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SIMPLIFIED RESEARCH TESTS OF TOXIC COMPOUNDS EMISSION'S FROM MARINE DIESEL ENGINES

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Abstract

Valid at present standards and measuring regulations of toxic compounds in exhaust gases oblige the manufacturers and exploiters of marine Diesel engines to use of a suitable tests and measuring procedures. In case of marine piston engines the fulfilment of required standards in engine bed test at manufacturer does not make any problem, however such tests on board of ship may be difficult or sometimes impossible to execute. The additional problem is a requirement of repetition of exhaust gas toxicity in definite time period. It the proposal of study of universal profile marine Diesel engines in article was contained was as well as two - and three-phases research test of toxic compounds in exhaust gas of engine installed in an engine room.

Keywords: *Marine Diesel engine, exhaust gas, emission, research test, at-site measurement*

1. Introduction

In having on aim the qualification of coefficients investigations and the standard is in force the characteristics of toxic compounds of marine Diesel engines ISO 8178 standard and connected with him prescriptions the IMO (for example " Technical Code").

Standard consists of 9 parts [1-9], that mentioned parts the exact researches conditions, their course, measuring apparatus as well as research report were described. As a validity research parameter, the coefficient f_a, fulfilling following condition was introduced:

$$0.98 \le f_a \le 1{,}02 \,, \tag{1}$$

The parameter f_a was counted according to the following examples:

- combustion-ignition engines not supercharged and charged mechanically:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_s}{298}\right)^{0,7} \,, \tag{2}$$

- combustion-ignition turbo-compressor engines charged with or without air cooling :

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{1,5} , \qquad (3)$$

where: T_a - the absolute temperature of air incoming to the engine [K],
p_s - the atmospheric dry air-pressure [kPa].

The formulas 2 and 3 are identical to regulations of the ECE (*Economic Commission for Europe*), EEC (*European Economic Community*) and EPA (*Environment Protection Agency*) relating the exhaust gas emission.

The base for exhaust gas emission is uncorrected effective power. The all installed on engine auxiliaries, indispensable only for running of ship's power station as: the compressor supporting of steering arrangement, the compressor of air-conditioning arrangement, pumps of hydraulic steering, should be disassembled to the tests. Losses on auxiliaries should not exceed 5% of maximum measured power.

The accuracy of gauges should assure the not exceeding of deviations introduced in ISO 8178-1 [1] for measurements executed on test post and in ISO 8178-2 [2] for measurements executed in place of installation.

The total error of measurement, including sensibility on interferential effect different gases, should not exceed of ± 5% read value or ± 3,5 % of the full range of scale, and the lower of these values should be taken. For concentration lower than 100 ppm, the measurement error should not exceed of ± 4%. The measurements in a place of installation comparing with measurements on test post are less exact and precise because of environmental influences and running conditions. The repeatability and accuracy also depends (for example) on, volumetric concentration (ppm), mass concentration ($\mu g/m^3$) or specific emission (g / (kW·h)).

The engine's load setting for each of test should be calculated according to formula:

$$S = \left[\left(P_m + P_{AUX}\right)\frac{L}{100}\right] - P_{AUX} , \qquad (4)$$

where: S - the setting of engine's break [kW],
P_m - maximum measured or declared power at the test engine speed under test conditions [kW],
P_{AUX} - declared total power absorbed by auxiliaries fitted for the test [kW],
L - percent torque related to the maximum torque for the test engine speed.

The measurements and estimation of gas exhaust emission should be executed using of suitable research cycle, proper for given use, accordingly to requirements ISO 8178-4 [4]. For researches of marine piston combustion engines the tests E2, E3, D2, C1 should be executed (table 1 and 2).

Tab. 1. The main engines' researches cycles with no time limitation - E2 the (running with constant rotational speed), E3 (running according to the screw characteristic) and the generators with variable load D2 (according to ISO 8178) [4]

	E2				E3				D2				
Engine speed [%]	100	100	100	100	100	91	80	63	100	100	100	100	100
Load [%]	100	75	50	25	100	75	50	25	100	75	50	25	10
Weighting factor	0,2	0,5	0,15	0,15	0,2	0,5	0,15	0,15	0,05	0,25	0,3	0,3	0,1

Tab. 2. Engines' researches cycles working at variable rotational speed and changeable load - cycle C1 (according to ISO 8178-4) [4]

	C1							
Engine speed [%]	Rated Power				Intermediate			Idle
Load [%]	100	75	50	10	100	75	50	0
Weighting factor	0,15	0,15	0,15	0,1	0,1	0,1	0,1	0,15

Part 2 of the standard ISO 8178 can be used for investigations guided in a place of engines' installation. However, if during researches in a place of installation it is not possible to keep exact working conditions as on the test post, the emission values may not be identical to values obtained on test post [2]. Moreover, the standard determines that the running of engine accordingly with researches cycles - as in ISO8178-4 - is not always possible in each case, yet the realization of researches should be the closest according to procedures of ISO 8178part 4.

