaust system) and the temperature of the exhaust gas, NO is typically transformed into NO_2, in amounts of 5 to 7% of the total amount of NO. Emitted NO_x continues oxidize in the atmosphere, getting the characteristic yellow-brown color. Depending on the formation of the jet of mixed and injected fuel, it creates the combustion chambers of different combustion temperatures for each particular engine, and due to the great influence of temperature on the formation of NO and produce various results of the NO_x emissions. Furthermore, the different fuels used for combustion, burn at different temperatures, and therefore also vary in the amount of generated NO_x[2].

Hydrocarbon emissions have a number of sources. Great portion of HC emissions comes from unburned lubricating oil cylinder liners and valves for leakage of fuel. For motors with a crosshead there is a possibility of lubricating oil to enter into the cylinder through the scavenging channels.

Forming CO is mainly a function excess air from the air/ fuel mixture. The formation of CO strongly affected by local conditions in the combustion chamber. For this reason, a good process of mixing of fuel and air and air surplus, which is possible to achieve in tubrocharged marine engine adjusted for minimum CO emissions.

Standard HC fuels are all organic origin and therefore different fuels contain different amounts of sulfur coming into the combustion chamber. During the combustion process, the sulfur is oxidized into various sulfuric oxides (SO_x), principally SO_2 and SO_3. For this reason, SO_x emissions from marine engines is a function of the sulfur content in the fuel. Furthermore, a smaller proportion of SO_x has a sulfur content in the lubricating oil, which is also combusted in the cylinder. SO_2 and SO_3connect on themselves part of the water content in the exhaust gases. SO_2 and SO_3 are condensed in sulfuric acid which appears on all the cooler places in the exhaust system where it reaches the point of condensation, which is usually around channels. For these reasons, to prevent corrosion of the engine, the lubricating oil is fed with various additives to neutralize acid. SO_x can be controlled either by removing sulfur from fuel or removing $SO_x$from exhaust gases [5].

The content of particulate matter in the exhaust gas is made up of several different components. Solid particles are formed, apart from the solid material contained in the fuel, and liquid condensed material from nucleic remains. During the combustion process, soot is formed and the process of decomposition of carbohydrates after oxidation of the products of decomposition. Connected with conglomerates soot and ash is composed of several metal oxides.

During the expansion process, and later in the exhaust system (or atmosphere) different carbohydrates and metal oxides continue to condense into particles, forming a final solid particles [1] friendly. In order to analyse the particles from exhaust gases that endanger people and the environment, adapted dilution method ISO 8178 for measuring the mass of particulate matter. This method is dilution of exhaust gases collected in the filter material which is maintained at a temperature of up to 51°C and subsequently analysed. Several methods based on the measurement of soot using a degree of opacity white filtring paper through which a fixed amount of gas. Finally, we have the optical measurement method. It is based on the percentage of light that breaks through a certain amount of exhaust gas to the instrument for measuring the brightness. The advantage of this method is the speed of obtaining results, or at any time the known state of the exhaust gases.

3.1. Detecting composition of exhaust gases and solids / *Određivanje sastava ispušnih plinova i krutih materija*

To determine the composition of the exhaust gas ise regulated by the norms and standards that describe measuring devices which are used to make such measurements, and measurement methods used for the measurement.

The measuring method is based on the sampling and can be divided into:

- non-extractive (measuring probe and the devices are located within or on the exhaust duct andanalyze the composition of gases directly or indirectly),
- extractive (exhaust gas sample is taken from the exhaust-gas and water in the device where analyses) [6].

Depending on the regulations and the size of the stationary source emission measurements are carried out continuously or intermittently. The sensors with which to determine the composition of the gas are divided according to the mode.

For the detection of concentrations of certain gases there can be used different types of measuring sensors, but for the detection of certain gases there can be used only certain measuring principles.

