RESEARCH ON INFLUENCE OF SELECTED FAILURES ON THE EXHAUST GAS CONTENT OF SHIP DIESEL ENGINE WORKING ON HEAVY FUEL OIL

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Abstract

The article is devoted to problems connected with pollution of the atmosphere by ship engines.

Atmosphere protection against pollution on sea vessels covers one of the most important areas of human ecological activity which has its own history as well as some achievements. The most crucial ones include 73/78 MARPOL Convention (International Convention for the Prevention of Pollution from Ships) referring to prevention against marine environment pollution, and later amendments to the Convention with Annex VI (Regulation for the Prevention of Air Pollution from Ships) dealing with reducing the emission of nitric oxides and sulphur oxides into the atmosphere by sea vessels engines

Nitric oxides emissions from a given engine will depend on engine technical condition. Therefore it was to decided execute laboratory tests on influence of selected failures ship diesel engine, on its exhaust gas content, first of all on change nitric oxygen emission level.

The article presents the results of experimental tests of the influence of charging air pressure, injection advance angle and injector opening pressure on content of exhaust gas, especially content nitric oxides (NO_x), of ship diesel engine supplied with marine heavy fuel oil IF40.

Keywords: *laboratory tests, exhaust gas content, emission of nitric oxides, heavy fuel oils.*

1. Introduction

Exhausts emitted by marine diesels contain a number of combustion products noxious for the environment. The composition of these gases depends on the content of working liquids delivered to the engine that is on the air, fuel and lubricating oil, and on the combustion process. Exhaust gases of marine diesels contain such components as: nitrogen, oxygen, carbon dioxide, water vapour, as wall as small amounts of carbon monoxide, sulphur and nitrogen oxides and some amount of unburned hydrocarbons and solid particles.

Atmosphere protection against pollution on sea vessels covers one of the most important areas of human ecological activity which has its own history as well as some achievements. The most crucial ones include 73/78 MARPOL Convention (International Convention for the Prevention of Pollution from Ships) referring to prevention against marine environment pollution, and later amendments to the Convention with Annex VI (Regulation for the Prevention of Air Pollution from Ships) dealing with reducing the emission of nitrogen oxides and sulphur oxides into the atmosphere by sea vessels engines.

2. Atmosphere protection against pollution from sea vessels in the context of Annex VI MARPOL Convention

In September 1997 the Annex VI to MARPOL Convention [5] was adopted, and it deals with the protection of atmosphere on sea vessels and comprises the emission of: nitric oxides, sulphur oxides and volatile organic compounds (VOC).

Regulation no.13 of the above mentioned annex defines the level of nitric oxides NO_x in relation to engines with the capacity higher than 130 kW. This regulation defines the nitric emission as follows:

- 17 g/kWh for engines with rated speed (n) is less than 130 rpm,
- $45 \cdot n^{-0.2}$ g/kWh when n is 130 rpm or more, bat less than 2000 rpm,
- 9.84 g/kWh when n is 2000 rpm or more,

where n = rated engine speed (crankshaft revolutions per minute).

These NO_x levels defined by the Convention concern new ships built after 1st January 2000 and existing ships undergoing major reconstruction. The basis for this regulation is the assumption that the average NO_x emission of new ships is about 30 per cent lower than in ships of 1990.

Regulation no. 14 of Annex VI defines the highest level of sulphur content in fuel that is 4.5 per cent. Further limitations in SO_x production were introduced to protect areas sensitive to the emission of these oxides. In these areas, fuel with sulphur content below 1.5 per cent is to be used, or special systems limiting SO_x emission to the level fewer than 6 g/kWh are to be introduced. The Baltic Sea represents such an area and others may follow in the future.

Regulation no. 15 of annex VI deals with volatile organic compounds (VOC) in tankers terminals.

Every vessel is required to have an Engine International Air Pollution Prevention certificate (EIAPP) for every engine on board having power output of more than 130 kW.