Basing on above mentioned records and researches over characteristics of exhaust gas toxicity of marine engines, the short test of toxicity for mean speed engine working according to screw characteristic has been undertaken.

2. Proposal of two and three-phases research test

During such researches over marine engine of Sulzer type 6AL 20/24 installed on test post at the Naval Academy in Gdynia [10] on the NO_x concentration speed characteristic it was observed some points, permitting on qualification the maximum and minimum values of NO_x concentrations without necessity the realization of whole E3 test accordingly to ISO 8178-4 (Fig. 1). These points are equivalent to the idle of engine and load of 25% P_n.

It is necessary to aid, that the E3 test does not foresee the researches of the no-load engine, which is result of normal working conditions. However, in a case of ships like, the fishing ships, tugs or battleships, such working state is quite often and can exceed 8% of all running time of the engine [11, 12].

In a case of researches on board, it can turn out to difficult or even the impossible to perform of whole test according with standard (as floating with power rating engine load depending on the weather) what induced the authors to study of test of two and three-phases based on requirements of E3 test, but possible and easier to realization in any conditions of engine exploitation.

The two-phase research test of NO_x emission of engines working according to screw characteristic covers the point of the minimum NO_x concentration related to the engines' idle and the point of maximum NO_x concentration related to the load of 25% P_n (Fig. 2).

