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RESEARCH ON INFLUENCE OF SELECTED CONTROL PARAMETERS OF THE INJECTION SYSTEM MARINE DIESEL ENGINE ON ITS EXHAUST GAS TOXICITY

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Abstract

This paper devoted to pollution of the atmosphere due marine 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 diesel engine, one-cylinder, two-stroke, crosshead of longitudinal scavenging, which was loaded by means of the water brake. This diesel engine combusting heavy fuel oil IF 40. The test-involved effect of two selected control parameters of fuel injection system ship diesel engine: fuel injection pressure and injection advance angle. Both selected control parameters were changed during the experiment separately, each of them three times. And so: changing the fuel injection pressure – for three selected values: 18, 22 and 26 MPa; changing the fuel injection advance angle – for three selected values: –10°, –13° and –16° before the piston's top dead centre (BTDC). 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% nominal loads.

Control parameters to change the injection pump and injector engine, during operation of the engine, by means of a supplementary-scaled instrumentation of the injector and injection pump. Owing to this is was not necessary to stop the engine before each successive test cycle. This way of realization of the measurements guaranteed running them in steady conditions. The elimination of influence of possible disturbances witch could arise from multiple starting and stopping the engine improved accuracy and reliability of the obtained results.

Keywords*: ship diesel engine, injection system, heavy fuel oil, control parameters, exhaust gas toxicity*

1. Introduction

Ship designers and operators for more than a half of century have dealt problem of the seawater protection against from ships. In recent years, the marine environmental protection was extended over the atmosphere. The relevant legal acts aiming at lowering emission of toxic exhaust gas components, especially nitric oxides (NO_x), are in force (annex VI to the MARPOL 73/78 Convention [2], ISO 8178 standard [1]).

Typical content of the exhaust gas emitted by two-stroke ship diesel engine is shown in Fig. 1.

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 solution, 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 have to be adjusted to compliance with the standards lowering NO_x emission. As it was proved in the publications [3–6], a relatively simple way to limit emission of nitric oxides is to apply appropriate adjustment operations. Among them can be measures related of changes operating parameters of the injection system. In this paper presented are results research on influence changing the fuel injection pressure and changing the fuel injection advance angle of a marine diesel engine on its exhaust gas content.

2. Exhaust gas composition

The composition of major pollutants in the exhaust gas from typical, two-stroke, low-speed, diesel engine, as shown in Fig.1, is a result of the engine process, its fuels and the means employed to control the emissions. In the remainder of the paper, the selected components of the exhaust will be briefly described.

Molecular oxygen (O_2) and nitrogen (N_2). Low speed, two-stroke, crosshead diesels operate with an air excess ratio of over 3. More than half of the air is available for the combustion process, while the remaining part is scavenged trough the cylinder. Hence, the exhaust gas contains some 13-16% oxygen, and this has to be considered when calculating the concentration of various compounds in the gas (some exhaust gas emission regulations refer to 15% oxygen).

Nitrogen makes up 80% of the atmosphere. Given the above-mentioned air excess ratio, it is clear that nitrogen constitutes the major part of the exhaust gas. As nitrogen is practically inactive, only a small but, important parts is involved in the chemical reactions in the engine.

Carbon dioxide (CO_2), water vapour (H_2O). Basically, the complete combustion of hydrocarbons will produce carbon dioxide and water vapour, and the relative amounts of these will be a function of the hydrocarbon composition of the fuel. Although traditionally not regarded as a pollutant, carbon dioxide has become of increasing concern in recent times through its importance as a "greenhouse gas" and the consequences for the global climate of the trend of rising carbon dioxide concentration.