The limitation of exhaust emission in internal combustion engines can happen in two ways [1-4, 6]:

- direct influence on working process realized in the cylinder – it is the so called primary exhausts emission reduction,
- exhaust purification outside the ship – secondary exhausts emission reduction.

Primary reduction of exhausts emission takes place by influencing the fuel combustion process in engine cylinder. The purpose of this action is to attack the problem at its source that is during the process of exhaust formation. As it was mentioned before the process of nitric oxides formation depends mainly on the combustion temperature as well as the content of oxygen and nitrogen in combustion chamber. All methods dealing with the reduction of nitric oxides formation sources tend to decrease the maximum combustion temperature and oxygen concentration in the exhaust. However it is necessary to remember that methods used in reducing nitric oxides emission may have a reverse effect in case of other exhausts emission. For example, the decrease of maximum combustion temperature allows the reduction of nitric oxides emission but causes the increase of particles emission. Type of fuel has a great influence on nitric oxides emission. In practice, in order to reduce nitric oxides emission the following steps are taken:

- change of air parameters,
- change of fuel injection parameters,
- change of injectors construction,
- supplying water to the cylinder,
- exhausts recirculation.

Primary methods are generally adequate for the IMO NO_x emission limits but regional controls may dictate the use of secondary methods – exhaust gas treatment techniques –either alone or in combination with engine modifications. Here the focus is on selective catalytic reduction (SCR) system, developed from land-based power station installations for shipboard applications, which can cut NO_x reductions by well over 90 per cent. The first SCR unit to be supplied for use on a ferry was supplied in 1992 by ABB Fläkt Marine.

New generation marine diesel engines can be delivered to comply with the IMO speed-dependent nitric oxides emission limits for the gas, measured according to the ISO 8178 test cycle for heavy duty diesel engines. NO_x emissions from a given engine will vary according to the engine load and the optimizing power.

NO_x emissions from a given engine will depend on engine technical condition. Therefore it was decided to execute laboratory tests on influence selected failures ship diesel engine on its exhaust gas content, first of all change of nitric oxygen emission level.

3. Laboratory tests on influence selected failures on its exhaust gas content diesel engine

3.1. Object of tests

Laboratory investigations on a special test stand were initiated by the Ship Power plant Department, Gdynia Maritime Academy, to better identify phenomena and processes appearing during combustion of heavy fuel oils in view of prevention of atmosphere pollution.

The tests were carried out with the use of the one –cylinder, two-stroke, crosshead engine of longitudinal scavenging, charged with the use of Roots blower.

The tests stand was equipped with the fuel oil supply installation which made it possible to supply the engine with diesel oil, heavy oil or their mixture. A special oil heating system was provided to heat heavy fuel oil up to 150°C.

The installed measurement instruments made possible:

- to measure torque – by using the brake directly or the torsiometer installed on the engine-brake shaft,
- to test combustion and fuel injection processes – by using special transducers and computerized recording system (electronic indicator),
- to test exhaust gas content – by using Wimmer electronic analyzer.

An additional device was installed on the engine for stepless changing the injection advance angle α_{ww}. A test stand block diagram is shown in Fig. 1.

The stand was used to investigate influence of selected failures on its exhaust content of two-stroke diesel engine.

