RESEARCH ON INFLUENCE OF CHANGE MARINE DIESEL ENGINE OF CHARGING AIR PARAMETERS ON ITS NITROGEN OXIDES EMISSION

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Abstract

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

Nitric oxides emissions for a given engine will depend on charging air parameters. Change of air parameters in this method of reducing NO_x emissions involves cooling the air and changes in pressure at the beginning of compression stroke.

The process of cooling the scavenging air means decreases the inlet air temperature and at the same time decreases the maximum cylinder temperature.

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.

Keywords: *laboratory tests, super charging air pressure, exhaust gas content, emission of nitric oxides, heavy fuel oils*

1. Introduction

Nowadays the marine diesel engines are to meet more and more stringent requirements for limitation of emission of toxic combustion products to the atmosphere in view of marine environment protection.

Exhaust gas emissions from marine diesel engines largely comprise nitrogen, oxygen, carbon dioxide and water vapour, with smaller quantities of carbon monoxide, oxides of sulphur and nitrogen, partially reacted and non-combusted hydrocarbons and particulate material.

Typical content of the exhaust gas emitted by ship diesel engines is shown in Fig. 1.

2. Controlling NO_X emissions

Nitrogen oxides (NO_x) generated thermally from nitrogen and oxygen at high combustion temperatures in the cylinder. NO_x are believed to be carcinogenic and contribute to photochemical smog formation over cities and acid rain.

Legal instruments to control nitrogen oxides emission are initiated at three levels:

- international (International Maritime Organization – IMO),
- national (e.g. Environmental protection Agency – EPA, USA),
- regional (e.g. California Air Resources Board – CARB, USA).

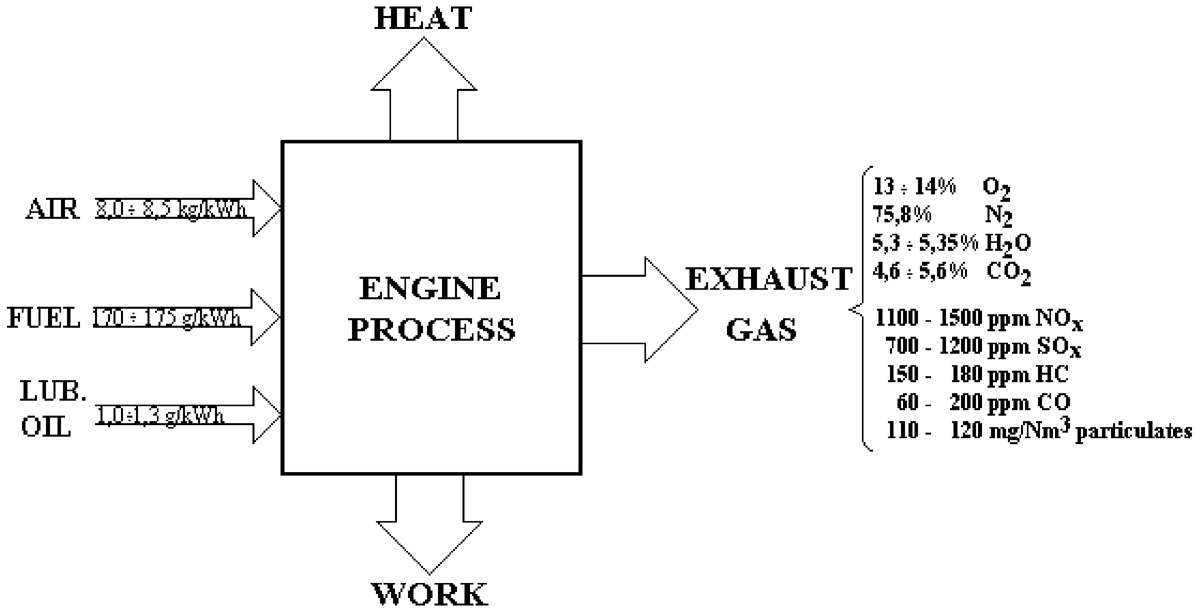

Fig. 1. Balance of substrates and combustion products of the typical ship two-stroke diesel engine

The global approach to NO_x emission controls was taken by the IMO by MARPOL'S 73/78 Annex VI (Regulations for the Prevention of Air Pollution from Ships) which was adopted at a diplomatic conference in 1997. Ship burning marine diesel oil and heavy fuel oil at that time were reportedly responsible for about 7 per cent of global NOx emissions, about 4 per cent of global sulphur dioxide emissions and 2 per cent of global carbon dioxide emissions. The annex addresses engines with a power output of more then 130 kW installed in new ships constructed after 1 January 2000 (date of keel lying) and engines in existing ships that undergo a major modification.