Table 1 Measuring principles [6]
Tablica 1. Principi mjerenja (6)

Measuring principles	SO_2	CO	CO_2	NO_x	H_2S	O_2	C_xH_y
Photo material IC	X	X	X	X			
Photo material UV	X			X			
Paramagnetism							X
Chemiluminescence					X		
Calorimetric			X				X
Flame ionization		X					X
el. Chemical potentiometry Electrolytically		X	X		X	X	X

Electrolytic sensors are used for the determination of O_2 in the exhaust gases, as well as harmful gases CO, CO_2 or H_2S. Smoke gases passing through the cathode and the chemical reaction occurring OH- ions traveling towards the anode. The flow of current is proportional to the concentration of oxygen in the exhaust gas [6]. These types of sensors commonly used in portable devices for measurement of emissions, as they are very compact, robust and does not require special conditions of work [5].

Sensors on the principle of infrared absorption are used to determine the emissions of CO, SO_2, CO_2 and NO_x. It works on the principle of selective absorption of infrared light by the gas. Gas at the specific wavelengths absorbed by infrared light, in proportion to the concentration of the detected gas. The exhaust gases pass through a chamber through which the gas transversely through the IR lamps emit infrared rays of a specific wavelength. On the basis of the absorbed ligh it is determined by the concentration of a particular gas in a mixture of exhaust gases. This type of sensor is used to determine the concentration of CO2 in the exhaust gas [5]. The optical signal can be a carrier of measurement information and a carrier signal is depending on the measuring physical values and transfer the media, because we have two types of optical radiation.

The first group consists of optical sensors based on photoelectrical effects that operate on the principles of photo emission, photoconductivity, photovoltage, photoniductive and photoionization [9].The second group of sensors absorb the photons being absorbed energy leads to a change in the material temperature sensors. The most famous optical sensors are: thermistor, bolmetar, bimetal and piezoelectric sensor. This type optical sensors for light source used LEDs and laser diodes.

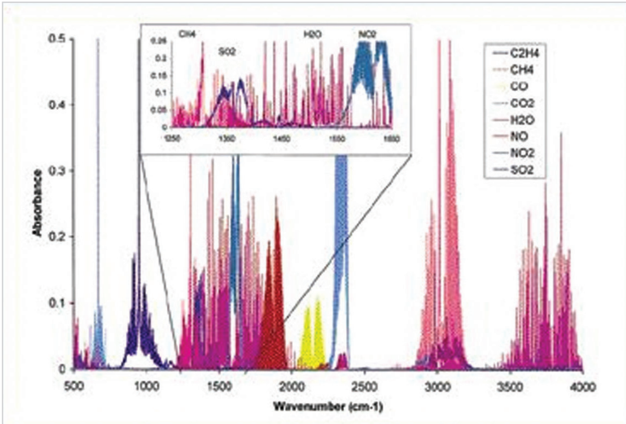

Figure 2 IC method for the determination of the exhaust gas [6]
Slika 2. IC metoda za određivanje ispušnih plinova (6)

Solid particles represent all components of the exhaust gases that are in the solid state, the composition of which can vary depending on the composition of the fuel and thecombustion conditions. The composition of the particles is not subject to analysis, but only determine the mass concentration ofparticles in the exhaust gases[9], [2]. Determination of particulate matter (PM) in the exhaust gas canbe performed in several ways using different methods:

- gravimetricis okinetic methods-determination of the mass of particles accumulated on the filterpaper, the method determines the specific conditions of sampling,
- optical methods-using the properties of absorption and/or reflection of light particles
- electrical methods-statical electricity.

Advantages of these types of devices are sensitivity to high concentrations of gases and acid compounds, and precision, as they can be calibrated continuously. These kinds of devices are mainly used for continuous monitoring of emissions from large power plants.