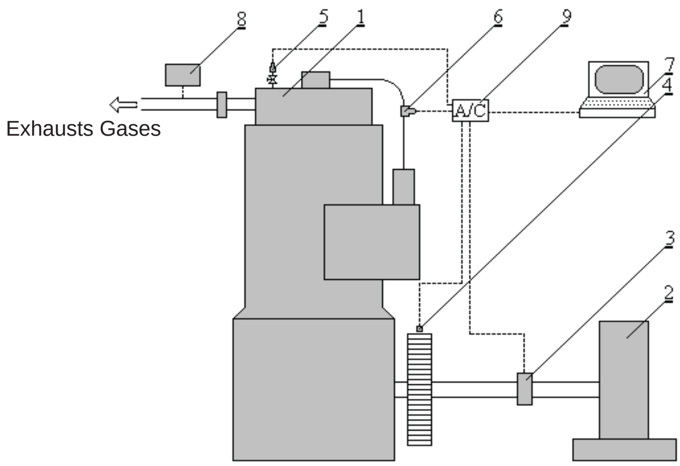

Fig. 1. Test stand block diagram: 1 – L-22 diesel engine, 2 – water brake, 3 – torsiometer, 4 – gauge for crankshaft position marking and rotational speed measuring, 5 – combustion pressure transducer, 6 – injection pressure transducer, 7 – computer, 8- exhaust gas analyzer, 9 – analog/digital converter

3.2. Scope of tests and their results

The aim of the tests was to establish influence selected failures on exhaust gas content engine working on heavy fuel oil:

a) failure charge air compressor; supply the engine with heavy oil IF40, different engine load levels from 50 per cent to 70 per cent rated torque (M_n) and at each load level the supercharging air pressure was changed from 0.1 to 0.02 MPa,
b) wear drive fuel injection pomp (changing the fuel injection advance angle α_{ww}); the engine with heavy oil IF40, different engine load levels from 25 per cent to 80 per cent rated torque (M_n) and at each load level the fuel injection advance angle α_{ww} is has the nominal value $\alpha_{ww} = -13°$ and changed in range ±3°,

c) failure fuel injector (changing fuel injection pressure); the engine with heavy oil IF40, different engine load levels from 25 per cent to 80 per cent rated torque (M_n) and at each load level opening fuel injector pressure is change from the nominal value 22 MPa in range ±4 MPa.

The laboratory tests were performed within at the permanent rotational speed 220 rpm. Results of the tests are presented in Tab. 1-3. Results changed NO_x content in the exhaust gas in function of engine load and super charging air pressure, angles of fuel injection and injector opening pressures presented in Fig. 2-4.

The performed tests indicated that the simultaneous decreasing of charge air pressure, decreasing angles of fuel injection and decreasing injector opening pressure to the decrease of nitric oxides content in exhausts. These results are very interesting considering that the IMO NO_x emission limits. Unfortunately the increase of specific fuel consumption has also been noted.

Reducing the super charging air pressure causes lowering NO_x content in exhaust gas as it can be observed from Tab. 1 and Fig. 2. The nitric oxides content drops by about 20 per cent on the average at loadings of 50 and 60 per cent M_n, and even about 65 per cent at 70 per cent M_n. However the large drop of NO_x content was obtained due to the large reduction of super charging air pressure: from 0.1 MPa to 0.02 MPa.

Delaying the fuel injection by 3° in respect to its nominal value causes distinct dropping of nitric oxides content at each assumed load level as it can be observed from Tab. 2 and Fig. 3. It amounts to about 20 per cent on average for 25 to 80 per cent M_n.

The obtained reduction of NO_x content can be considered satisfactory. However simultaneous worsening of the power and economy indices of the engine should be taken into account. It was revealed, when performing electronic indication tests of the engine, that the maximum combustion pressure and mean indicated pressure propped along with the fuel injection delay, within the entire assumed range of engine loading.

A drop of the injector opening pressure makes the fuel is injected to the cylinder a little earlier and the injection lasts longer, and spraying the fuel, especially its first portions, is worse. The result of worsening of the combustion process is lower level of NO_x within the whole range of the applied engine loads, lower (more than 10 per cent).

The super charging air pressure reduction and delaying the fuel injection and drop of the injector opening pressure, causes a small increase of carbon monoxide (CO).