The permissible NOx emission level according to IMO provisions is shown in Fig. 2.

IMO's current maximum allowable NOx emission levels depended on the speed category of the engine and range from 17 g/kWh for engines of speed is less than 130 rev/min, 45n-0.2 g/kWh when speed is 130 or more but less then 2000 rev/min, to 9.84 g/kWh for engines of speed in 2000 rev/min or more [3].

To show compliance, an engine has to be certified according to the NOx Technical Code and delivered with Engine International Air Pollution Prevention (EIAPP) letter compliance. The certification process includes NO_x measurement for the engine type concerned, stamping of components that affect NO_x formation and Technical File that is delivered with the engine.

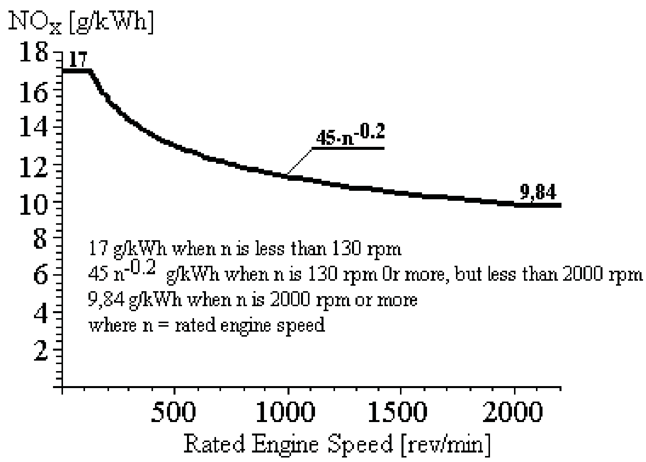

Fig. 2. NOx emissions limit according to the IMO regulation 13, Annex VI of MARPOL 73/78

3. Primary reduction of NO_x emission (in-engine)

Primary measures aimed at reducing the amount of NO_x formed during combustion by optimizing engine parameters with respect to emissions. In practice, in order to reduce NO_x emission the following steps are taken:

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

Change of air parameters in this method of reducing NO_x emissions involves cooling the air and changes in pressure at the beginning of compression stroke. The process of cooling the scavenging air means decreasing the inlet air temperature and at the same time decreasing the maximum cylinder temperature. The easiest way is to decrease the air temperature by increasing the efficiency of air cooler after the compressor. Tests proved that lowering the air temperature of 3°C causes 1 per cent decrease of NOx emission. The physical border of cooling the air is defined by the temperature of cooling water, witch in the tropics can by 32°C. It is believed that the change of air temperature at full engine load should not exceed 40°C.

Further decrease of temperature by means of conventional cooler is not possible and requires special solutions. One of the solutions is based on compressing and cooling the air, and then decompressing it witch ensures further decrease of this temperature. However this solution requires another compressor can be installed after the cooler. The disadvantage of such idea is the additional coast of the system, decrease of change efficiency as well as the increasing of fuel consumption.

The problem can by solved by Miller supercharge system used by SULZER in four stroke engines [1, 2]. The idea of this system introduces high pressure cooler in charge system (higher pressure – greater density – greater air mass) and also changes the closing angle of inlet valve. It this system the required mass of charge air can by delivered in shorter time than in standard system and the air inlet can be closed before BDC – see Fig. 3. In this way time of filling the cylinder is also shortened. Further piston movement to BDC causes the expansion of the air closed in cylinder and decreasing of this temperature. Miller supercharging is one of the very few measures to reduce both NO_x emissions [1, 2].