Extractive methods are used mostly for periodic measurement, but also for continuous measurement.The extractive measurement method is characterized by sampling gas from the exhaust and analysing in a separate device. The sample gas is rapidly cooled and separated from the condensate (water vapour). The processed gas is delivered to sensors for detecting particular gases (O_2, NO, NO_2, SO_2,…)

In order to properly use the emission measuring device it is necessary to conduct a thorough preparation for measurement. Important parameters are: diameter of the exhaust pipe, distance from the source device, and a way of connecting devices to the exhaust pipe, measuring time and to prevent leakage of exhaust gases during measurement through the measurement hole. In conjunction with mentioned parameters, it is essential to incorporate in analyses also: ambient air temperature, humidity, sea state and the whole system of marine plants, characteristics of engine and engine process, to avoid sudden fluctuations in the system. When all of these conditions are met, then the experiment with sampling at different engine loads can be performed. While the sample is taken, exhaust gas analyser processes the data and provides insight into the state of the sample taken. Parameters can be obtained in the percentage, mg / m ^{3}, ppm, and°C [9].

All parameters and theirs dimension must be initially determined, as well as the proper method for measuring each parameter, to avoid mistakes such as wrongly adjusted fuel or engine process, or engine characteristics.

3.3. Equipment and methods for measuring emissions on the test bed / *Oprema i metode mjerenja emisija na test uzorku*

The most common procedures for measuring exhaust gas emission on the test bench is according to MAN B&W document "Emission measurement procedures for IMO certification of MAN B & W two stroke engines". Table 2.specifies example of exhaust gas analysers and their working range for the measurement obtained on test bed.

Table 2 Exhaust gas analysers [4]

Tablica 2. Analitički pokazatelji ispušnih plinova (4)

Component	Manufacturer	Model	Working range
NOx (wet)	ECO Physics	CLD 82 S hr	0 – 2000 ppm
CO (dry)	ABB	Advanced Optima URAS 14	0 - 1000 ppm 0 - 250 ppm
CO2 (dry)			0 – 12 %
O2 (dry)			0 – 22 %
HC (wet)		Adv. Optima Multi-FID 14	0 – 100 ppm 0 – 500 ppm

One of the most important parameteris the quality of fuel used in engine and fuel must be specified according to following fuel specification: ISO code: DM; Density: 0.8462 (g/mlat 15 °C); Heat value: 42.60 (MJ/kg); Viscosity: 3.13(cStat 40 °C); Sulphur content:0.49 (%); Nitrogen: 0.24 (%); Carbon content: 85(%); Hydrogen: 13.4 (%); Oxygen: < 0.1(%).

The testing program described in IMO E3 cycle includes certification test at 25%,50%,75% and 100% load.

The raw data was obtained directly from the engine on test bench, with the atmospheric conditions and environmental that was at that time on test bench.

Duration of each test is at least 10 minutes, and the average value for each exhaust component is calculated to last for about 3 minutes of measured time. The actual value is calculated as a percentage (%) or parts per million (ppm), using zero and the calculated values for each component [4].

The most important engine characteristics used in calculation are:• p_{max} - maximum cylinder pressure;

- T_{cool} – cooling water temperature; • T_{scav} – scavenging air temperature; • p_{back} – turbine back pressure
- p_{com} - compression pressure in the cylinder

For the purpose of comparing measured values with standard characteristic for tested engine, measured values is corrected to the standard ISO environmental conditions, using the equation for the correction as it is given in the 'IMO Technical Code''

3.4. Exhaust gas emissions analyse during sea trial / *Emisije ispušnih plinova za vrijeme pokusna putovanja*

Proper engine monitoring and optimisation of the exhaust emission imply proper measurement of exhaust gas during sea trial and during exploitation of the engine.It is necessary to experimentally determine the method that could give relevant parameters for process modelling and getting results to decide about engine condition and possibility for optimisation. MRU-Vario plus SE, exhaust gas analyser use extractive method for sampling gas from the exhaust-gas analysis. The processed gas is lead away to the individual sensors. A list of sensors and their accuracy are given in Table 3.