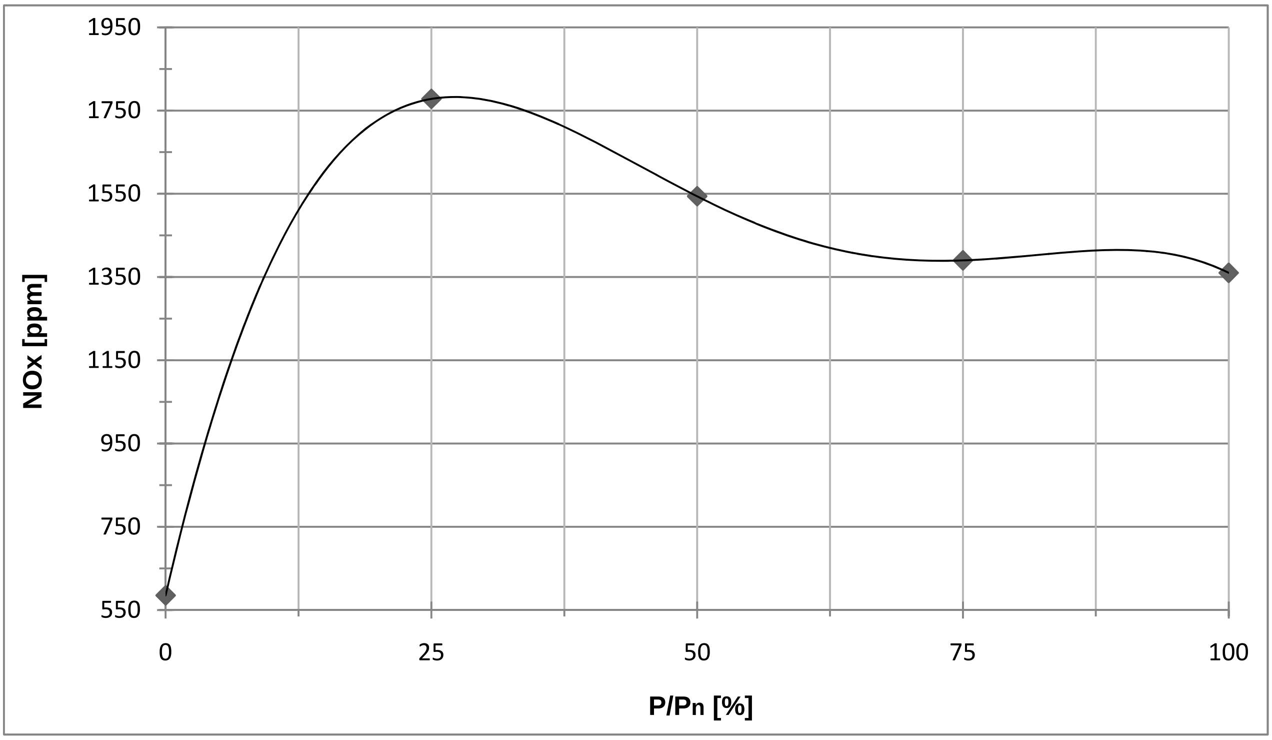

Fig 1. The characteristic of NOx concentration changes as a function of engine 6AL20 / 24 load according to the test E3 of ISO8178-4

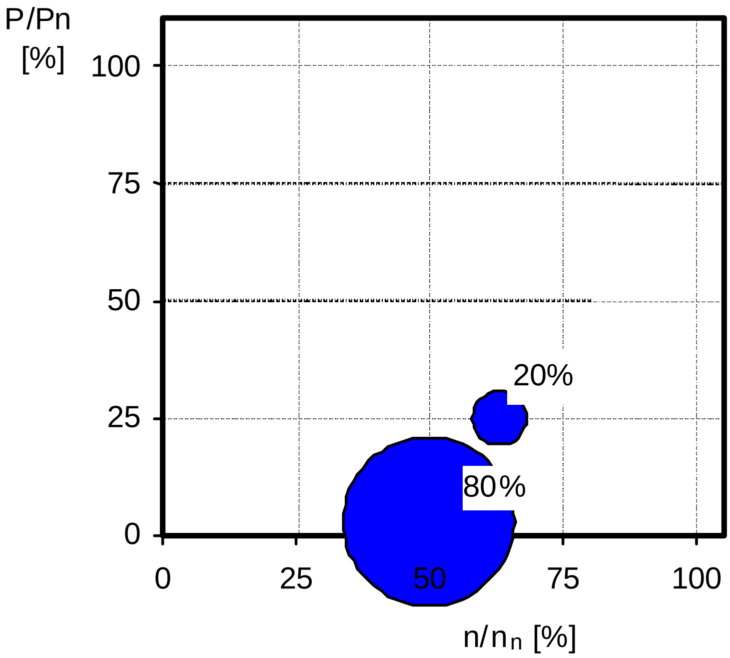

Fig 2. Two-phase research test of exhaust gas toxicity of marine engine working according to he screw characteristic

In aim receipt of three-phase test, the point of 50 % engines' load P_n for which NO_x concentrations are close to other points of E3 test was added (Fig. 3).

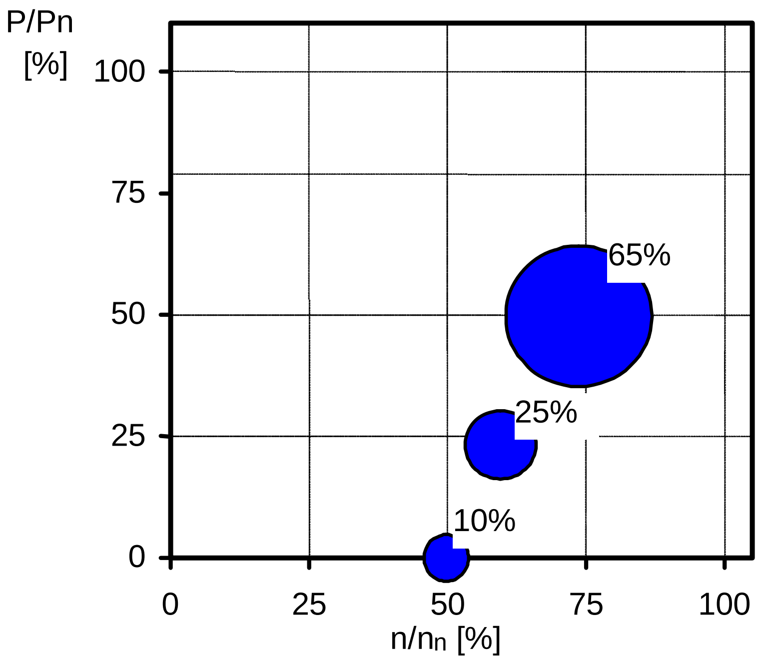

Fig 3. Three-phase exhaust gas toxicity of marine engine working according to screw characteristic

In order to the proposed tests permitted on realization of researches adequate to full E3 test it was necessary to determine proper parameters of running test (test phase weight coefficients – W_f) as well as to modify the equation describing the NO_x specific emission of the studied engine.