Tab. 1. Results of analysis of exhaust gas content at different engine load and super changing air pressure values

Engine load level	Charging air pressure	Results of exhaust gas analysis					
M/M_n	p_d	O_2	CO	SO_2	NO_X	NO_X	CO_2
[%]	[MPa]	[%]	[ppm]	[ppm]	[ppm]	[mg/m^3]	[%]
50	0.02	15.6	638	3	259	355	3.9
	0.04	16.6	498	1	270	370	3.2
	0.06	17.8	307	0	248	340	2.3
	0.08	17.9	322	0	279	383	2.2
	0.10	17.9	272	0	306	420	2.2
60	0.02	15.3	1446	48	241	331	4.1
	0.04	16.3	1136	76	284	390	3.4
	0.06	16.3	836	104	330	453	3.4
	0.08	16.8	660	93	348	478	3.0
	0.01	16.7	450	87	394	541	3.1
70	0.02	14.2	4807	291	220	302	4.9
	0.04	13.7	4873	370	233	320	5.3
	0.06	14.7	1081	249	400	549	4.6
	0.08	15.2	825	216	477	655	4.2
	0.10	14.8	845	206	601	825	4.5

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

Engine load level	Fuel injection advance angle	Results of exhaust gas analysis					
M/M_n	α_{ww}	O_2	CO	SO_2	NO_X	NO_X	CO_2
[%]	[°]	[%]	[ppm]	[ppm]	[ppm]	[mg/m^3]	[%]
25	–10	18.9	210	29	117	160	1.5
	–13	19.0	159	27	155	212	1.4
	–16	19.1	264	25	215	295	1.3
40	–10	18.3	215	24	161	221	1.9
	–13	18.2	167	27	211	289	2.0
	–16	18.3	231	28	325	446	1.9
50	–10	17.4	263	21	215	295	2.6
	–13	17.4	243	21	267	366	2.6
	–16	17.1	418	30	400	549	2.8
60	–10	16.6	345	19	266	365	5.2
	–13	15.8	267	19	360	494	3.8
	–16	15.6	622	28	499	685	3.9
70	–10	14.0	610	24	358	491	5.1
	–13	13.7	707	23	436	599	5.3
	–16	13.3	1170	34	563	774	5.6
80	–10	9.9	9882	53	297	408	8.1
	–13	9.0	6043	30	382	524	8.8
	–16	8.8	8061	68	464	637	8.9

Tab.3. Results of analysis of exhaust gas content at different engine load and three injector opening pressures

Engine load level	Fuel injection pressure	Results of exhaust gas analysis					
M/M_n	p_{otw}	O_2	CO	SO_2	NO_X	NO_X	CO_2
[%]	[MPa]	[%]	[ppm]	[ppm]	[ppm]	[mg/m^3]	[%]
25	18	19.0	199	21	136	186	1.4
	22	19.0	159	27	155	212	1.4
	26	18.8	193	33	186	255	1.5
40	18	18.1	238	17	183	251	2.1
	22	18.2	167	27	211	289	2.0
	26	18.2	209	32	240	329	2.0
50	18	17.3	320	17	250	343	2.7
	22	17.4	243	21	267	366	2.6
	26	17.6	336	32	291	399	2.4
60	18	16.7	337	14	316	434	3.1
	22	15.8	267	19	360	494	3.8
	26	16.0	376	48	369	507	3.6
70	18	14.3	1022	21	388	533	4.9
	22	13.7	707	23	436	599	5.3
	26	13.5	1228	76	424	582	5.5
80	18	12.2	2849	50	397	545	6.4
	22	9.0	6043	30	382	524	8.8
	26	10.8	4050	128	407	559	7.4

4. Conclusions

1. The above presented results of laboratory tests could be directly taken into account by the shipowners as the tests were conducted with the use of IF40 heavy fuel oils.
2. On the basis of the performance tests the following general conclusions can be presented:

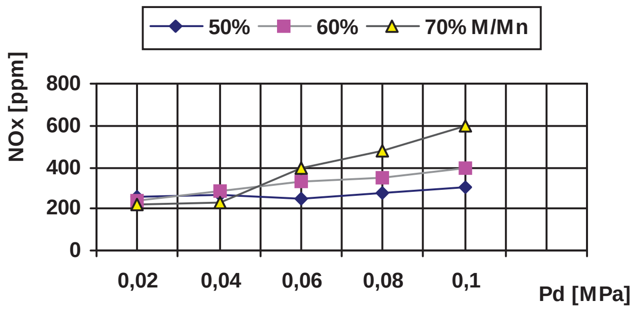

Fig. 2. NO_x content in the exhaust gas plotted against charging air pressure at three different engine load levels

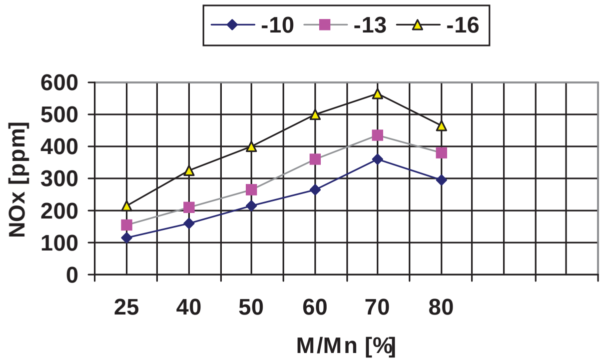

Fig. 3. NO_x content in the exhaust gas in function of engine load at three different values of injection advance angle

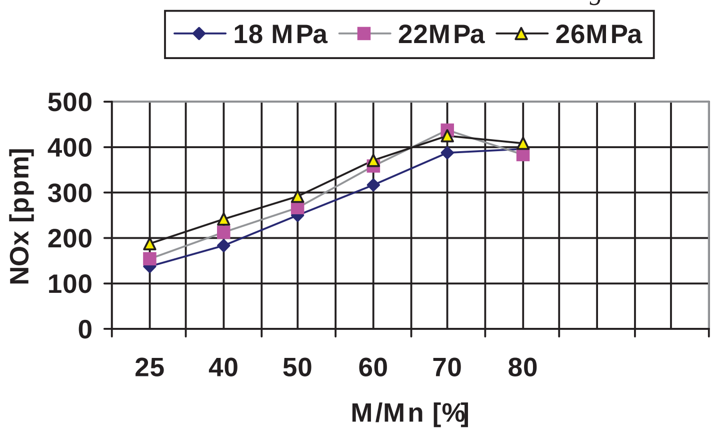

Fig. 4. NO_x content in the exhaust gas in function of engine load at three different injector opening pressures

simultaneous selected failures ship diesel engine makes nitrogen oxides emission to the atmosphere lover. 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 repair).

3. Application for example of the fuel injection delay method to lower exhaust gas toxicity introduced limitations to engine performance, especially to the indicated power. Hence the method should be considered as a substitute remedy, of a limited applicability. However it could be very useful for the ships operating in the waters to which stricter requirements apply (e.g. the Baltic Sea, California Bay, ports and port roads in general).
4. Occurrence of the considered malfunction increases the exhaust gas toxicity by increasing content of carbon monoxide (CO).

References

[1] *Low Eemission News*, The Wartsila 30, 1996.
[2] *MaK Toplateure*, Diesel Engine Journal for our Business Friends, No. 68, 1994.
[3] *Emission Control of Two-stroke Low-speed Diesel Engines*, MAN-B&W.
[4] Vollenweider, J., *Exhaust Emission Control of SULZER Marine Diesel Engines*, New Sulzer Diesel LTD, Wintherthur, Switzerland 1996.
[5] *International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and Annex VI – Regulations for the prevention of air pollution from ships*, Consolidated Edition, IMO London 2002.
[6] Holtbecker, R., Geist, M., *Emission technology. Sulzer RTA series*, Wartsilia NSD, 1998.