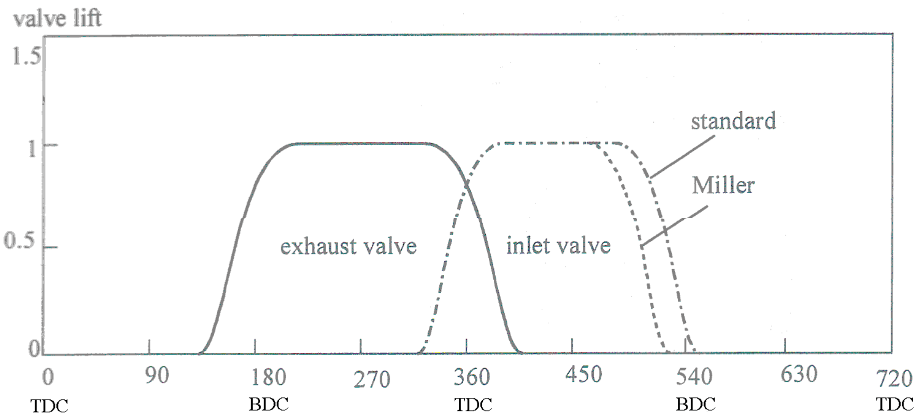

Fig. 3. Exhaust and inlet valve lifts for four-stroke diesel engine with standard and Miller supercharging

Another way of introducing water into the combustion zone is by humidifying the scavenge air: warm water is injecting and evaporating in the air intake, which absolute humidity is thereby increasing. For the marine diesel engine, are known two projects:

- Combustion Air Saturation System (CASS),
- Humid Air Motor (HAM) system.

In the Combustion Air Saturation System (Watrsila and Marioff Oy Company) special Hi-Fog nozzles introduce water directly into the charge air stream after the turbocharger in the as very small droplets.

MAN has also pursued NOx reduction by increasing the humidity of the charge air with water vapour. The process is based on the Humid Air Motor system. Compressed and heated air from the turbocharger is passed trough a cell that humidifies and cools the air with evaporated water, the distillation process makes it possible to use sea water rather than fresh water (Fig. 4). Marine medium speed diesel engine Pielstick was equipped by prototype HAM system. This system showed a NO_x reduction by 25 per cent. This was no significant influence on specific fuel consumption, on significant increase in carbon monoxide and hydrocarbon emission and no smoke deterioration [4].

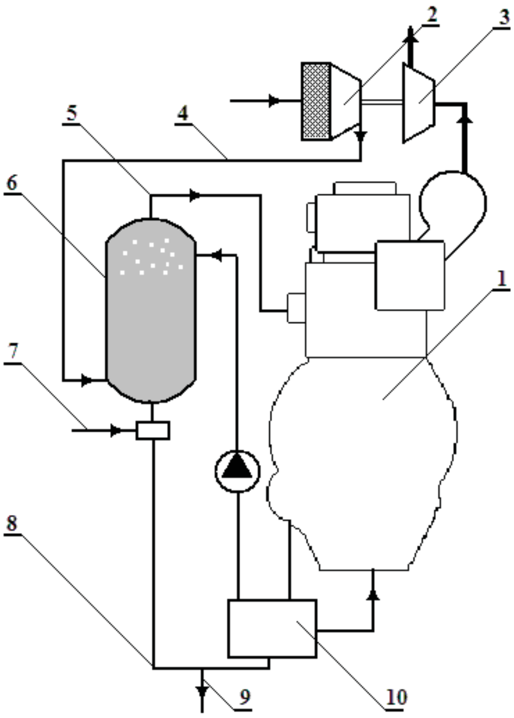

Fig. 4. Schematic diagram of Humid Air Motor system for NOx emission reduction: 1 - engine, 2 - compressor, 3 - turbine, 4 - hot compressed air, 5 - humidified and cooled air, 6 - humidification tower, 7 - water filling, 8 - water circuit, 9 - bleed-off, 10 - heat exchanger

The influence of reducing the supercharging air pressure, on NO_x emission was also examined in the laboratory tests.

4. Laboratory tests

The laboratory 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 makes 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 torquemeter 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.