The specific emission coefficient of exhaust gas components Gas_{in} [g / (kW·h)] is expressed by formula:

$$Gas_{in} = \frac{\sum_{i=1}^{i=n} B_{si} \cdot W_f}{\sum_{i=1}^{i=n} P_{ei} \cdot W_f}, \quad (5)$$

where: W_f - weighting factor,

P_{ei} - the effective power of the engine [kW],

B_{si} - the mass emission intensity [kg /h] or [g /h].

In a case of shortened two-phase test the formula (5) is as:

$$Gas_2 = \frac{[(B_{s0}/3)\times 0{,}8 + (B_{s25}/2)\times 0{,}2]}{P_{e0}\times 0{,}8 + P_{e25}\times 0{,}2}, \quad (6)$$

where: B_{s0} and P_{e0} - the NO_x emission intensity values and the effective power for idle,

B_{s25} and P_{e25} - the NO_x emission intensity values and the effective power for 0,25 P_n.

and for the proposed three-phase test:

$$Gas_3 = \frac{\left[(B_{s0}/3)\times 0{,}1 + (B_{s25}/2)\times 0{,}25 + B_{s50}\times 0{,}65\right]}{P_{e0}\times 0{,}1 + P_{e25}\times 0{,}25 + P_{e50}\times 0{,}65}\ , \qquad (7)$$

where: B_{s0} and P_{e0} – NO_x emission intensity values and the effective power for idle,
B_{s25} and P_{e25} - NO_x emission intensity values and the effective power for 0,25 P_n,
B_{s50} and P_{e50} - NO_x emission intensity values and the effective power for 0,5 P_n.

3. Verification of exactitude of proposed tests

In the aim of the proposed tests exactitude verification, for NO_x emission estimation, the two Sulzer diesel engines were tested:

- six- cylinder type 6AL20/24 of P_n = 432 kW and n = 720 min^{-1},
- sixteen-cylinder 16ASV25 / 30 of P_n = 3600 kW and n = 1000 min^{-1}.

The results that research were introduced on drawings 4 and 5.

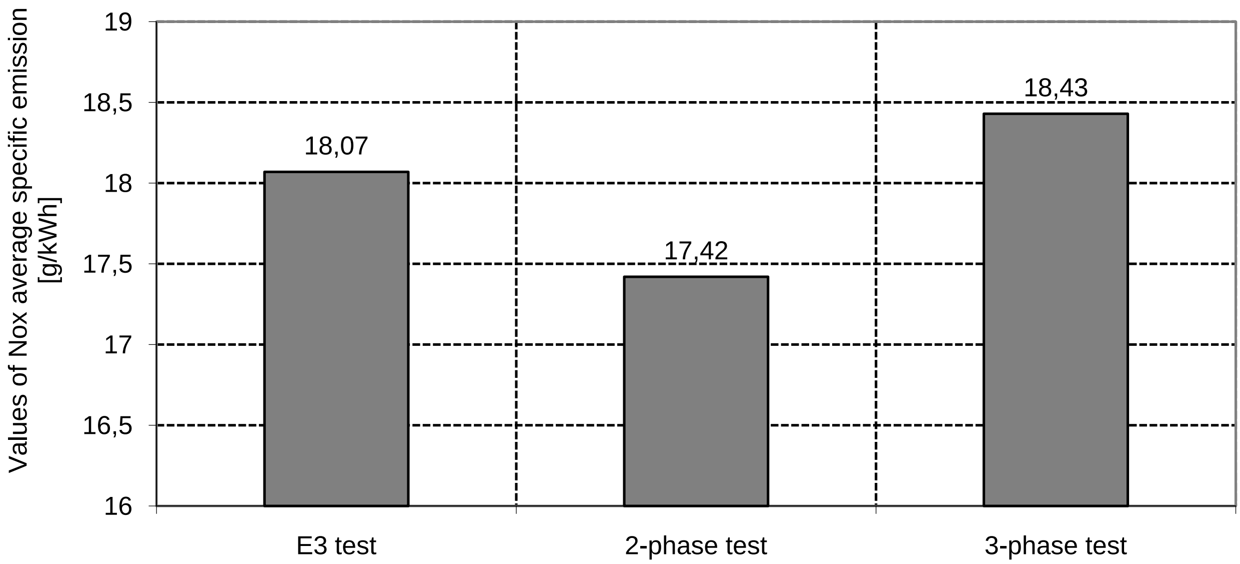

Fig.4. The comparison of NO_x average values specific emission determined using the E3 test according to ISO 8178-4 and two and three-phase test for engine of the Sulzer 6AL20/24 type