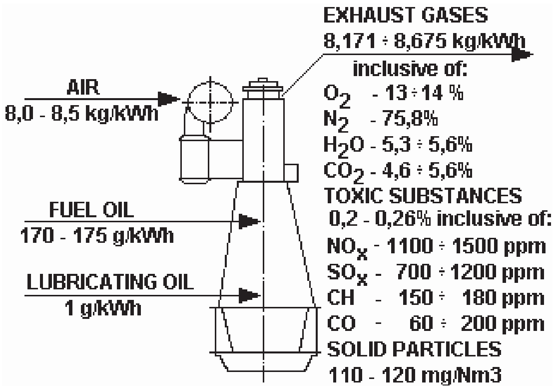

Fig. 1. Typical emissions from two-stroke, low-speed ship diesel engine

Nitrogen oxides (NO_x). Are formed during the combustion process within the burning fuel sprays. NO_x is controlled by the local conditions in the fuel spray with temperature and oxygen concentration as the dominant parameters. As heavy fuel oil a greater content of organic nitrogen than marine diesel oil or other distillate fuels, the NO_x emissions of an engine running on heavy fuel are thus greater.

Nitric oxide NO is a primary reaction product, but around 5% of it is converted to nitrogen dioxide NO_2 later in the combustion cycle, during expansion and during the flow through the exhaust system. At the same time, a very limited proportion of nitrous oxide N2O is also formed. Further oxidation of NO to NO_2 subsequently continues at ambient temperatures after the exhaust gases have passed out to the atmosphere.

The environmental effects of NO_x are diverse. Nitrogen oxide is of particular concern because of its detrimental effects on respiration and plant life, as well as its significant contribution to acid rain. Nitrogen oxides are one of the primary pollutants which have been introduced in regulations, such as those adopted by the IMO (International Maritime Organization).

Sulphur oxides (SO_x). The oxides of sulphur, SO_x, derive directly from the sulphur content of the fuels used. Sulphur oxides are the major source of acid rain. The alkaline lubricants employed to protect the cylinder liner surface from acidic corrosion convert a small proportion of the SO_x

produced by the combustion process to calcium sulphate. However, this is a relatively insignificant proportion and the sulphur emissions from the marine engine will essentially be proportional to the sulphur content of the fuel and the fuel consumption.

Limitation of the emission from the marine diesel engine of SO_x has been introduced also by IMO regulations.

3. Laboratory tests

3.1. The test object and stand

The laboratory test were carried out on one-cylinder, two-stroke, crosshead engine of longitudinal scavenging, which was loaded by means of the water brake. The engine was charged with IF 40 heavy fuel oil. A special oil heating system was provided to head heavy fuel oil up to 150°C.

The stand consisted of the engine and water brake. The laboratory service installations, similar to those applied to ship power plants but also adjusted to land conditions ensured the engine-brake system to work correctly.

The installed measurement instruments made it possible:

1. to measure:
– torque – by using the brake directly or the torsiometer installed on the engine-brake shaft,
– rotational speed – by using on electronic system (marker, transducer),
2. to test:
– combustion and fuel injection processes – by using special transducers and computerized recording system,
– 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}).

The stand was used to investigate influence of selected control parameters of the injection system of the engine on exhaust gas purity.

3.2. Scope of the tests

The test program was prepared series of measurements on the engine, during which the changed values of two control parameters in the engine injection system, as follows:

– changing the fuel injection pressure – for three selected values: 18, 22 and 26 MPa,
– changing the fuel injection advance angle – for three selected values: –10°, –13° and –16° before the piston's top dead centre (BTDC).

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 torque to nominal torque.

3.3. Description of the tests and their results

Control parameters to change the injection pump and injector engine, during operation of the engine, by means of a supplementary-scaled instrumentation of the injector and injection pump. Owing to this is was not necessary to stop the engine before each successive test cycle.

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

The measurement results are present in Tab. 1 and 2 and in Fig. 2 and 3.

