

Technical sciences

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Pham Van Ha

Master of the

Naval Technical Institute, Vietnam

Nguyen Ha Hiep

PhD in Technical Sciences

Le Quy Don Technical University, Vietnam

TEST RESULTS FOR TOXICITY AND REDUCING TOXIC EXHAUST EMISSIONS OF THE MARINE DIESEL ENGINE

Summary. *The tests were carried out on the marine diesel engine operating by the load characteristic in seven modes, including five modes according to the test cycle D2 regulated by ISO 8178. Based on the experimental results obtained, the specific weighted NO_x emissions and their average values were calculated and compared with IMO regulations. In addition, the study carried out a comparative experimental investigation on diesel fuel and dimethyl ether, and different injector opening pressures in the marine diesel engine to reduce its toxic exhaust emissions.*

Key words: *test results, exhaust emission, IMO, marine diesel engine.*

Introduction. There are restrictions on toxic components in the exhaust gases of the combustion of marine fuels following international programs to protect the atmosphere and the requirements of the International Maritime Organization (IMO). For example, the MARPOL 73/78 Annex VI of IMO for the Prevention of Pollution from Ships (entered into force on 19 May 2005) sets limits on nitrogen oxide (NO_x) and sulfur oxide (SO_x) emissions from ship exhausts. According to the new requirements, a three-tier system of standards

for NOx emissions is introduced [1]: Tier I applies to diesel engines installed on ships constructed on or after 1st January 2000 and before 1st January 2011, and represents the 17 g/kWh NOx emission standard stipulated in the original; Tier II covers diesel engines installed on ships constructed on or after 1st January 2011 and reduces the NOx emission limit to 14.4 g/kWh; Tier III covering diesel engines installed on ships built on or after 1st January 2016 and reduces the NOx emission limit to 3.4 g/kWh when the ships are operating in a designated emission control areas (ECA). It is shown in Fig. 1 (author's drawing based on the data with [1]).

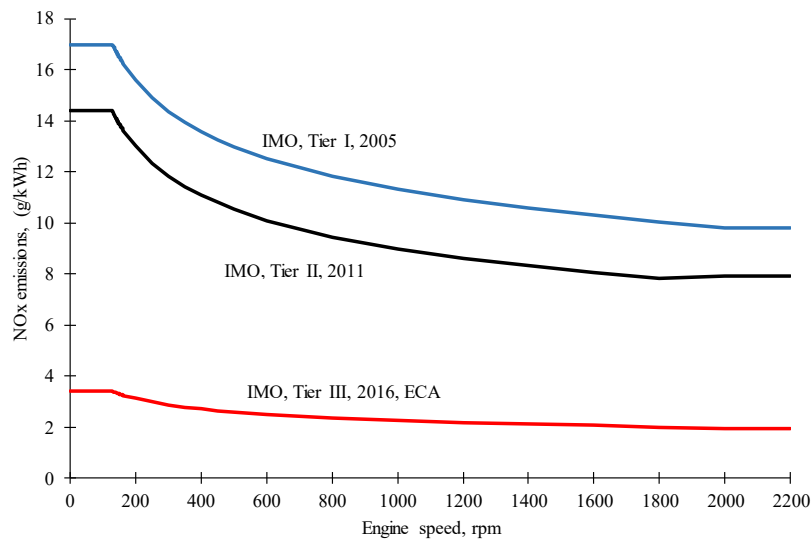


Fig. 1. The NOx emissions by MARPOL Annex VI

The purpose of this experimental research is to assess the compliance of NOx emissions of the marine diesel engine with the requirements IMO and reduce it.

The research object, test modes, instrument base set. The tests were carried out on the marine diesel engine 1NVD24, which was installed on engine test benches in the laboratory of heat engines.

The 1NVD24 marine diesel engine is a non-reversible single-cylinder four-stroke and naturally aspirated engine manufactured by SKL (Germany).

The main technical characteristics of the diesel engine are: the nominal effective power is 16 kW; the speed of the crankshaft is 630 rpm; the average effective pressure at the nominal mode is 0.535 MPa; the maximum combustion pressure is 5.2 MPa; the nominal compression ratio is 14.85; the specific fuel consumption at the nominal effective power is $245 \pm 10\%$ g/(kWh).

All tests were carried out when the diesel engine was operating by the load characteristics in seven modes, including five (from 2 to 6) modes according to the test cycle D2 regulated by ISO 8178-3 and ISO 8178-9 [2; 3] (Table 1), while the diesel was running on standard diesel fuel [4].

Table 1

Test cycle D2

Mode number	1	2	3	4	5	6	7
Torque, %	110	100	75	50	25	10	Idle
Speed, %	100						
Weighting factor	–	0.05	0.25	0.30	0.30	0.10	–

The determination of the hourly fuel consumption was carried out in a volumetric manner. The throttle device determined the air mass flow. The measurements of the exhaust gas and water temperatures were carried out with verified thermometers [5].

The measurements of the exhaust emissions were carried out using the Testo 350-MARITIME gas analyzer certified by the Germanischer Lloyd (Fig. 2). The exhaust gas take-off point is located at a distance of six diameters of the straight pipe section from the connecting flange of the exhaust manifold [6].



