Research on influence of some ship diesel engine malfunctions on its exhaust gas toxicity

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ABSTRACT

This paper is a continuation of the previous articles of the authors, published in Polish Maritime Research [1, 2], devoted to pollution of the atmosphere due ship diesel engines in operation. In the paper presented are results of the investigations carried out in the Gdynia Maritime Academy laboratory with the use of a ship one-cylinder diesel engine combusting heavy fuel oil. Two its possible malfunctions : changes of fuel injection pressure and changes of injection advance angle were simulated. Both malfunctions, which might occur as a result of incorrect engine regulation or wearing or contamination of engine elements, were simulated separately. The presented investigations were focused on finding out relationships between the assumed malfunctions and exhaust gas content, especially content of nitric oxides (NO_X), very toxic compounds. The paper is ended by several conclusions arising from analysis of the results which have – apart from their cognitive merits – also an utilitarian character as they may be put into practice by ship operators, provided that some limitations resulting from the specific conditions of the reported laboratory investigations are appropriately taken into account.

Key words : atmosphere protection, emission of nitric oxides, laboratory test

INTRODUCTION

Problems of the sea water protection against pollution from ships have been dealt by ship designers and operators for more than a half of century. In recent years the marine environmental protection was extended over the atmosphere. The revelant legal acts aiming at lowering emission of toxic exhaust gas components, especially nitric oxides (NO_X), are in force (App. IV to MARPOL Convention, ISO 8178 standard [3]).

Technical undertakings to cope with the requirements determined in the standards go in two directions. The first one deals with new engines for which the designers and producers search for solutions which would make it possible to obtain NO_X emission low enough to comply with the standards. The other trend is connected with the engines in service. During their designing no sufficient attention was paid to exhaust gas purity. However today they have to be adjusted to comply with the being-in-force requirements for lowering nitric oxides (NO_X) emission. As it was proved in the publications [1], [2], [4], [5], [6], [7] a relatively simple way to limit emission of nitric oxides is to apply appropriate adjustment operations.

Despite the adjustment of ship diesel engines is made to comply with the exhaust gas purity standards, the emission may be changed as a result of changing technical state of the engines during service. In this paper presented are results of the research on influence of some injection system's malfunctions of a ship diesel engine on its exhaust gas content. The investigations were performed as an active experiment on the engine charged with a heavy fuel oil and operating in the laboratory conditions.

LABORATORY TESTS

The test object and stand

The laboratory tests were carried out on the one-cylinder, two-stroke, crosshead engine of longitudinal scavening, which was loaded by means of the water brake. The engine was charged with IF 40 heavy fuel oil. The whole stand together with its measurement instrumentation was described in [1]. In comparison to the earlier presented stand a basic change consisted in adding an Alfa-Laval viscometer which made it possible to continuously measure fuel viscosity and stabilize it at a demanded level.

Scope of the tests

The test program was prepared for performing series of measurements on the engine with two simulated malfunctions of the injection system, as follows :

- changing the fuel injection pressure - to three selected values : 180, 220 and 260 bar
- changing the fuel injection advance angle - to three selected values : -10°, -13° and -16° before the piston's upper dead centre (UDC).

The measurements were performed within the wide range of engine load at the permanent rotational speed of 220 rpm. For each of the above selected values six measurements were performed at the following engine loads : 25%, 40%, 50%, 60%, 70% and 80%. The engine load was defined as the percentage ratio of a given engine torque and that rated.

Description of the tests and their results

The injection system's malfunctions were introduced – during operation of the engine – by means of a supplementary scaled instrumentation of the injector and injection pump. Owing to this it was not necessary to stop the engine before each successive test cycle.

This way of realization of the measurements guaranteed runing them in steady conditions. The elimination of influence of possible disturbances which could arise from multiple starting and stopping the engine improved accuracy and reliability of the obtained results.

The measurement results are presented in Tab.1 and 2 and in Fig.1 and 2.