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_n	O_2	CO	SO_2	NO_x	NO_x	CO_2
[MPa]	[%]	[%]	[ppm]	[ppm]	[ppm]	[mg/m^3]	[%]
18	25	19.0	199	21	136	186	1.4
	40	18.1	238	17	186	251	2.1
	50	17.3	320	17	250	343	2.7
	60	16.9	337	14	316	434	3.1
	70	14.4	1022	21	388	533	4.9
	80	12.2	2849	50	397	545	6.4
22	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	6043	30	382	524	8.8
26	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	1228	76	424	582	5.5
	80	10.8	4050	128	407	559	7.4

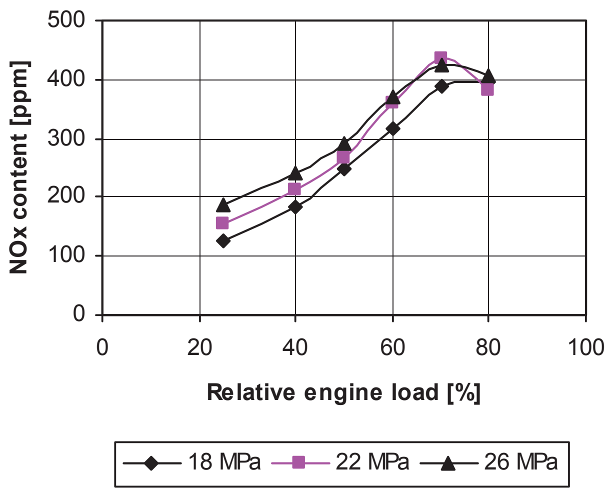

Fig. 2. NO_x content in exhaust gas in function of three different injector-opening pressures

3.4. Analysis of the results

The rated value of the injector opening pressure for the tested engine amounts to 22 MPa. The chosen values different by 20% of that rated, i.e. they amounted to 18 and 26 MPa.

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 worse. The worsening of the combustion process resulting from that makes NOx level within the whole range of the applied engine loads, lower.

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_n	O_2	CO	SO_2	NO_x	NO_x	CO_2
[°]	[%]	[%]	[ppm]	[ppm]	[ppm]	[mg/m^3]	[%]
–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	9882	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	6043	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	1170	34	563	773	5.6
	80	8.8	8061	68	464	637	8.9

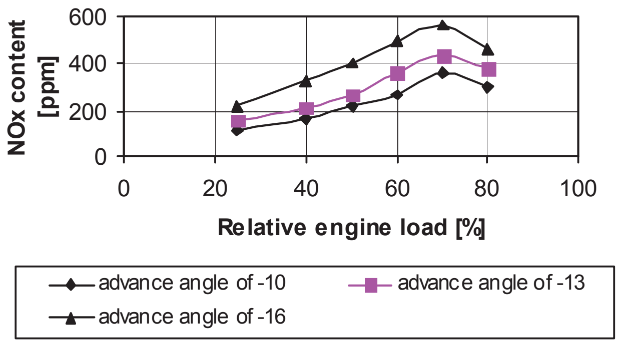

Fig. 3. NO_x content in exhaust gas in function of three different advance angles of fuel injection

The rise of the injection opening pressure from 22 MPa to 26 MPa results in an increase of NO_x emission within the whole engine load range. This can by 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 by 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 change of the injection advance angle was realized for the three selected settings: –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 loads, whereas a delay of the injection beginning (decrease of the injection advance angle) unambiguously makes NO_x content in exhaust gas lower. However is 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 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 change in injector opening pressure and injection advance angle causes that content of carbon oxide (CO) in exhaust gas is greater. Both an increase and decrease of the injector opening pressure and injection advance angle with respect to their values led to the above-mentioned change.

4. Conclusions

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

– increase the injector opening pressure relative to its rated value, causes the engine to the atmosphere emits greater amounts of NO_x; reducing of this pressure relative to its rated value, causes the engine to the atmosphere emits smaller amounts of NO_x,
– however the accompanying consequences should be also remembered, namely: increasing the fuel consumption and possible rising the thermal load on engine combustion chamber elements; cause a negative economic impact – increase in operating costs (cost by increasing the fuel consumption and decreasing engine durability – costs of engine repairs).
– increase the injection advance angle relative to its rated value, causes the engine to the atmosphere emits greater amounts of NO_x; reduction of this angle relative to its rated value, causes the engine to the atmosphere emits smaller amounts of NO_x,
– changing fuel injection pressure and injection advance angle in the considered diesel engine, increases the exhaust gas toxicity by increase content of carbon oxide (CO).

5. References

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