Fig. 2. The gas analyzer Testo 350-MARITIME

Processing of experimental data. The calculation of the exhaust emission standards according to ISO 8178-6 [7] is carried out according to the formula:

$$e_i^p = 0,446\mu_i \frac{\sum_{j=1}^m C_{ij}V_{exh_j}W_j}{N_e \sum_{j=1}^m \bar{P}_j W_j}$$

where e_i^p is the specific weighted average of the i -th toxic emission, g/kWh; μ_j is the molecular weight of the i -th toxic emission, kg/kmol ($\mu_{NO_2} = 46$); m is the number of test modes in the test cycle; j is the mode number; i is the index of the toxic emission; C_{ij} is the concentration of the i -th toxic emission in the exhaust gas measured during tests in the j -th mode, %; \bar{P}_j is the ratio of the effective power for the given test mode to the nominal effective power; N_e is the nominal effective power of the diesel engine, kW, W_j is the mode weighting factor.

Results and discussions. The result obtained when testing the 1NVD24 diesel engine with the injector opening pressure of 15 MPa is $e_{NOx}^p = 5.81$ g/kWh. The experimental results and their comparison with IMO regulations are plotted

in Fig. 3. This shows that the diesel engine complies with the MARPOL 73/78 Annex VI of IMO for NO_x according to Tier I and Tier II, but Tier III does not.

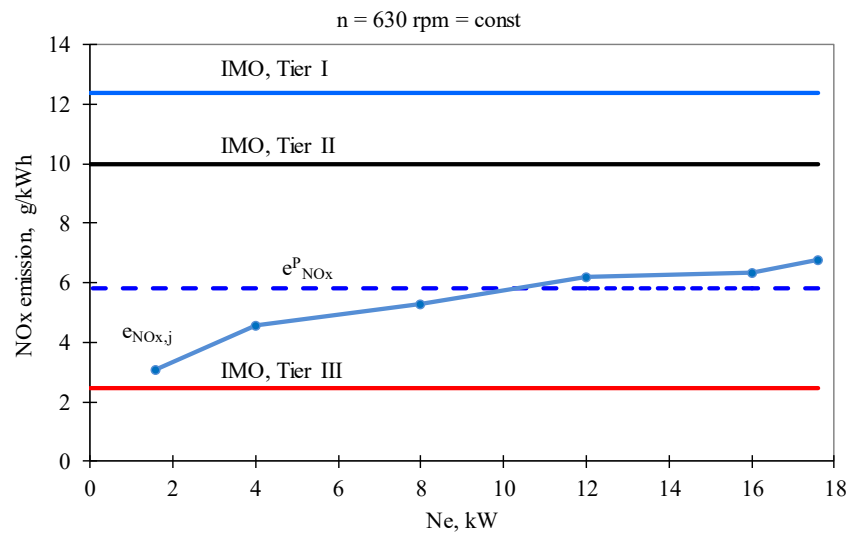


Fig. 3. The experimental results and their comparison with IMO regulations

This diesel engine was also tested with an injector opening pressure of 28 MPa. In this case, the NO_x emission obtained is = 2.89 g/kWh, which is almost two times less than in the case of 15 MPa.

There are different methods of reducing toxic exhaust emissions of marine diesel engines [8]. Therefore, the study carried out a comparative experimental investigation on the use of diesel fuel (DF) and dimethyl ether (DME) in the marine diesel engine. With a percentage of DME from 1.78 to 3.56% as an additive to air, the NO_x emission decreases, especially the NO_x emission is absent when the diesel engine is idling on pure DME (Fig. 4).

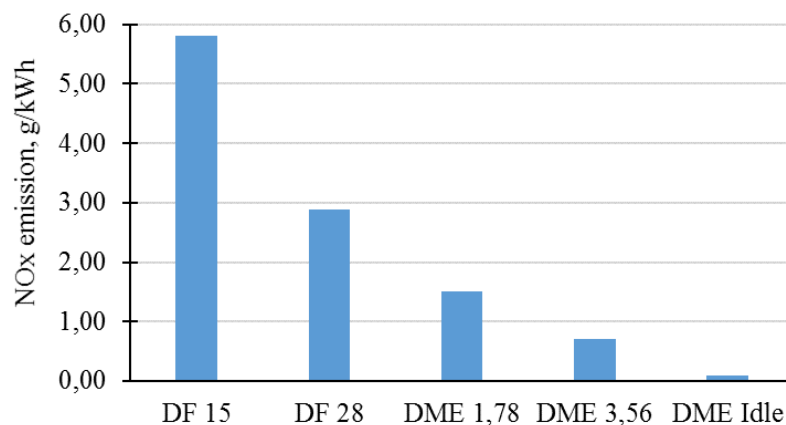


Fig. 4. The NO_x emissions of the marine diesel engine using different fuels

Conclusions. Analysis of the experimental results allows us to draw the following conclusions:

- In all test modes, the specific NO_x emission of the 1NVD24 marine diesel engine complies with the MARPOL 73/78 Annex VI of IMO for NO_x according to Tier I and Tier II, but Tier III does not;
- The specific exhaust emissions depend on the injector opening pressure. An increase in the injector opening pressure leads to a decrease in the toxic emissions of exhaust gases;
- It is recommended to use DME as an additive to air or as fuel to reduce emissions of toxic exhaust emission of marine diesel engines.

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