4. EXPERIMENTAL METHOD FOR DETERMINING THE OPTIMAL OPERATION OF THE ENGINE IN ORDER TO REDUCE EXHAUST EMISSIONS / *Eksperimentalna metoda određivanja optimalna djelovanja stroja da bi se smanjile ispušne emisije*

In order to start with experimental method, the system must first be calibrated i.e., measured and tested in order to obtain the characteristics of the system on which the experimental method must be implemented.

When conducting tests, it is important to find out whether the engine obtains all the tasks it is designed for. Therefore, testing is carried out according to the purpose and location.

Control tests are used to determine the values of the most important engine parameters such as power, fuel consumption, technical condition etc... Tests are conducted on new or serviced engine. Additional test, related to the consumption of fuels and lubricants, developing strength, speed and thermal state are performed for different engine working load.[5].

Experimental method, described in this paper, is used to verify the assumption upon the model is chosen for the calculations. This type of data obtained allows more accurate engine parameters calculations and improvement of engine design. The main targets of the above mentioned experimental method are the fuel injection pump, injection timing and fuel type and therefore the exhaust emissions. This experimental method can obtain a new achievements for the improvement of the engine construction [5], and can reduce the time required for additional mathematical analysis and interpolation whenever it is possible. Engine parameters obtained by this experimental method must be compared to the real engine parameters, which are measured, and thus able to perform the most accurate engine construction. In addition to this method, time necessary for engine tests is shorter and numbers of real time sensors are reduced without any unnecessary test repeating and excessive variation of parameters. The following parameters are measured and analysed:T_{gas}, T_{amb}, O_2, CO_2, CO, NO, NO_2, SO_2. The sensors which are measuring above mentioned parameters are described in Chapter. 3.

Table 3 Sensors characteristics and accuracy of MRU exhaust gas analyser [4]
Tablica 3. Karakteristike senzora i točnost MRU analitičara ispušnog plina (4)

Measured component	Sensor type	Minimun range	Maximum range	Resolution	Accuracy (whichever is larger)
O_2	electrochemical	0 - 21%	0 - 21%	0,10%	± 0,2% absolute
CO / H_2 comp.	electrochemical	0 - 4000 ppm	0 - 10000 ppm	1 ppm	± 10 ppm or ± 5% reading
CO	electrochemical	0 - 40.000 ppm	0 - 100.000 ppm	100 ppm	± 200 ppm or ± 5% reading
NO	electrochemical	0 - 1.000 ppm	0 - 5.000 ppm	1 ppm	± 5 ppm or ± 5% reading
NO_2	electrochemical	0 - 200 ppm	0 - 1.000 ppm	1 ppm	± 5 ppm or ± 5% reading
SO_2	electrochemical	0 - 2.000 ppm	0 - 5.000 ppm	1 ppm	± 10 ppm or ± 5% reading
H_2S	electrochemical	0 - 50 ppm	0 - 500 ppm	1 ppm	± 5 ppm or ± 5% reading
H_2	electrochemical	0 - 1 %	0 - 2 %	0,01 %	± 0,05 % or ± 5% reading
CO	NDIR (%)	0 - 3%	0 - 10 %	0,01 %	± 0,03 % or ± 5% reading
CO	NDIR (ppm)	0 - 10.000 ppm	0 - 30.000 ppm	1 ppm	± 40 ppm or ± 5% reading
CO_2	NDIR	0 - 3%	0 - 30 %	0,10 %	± 0,6 % or ± 5% reading
HC (as C_3H_8)	NDIR	0 - 1.000 ppm	0 - 5.000 ppm	1 ppm	± 30 ppm or ± 5% reading
HC (as CH_4)	NDIR	0 - 10.000 ppm	0 - 3%	1 ppm / 0,01 %	± 60 ppm or ± 5% reading
Combustion air	NiCrNi thermocouple	-50° ... +250°C	-50° ... +250°C	0,1 °C	1°C or ± 2% reading
Stack gas temp	NiCrNi thermocouple	0 ... 1100°C	0 ... 1100°C	0,1 °C	1°C or ± 2% reading
Stack gas temp	PtRhPt thermocouple	0 ... 1700°C	0 ... 1700°C	1 °C	1°C or ± 2% reading
Diff. pressure	piezoresistiv	±100mbar	0,1 mbar	0,1 mbar	0,03 mbar or ± 1% readi