Tab.1. *Results of analysis of exhaust gas content at three different injector opening pressures*

Fuel injection pressure	Relative engine load	Exhaust gas content					
p	M/M_r	O_2	CO	SO_2	NO_x	NO_x	CO_2
[bar]	[%]	[%]	[ppm]	[ppm]	[ppm]	[mg/m³]	[%]
180	25	19.0	199	21	136	186	1.4
	40	18.1	238	17	183	251	2.1
	50	17.3	320	17	250	343	2.7
	60	16.7	337	14	316	434	3.1
	70	14.3	1 022	21	388	533	4.9
	80	12.2	2 849	50	397	545	6.4
220	25	19.0	159	27	155	212	1.4
	40	18.2	167	27	211	289	2.0
	50	17.4	243	21	267	366	2.6
	60	15.8	267	19	360	494	3.8
	70	13.7	707	23	436	599	5.3
	80	9.0	6 043	30	382	524	8.8
260	25	18.8	193	33	186	255	1.5
	40	18.2	209	32	240	329	2.0
	50	17.6	336	32	291	399	2.4
	60	16.0	376	48	369	507	3.6
	70	13.5	1 228	76	424	582	5.5
	80	10.8	4 050	128	407	559	7.4

Tab.2. *Results of analysis of exhaust gas content at three different advance angles of fuel injection*

Fuel injection advance angle	Relative engine load	Exhaust gas content					
α	M/M_r	O_2	CO	SO_2	NO_x	NO_x	CO_2
[°]	[%]	[%]	[ppm]	[ppm]	[ppm]	[mg/m³]	[%]
-10	25	18.9	210	29	117	160	1.5
	40	18.3	215	24	161	221	1.9
	50	17.4	263	21	215	295	2.6
	60	16.6	345	19	266	365	5.2
	70	14.0	610	24	358	491	5.1
	80	9.9	9 882	53	297	408	8.1
-13	25	19.0	159	27	155	212	1.4
	40	18.2	167	27	211	289	2.0
	50	17.4	243	21	267	366	2.6
	60	15.8	267	19	360	494	3.8
	70	13.7	707	23	436	599	5.3
	80	9.0	6 043	30	382	524	8.8
-16	25	19.1	264	25	215	295	1.3
	40	18.3	231	28	325	446	1.9
	50	17.1	418	30	400	549	2.8
	60	15.6	622	28	499	685	3.9
	70	13.3	1 170	34	563	773	5.6
	80	8.8	8 061	68	464	637	8.9

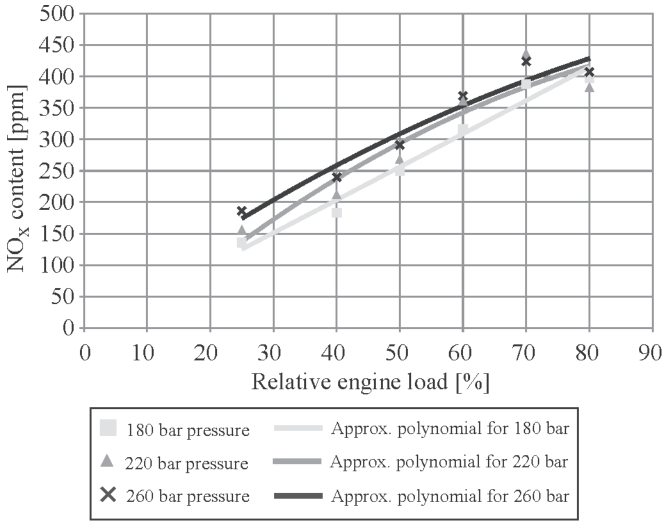

Fig.1. *NO_x content in exhaust gas in function of three different injector opening pressures*