5. Scope of tests and their results

The test program figured on influence of reducing the supercharging air pressure on NO_x emission. The supercharging air pressure changed from 0.02 MPa to 0.1 MPa with 0.02 MPa pressure step. The engine operated at the different load levels from 50 per cent to 70 per cent rated torque (Mn) at the permanent rotational speed of 230 rpm and supply the engine with heavy oil IF30.

The specified engine loads applied by the water brake. Changes in the supercharging air pressure were effected by changing the rotational speed of the Roots blower.

Results of the test are presented in Tab. 1 as well as Fig. 5 and Fig. 6.

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

Engine load level	Charging air pressure	Indicated parameters				Results of exhaust gas analysis		
M/M_n	p_d	p_{max}	α_{pmax}	p_i	p_{exp}	NO_x	CO	CO_2
[%]	[MPa]	[MPa]	[°]	[MPa]	[MPa]	[ppm]	[ppm]	[%]
50	0.02	4.1	15	0.78	3.1	259	638	3.9
	0.04	4.5	17	0.81	3.2	270	498	3.2
	0.06	4.6	8	0.81	3.3	248	307	2.3
	0.08	4.6	9	0.79	3.3	279	322	2.2
	0.10	4.7	10	0.82	3.3	306	272	2.2
60	0.02	4.3	14	0.86	3.2	241	1446	4.1
	0.04	4.7	14	0.92	3.5	284	1136	3.4
	0.06	4.6	15	0.88	3.4	330	836	3.4
	0.08	4.8	15	0.91	3.4	348	660	3.0
	0.01	4.7	16	0.91	3.4	394	450	3.1
70	0.02	4.5	14	1.00	3.5	220	4807	4.9
	0.04	4.6	13	0.98	3.4	233	4873	5.3
	0.06	4.8	15	0.98	3.6	400	1081	4.6
	0.08	4.8	15	1.02	3.5	477	825	4.2
	0.10	5.0	14	1.01	3.6	601	845	4.5

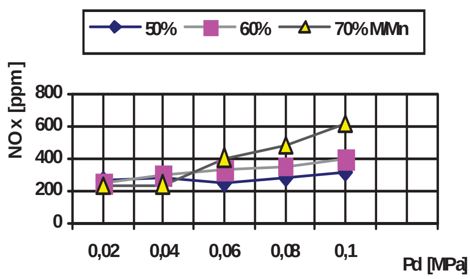

Fig. 5. NOx content in the exhaust gas plotted against charging air pressure at three different engine load levels

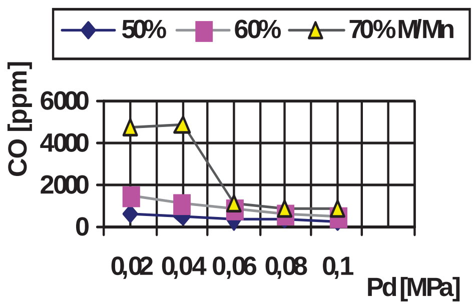

Fig. 6. CO content in the exhaust gas plotted against charging air pressure at three different engine load levels

It can be stated from the tests that changing the super charging air pressure, affects the exhaust gas content. Their influence on NOx content is especially important in view of the IMO requirements.

Reducing the supercharging air pressure causes lowering NOx content in exhaust gas as in Tab. 1 and Fig. 5. The NOx content drops by about threefold (for 601 ppm to 220 ppm) on the average at loading 70 per cent Mn. However the large drop of NOx content was achieved by large reduction of super charging air pressure from 0.1 MPa to 0.02 MPa.

The super charging air pressure reduction from 0.1 MPa to 0.02 MPa causes small increase of CO content in exhaust gas at 50 and 60 per cent Mn, and very large one (about tenfold higher) at 70 per cent M_n (see Tab. 1 and Fig. 6).

6. Conclusions

1. Decrease of the supercharging air pressure also makes it possible to notably reduce NO_x content in exhaust gas from the diesel engine working on heavy fuel oil IF30.
2. However it is necessary to remember that methods used in reducing NO_x emission may have a reverse effect in case other exhausts emission – among others increasing content of carbon monoxide (CO).
3. 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 IF30 heavy fuel oils.

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