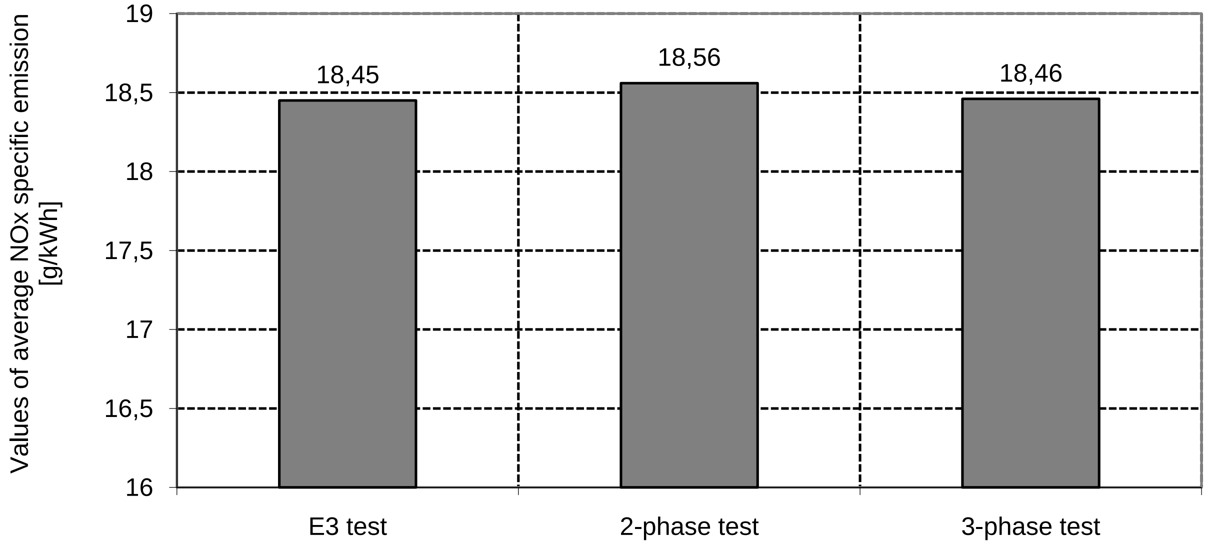

Fig.5. The comparison of NO_x average values specific emission determined using the E3 test according to ISO 8178 – 4 and the and two and three phase test for the engine of Sulzer 16ASV25 / 30 typ.

In the case of Sulzer 6AL20/24 type engine the difference between NO_x average specific emission determined by E3 test, according to ISO 8178-4 and adequately:

- shortened two - phase test was 3, 6 %;
- shortened three - phase test was 1, 9 %;

Differences between average specific emission fulfil the requirements of ISO 8178 standard with regard on the exactitude and repeatability of measurements results in place of installation (table 2), which allows ± 9% error for measurement of exhaust gas components.

For Sulzer 16ASV25/30 type engine the results of measurements proved the considerable similarity of tests, because the difference between the average NO_x emission value determined by E3 test according to the ISO 8178-4 and proposed adequately:

- two-phase test was 0, 1 %;
- **t**hree-phase test was 0, 01%;

Summary

Basing on conducted researches it was confirmed the possibility of applying of the simplified and sufficiently effectives tests of NO_x emission for marine mean speed combustion engines working according to screw characteristic. In the case of low speed engines the research verification should be made, in order to determine usefulness of proposed tests and equations to determine the average NO_x emission value.

The accuracy of measurement grows up along with the quantity of test phases so the two and three-phases tests could be applied first of all to follow-up control tests of engines (as periodical, required by regulations or ship-owners) and for certification, if realization of the full test would be impossible.

The further researches over tests of research of toxic compounds in exhaust gas can permit on preparation of the universal test for all kinds of main power marine engines regardless of load during exploitation

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