Experimental method is performed for different working conditions of ship engines, and these conditions of operation may be linear, stepped and oscillating [5].

4.1. An example of emissions measuring for medium speed marine engine using measuring device MRU / *Primjer emisija koje su izmjerene za srednjehodne brodske strojeve koristeći MRU napravu*

The measuring device MRU Vario plus SE (Figure 3.), that meets the requirements, was used for this experiment. The mentioned device processes the data obtained from the medium speed marine engine MaK and compares them with the regular data for this type of engine. This type of data obtained allows more accurate calculations and development of engine design. Due to the complexity of the problems it is necessary to compare the results obtained from simulations and evaluate measurements. Values must be in limits according to EU and IMO regulations[1].

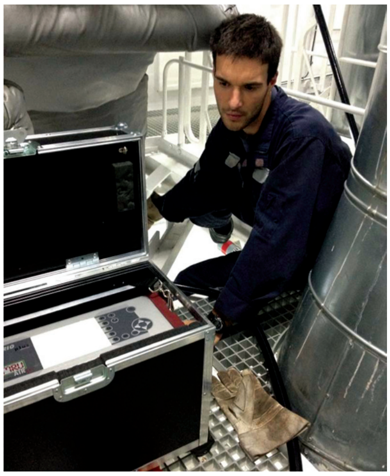

Figure 3 Meassuring exhaust emission onMak 9M 32C engine with MRU
Slika 3. Mjerenje ispušnih emisija na Mak 9M 32C stroju s MRU