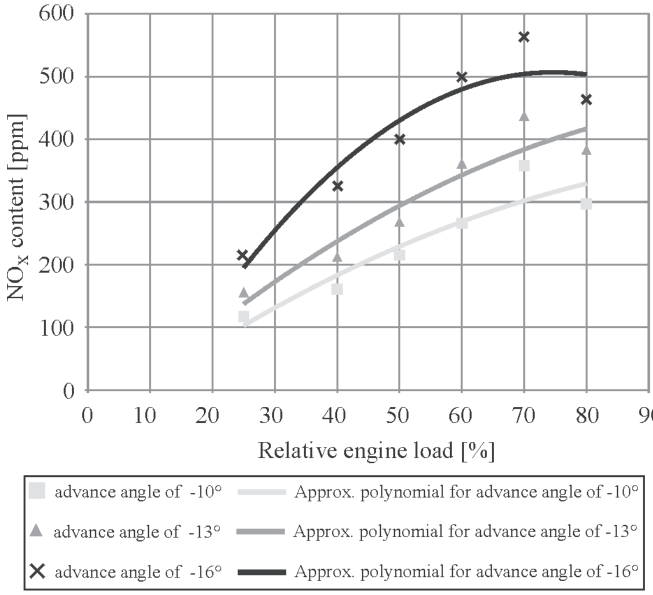

Fig.2. *NO_x content in exhaust gas in function of three different advance angles of fuel injection*

Analysis of the results

The rated value of the injector opening pressure for the tested engine amounts to 220 bar. A change of the pressure may be caused by an incorrect initial setting of the injector (operator's mistake), or its maladjustment during service (a change of technical state of injector's spring). The chosen values differed by 20% of that rated, i.e. they amounted to 180 and 260 bar.

A drop of the injector opening pressure makes that the fuel is injected to the cylinder a little earlier and the injection lasts longer, and spraying the fuel, especially its first portions, is worser. The worsening of the combustion process resulting from that makes NO_x level within the whole range of the applied engine loads, lower.

The rise of the injector opening pressure from 220 bar to 260 bar results in an increase of NO_x emission within the whole engine load range. This can be caused due to improving the quality of fuel spraying and combustion process, which leads to a higher combustion temperature and – in consequence – to a higher NO_x content in exhaust gas.

An incorrect setting of the injector opening pressure, not complying with that recommended by the producer, is always considered as a malfunction which should be removed as soon as possible. However, from the ecological point of view the drop of injector opening pressure makes NO_x content in exhaust gas lower. Hence it may be a simple way which makes it possible to so adjust an existing engine as the NO_x emission standards to be satisfied. However the accompanying consequences should be also remembered, namely : increasing the fuel consumption and possible rising the thermal load on engine combustion chamber elements.

The malfunction consisting in a change of the injection advance angle may result from an incorrect initial adjustment of the engine, or from a random change of that quantity during the engine's operation process. The three following values of the advance angle were selected : -16°, -13° (rated) and -10°.

An increase of the injection advance angle unambiguously leads to important increments of NO_x content in exhaust gas within the entire range of the engine's load, whereas a delay of the injection beginning (a decrease of the injection advance angle) unambiguously makes NO_x content in exhaust gas lower.

However it should be remembered that both an advance and delay of fuel injection starting – in relation to the values recommended by the producer and set during statical regulation of the engine – influences not only the exhaust gas content but also other important operational parameters of the engine by changing combustion process quality. An increase of the advance angle causes an increase of the maximum combustion pressure p_{max} which may lead to mechanical overloading, and its drop – to increasing the fuel oil consumption by dropping p_{max} and increasing exhaust gas temperature.

The investigations also revealed (Tab.1 and 2) that the simulated malfunctions made content of carbon oxide (CO) in exhaust gas greater. Both an increase and decrease of the injector opening pressure and injection advance angle with respect to their rated values led to the above mentioned change.

CONCLUSIONS

On the basis of the performed tests
the following general conclusions may be offered :

- The engine's malfunction consisting in an increased injector opening pressure makes NO_x emission to the atmosphere greater.
- The malfunctions consisting in decreasing the fuel injection pressure and in delaying the fuel injection beginning favourably reduce NO_x emission to the atmosphere. However it should be remembered that excessive deviations from the rated settings recommended by the engine producer may negatively affect its operational cost by increasing the fuel oil consumption and its durability (cost of engine repairs).
- Occurrence of the considered malfunctions increases the exhaust gas toxicity by increasing content of carbone oxide (CO).
- In practical applications all the conclusions should be considered with taking into account the limitations associated with the used test object and the realized testing program.

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Miscellanea

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