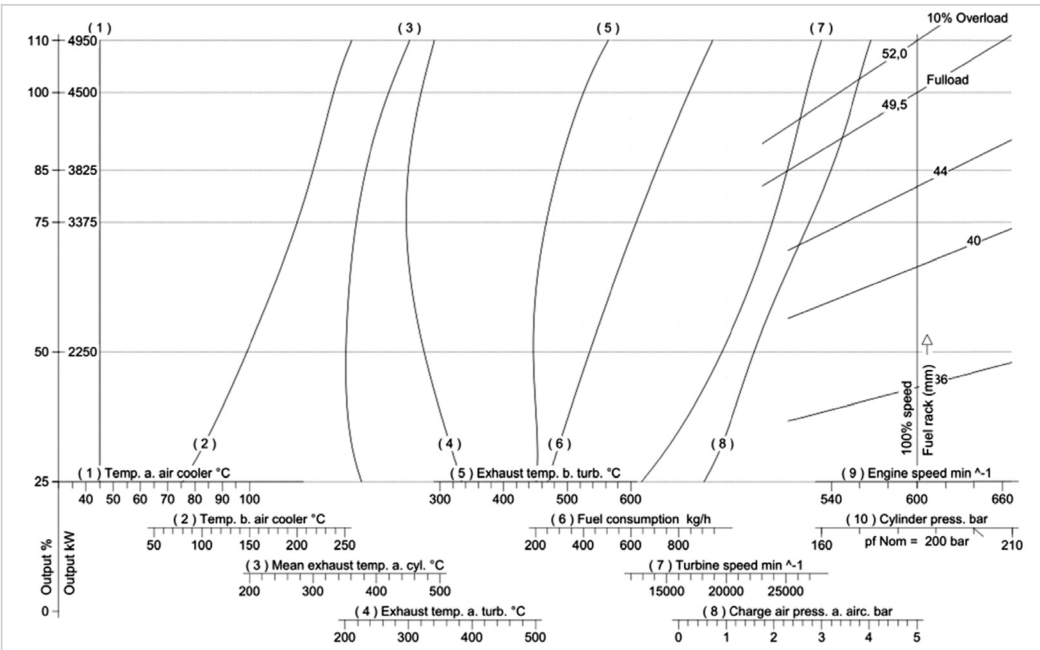

Figure 4 Characteristics of Mak 9M 32C engine during testing on the test bed [7]
Slika 4. Karakteristike Mak 9M 32C stroja za vrijeme testiranja na test uzorku (7)

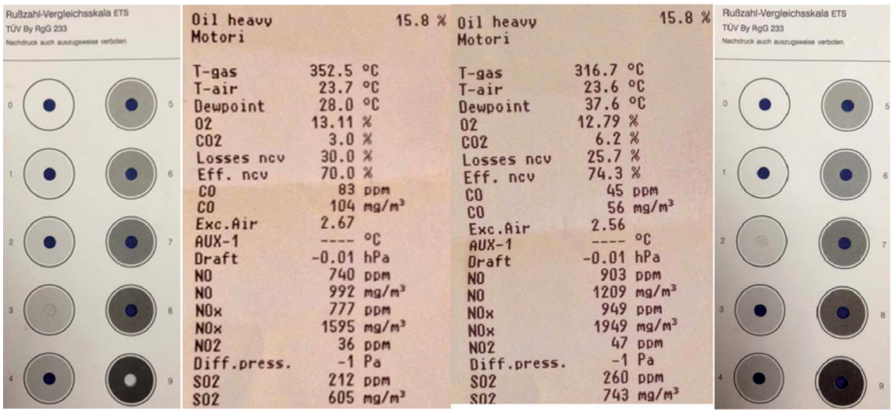

Figure 5 Exhaust emissions of IC engine at 50% (left) and 100% (right) load with smoke number
Slika 5. Emisije ispuha IC stroja na 50% (lijevo) i 100% (desno) opterećenja s brojčanom oznakom

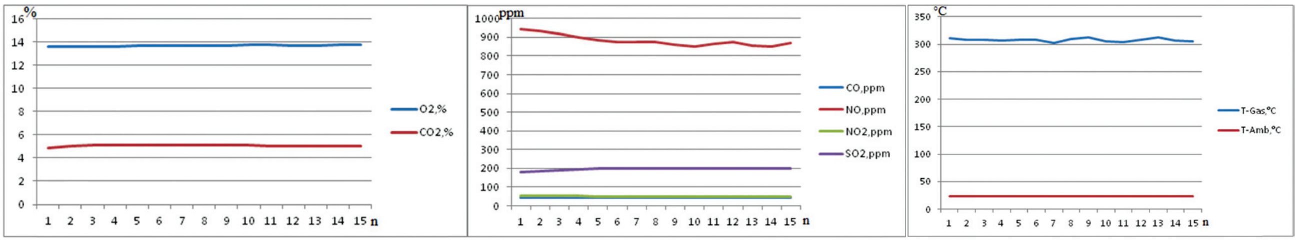

Figure 6 Characteristic values of exhaust emissions T_{gas}, T_{amb}, O_2, CO_2, CO, NO, NO_2 measured at 50% working load
Slika 6. Karakteristične vrijednosti emisija ispuha izmjerenih kod 50% opterećenja

The measured values are obtained by the experimental method which is performed on four stroke marine engine Mak 9M 32C, with sensor placed in exhaust pipe after turbocharger .Resulting data can be used to better describe the working values of measured engine and it can be summarised in tables to obtain better understanding of engine working status in particular moments. These data show how the engine behaves under different working loads, thus enabling the improvement of simulation systems that will take place in one of the simulation programs, allowing the improvement of engine performance and reduce emissions.The characteristics of the engine exhaust emissions at 50% working load are shown in Figure 5. with the smoke number which was 3 and at 100% load smoke number was 2 (measuring range is from 0 to 9).

Characteristic values (O_2, CO_2, CO, NO, NO_2, SO_2) were measured in ppm unit, and it is taken 15 measurements every 3 sec. The test has found that the measured parameters reach steady values only after some time which is clearly seen on the graphs in Figure 6. It was concluded that after 30 sec. the steady values of measured parameters can be taken with sufficient accuracy.

The next experiment was performed at 100% working load. The exhaust gas temperature was slightly higher at 100% load. After the working parameters obtained steady value, smokenumber was 2. Characteristic emission values (O_2, CO_2, CO, NO, NO_2, SO_2) were measured in ppm units, and again it is taken 15 measurements every 3 sec. (Figure 7).

Emission levels of this tested medium speed marine diesel engineare lower than the levels required by the regulations of MARPOL 73/78 Annex VI.

Comparing the characteristic values of exhaust gases following is concluded:

- carbon dioxide emission is lower at 50% load (approx. 1%) comparing it to 100% load,
- nitrogen monoxide was lower by 50 ppm at 50% working load,
- sulphur dioxide was lower for 40-60 ppm at 50% working load.

During experimentengine working parameters needed certain time to reach steady values, and minimum time to perform measurement is determined. All measuring parameters and influencing parameters on the measured values has to be

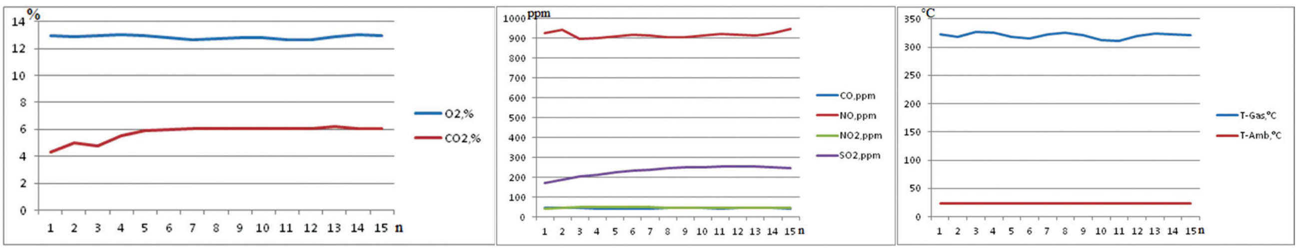

Figure 7 Characteristic values of exhaust emissions T_{gas}, T_{amb}, O_2, CO_2, CO, NO, NO_2 measured at 100% working load
Slika 7. Karakteristične vrijednosti ispušnih emisija izmjerenih kod 100% opterećenja

properly determined and then corrections has to be performed to the standard conditions according to ISO correction method. When using a calculation method for emission analysis and for modelling of engine working process [10,11,12], it is necessary to take into account all influencing parameters such as the size of the combustion chamber, the injection timing and the injection angle, the characteristics of the fuel pump and other parts of the engine, as well as internal and external parameters which affect the characteristics of emissions.

For efficient implementation of future tests based on the results of the above experimental method, it is necessary to make the development of important characteristic values which will determine the emission quantities, and then that important values must be included in standard engine characteristics diagram as shown on Figure 4.

5. CONCLUSION / *Zaključak*

This paper describes the experimental method for analysing exhaust emissions of internal combustion engines. Using the measuring device, emission level of medium speed diesel engine is analysed and it is determined that the value levels obtained by this testing are not higher than the requiring limit. Further research will be implemented and the impact of the various parameters on the working characteristics of the engine will be analysed in order to reduce emission levels. The main target of this research is to get a reliable method for obtaining information of the engine working parameters which could be used to determine the optimal operating point of the engine with regard to fuel consumption and exhaust emissions.

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