# Influence of running ship diesel engines on mixtures of fuel oil and rape oil methyl esters – – experimental tests

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ABSTRACT

*The paper presents results of experimental tests being continuation of the research project described in the preliminary report [4]. The tests were carried out on a ship diesel engine supplied with marine diesel oil, and the oil and rape oil methyl esters mixed in different proportions. In the tests special attention was paid to influence of combustion of the mixtures on exhaust gas content, including its noxious components, as well as on possible changes of indicated working parameters of the engine.*

**Keywords** : tests, ship engines, renewable fuels, alternative fuels, ecology

## INTRODUCTION

In [4] the authors presented an analysis of possible application of alternative fuels to ship diesel engines. As it results from the subject-matter literature on the state of research in this area, for diesel engines possible application of mixtures of diesel oil and vegetable oil esters is most seriously considered. In European conditions it first of all concerns the mixture containing from a few to a dozen or so percent of rape oil esters (RME). Though many tests have been performed, their results are often contradictory, as they have been carried out in very different conditions (different types of diesel engines tested under different loading). Therefore has been emphasized necessity of carrying out tests under constant rotational speed. Simultaneously no report concerning application of alternative fuels in question to ship diesel engines can be found. For this reason the authors were encouraged to undertake the laboratory tests satisfying the above mentioned premises.

## LABORATORY TESTS

### *Object of tests*

The tests were carried out with the use of the one-cylinder, two-stroke, crosshead supercharged diesel engine which is an element of the test stand already used for the previous investigations on emission of exhaust gas noxious components, presented by the authors in [1, 2, 3].

The test stand makes it possible to load the engine both with torque and rotational speed. During operation of the engine its most important working parameters, including those electronically indicated, can be recorded. An applied analyzer allows to investigate exhaust gas content.

To supply the engine during the tests in question the marine diesel oil (**MDO**) and its mixtures with rape oil esters (**RME**) of the following proportions, were prepared :

- 5% of RME in MDO
- 10% of RME in MDO.

The MDO was of the density of 831 kg/m$^3$, and the RME of 883 kg/m$^3$. As a result of the mixing the biofuel of the density of : 833 kg/m$^3$ in the first case, and of 836 kg/m$^3$ in the second case, was obtained. Detail properties of the marine diesel oil and the above specified mixtures were given in [4].

### *Test program*

The tests were carried out within the broad range of engine's loading, namely : at 25, 40, 50, 60, 70, 80 % $M/M_r$ , and for constant rotational speed of the engine, set twofold : at 220 rpm and 320 rpm.

At a given rotational speed and successively set loads, were realized measurements of the engine's working parameters and its exhaust gas content during combusting by the engine : the MDO alone, and the two above specified mixtures (i.e. 5 % RME in MDO, and 10 % RME in MDO).

The results obtained from the tests when supplying the engine with the MDO alone was assumed the reference point for determination of influence of combustion of the MDO/RME mixtures on the engine's working parameters and its exhaust gas content.

### *Test results and their analysis*

The test results are presented in Tab.1 and 2, and the changes of values of selected working parameters of the engine, and of exhaust gas content are graphically shown in Fig.1÷10

*Tab. 1. Test results – exhaust gas content and values of selected working parameters of the engine in function of loading level and kind of fuel, at the constant engine speed of **220** rpm*

| Kind of fuel | Loading level $M/M_r$ | Content of exhaust gas $O_2$ | $CO$ | $NO_x$ | | $CO_2$ | Values of selected engine working parameters $p_i$ | $p_{max}$ | $\alpha p_{max}$ | $p_{max.\,in}$ | $f_e$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | ppm | ppm | ppm | mg | % | MPa | MPa | °CSR | MPa | g/kWh |
| MDO | 25 | 18.5 | 150 | 185 | 254 | 1.8 | 0.207 | 4.32 | 5.0 | 26.6 | 400 |
| | 40 | 18.4 | 145 | 273 | 375 | 1.8 | 0.264 | 4.68 | 4.5 | 27.8 | 316 |
| | 50 | 17.7 | 156 | 338 | 464 | 2.4 | 0.309 | 4.98 | 6.0 | 28.5 | 299 |
| | 60 | 16.7 | 198 | 515 | 707 | 3.1 | 0.352 | 5.34 | 6.5 | 32.1 | 291 |
| | 70 | 14.4 | 257 | 793 | 1035 | 4.8 | 0.407 | 5.57 | 6.0 | 28.5 | 291 |
| | 80 | 12.4 | 257 | 1089 | 1422 | 6.3 | 0.441 | 5.73 | 5.0 | 28.8 | 285 |
| MDO +5 % RME | 25 | 18.4 | 164 | 194 | 266 | 1.8 | 0.223 | 4.29 | 4.5 | 27.0 | 410 |
| | 40 | 18.2 | 123 | 244 | 335 | 2.0 | 0.262 | 4.57 | 5.0 | 29.4 | 326 |
| | 50 | 17.8 | 176 | 328 | 450 | 2.3 | 0.303 | 4.90 | 6.0 | 28.2 | 305 |
| | 60 | 16.4 | 221 | 483 | 663 | 3.3 | 0.355 | 4.87 | 6.3 | 32.1 | 300 |
| | 70 | 14.2 | 208 | 759 | 1042 | 4.9 | 0.386 | 5.39 | 6.0 | 28.4 | 292 |
| | 80 | 12.2 | 237 | 1005 | 1380 | 6.4 | 0.451 | 5.60 | 6.0 | 28.2 | 290 |
| MDO +10 % RME | 25 | 18.4 | 186 | 178 | 244 | 1.8 | 0.193 | 4.18 | 5.0 | 26.6 | 392 |
| | 40 | 18.5 | 119 | 226 | 310 | 1.8 | 0.255 | 4.51 | 7.0 | 28.2 | 314 |
| | 50 | 17.8 | 170 | 318 | 436 | 2.3 | 0.314 | 5.22 | 7.0 | 29.1 | 310 |
| | 60 | 16.8 | 168 | 454 | 623 | 3.0 | 0.341 | 5.20 | 6.0 | 30.0 | 298 |
| | 70 | 14.9 | 186 | 689 | 946 | 4.4 | 0.391 | 5.39 | 6.0 | 28.5 | 290 |
| | 80 | 11.9 | 280 | 1009 | 1386 | 6.6 | 0.439 | 5.56 | 6.0 | 28.4 | 293 |

*Tab.2. Test results – exhaust gas content and values of selected working parameters of the engine in function of loading level and kind of fuel, at the constant engine speed of **320** rpm*

| Kind of fuel | Loading level $M/M_r$ | Content of exhaust gas $O_2$ | $CO$ | $NO_x$ | | $CO_2$ | Values of selected engine working parameters $p_i$ | $p_{max}$ | $\alpha p_{max}$ | $p_{max.\,in}$ | $f_e$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | ppm | ppm | ppm | mg | % | MPa | MPa | °CSR | MPa | g/kWh |
| MDO | 25 | 17.4 | 141 | 288 | 395 | 2.6 | 0.224 | 4.29 | 4.5 | 32.8 | 384 |
| | 40 | 17.4 | 121 | 305 | 419 | 2.6 | 0.284 | 4.57 | 6.0 | 32.6 | 297 |
| | 50 | 17.7 | 122 | 298 | 409 | 2.4 | 0.340 | 4.82 | 6.0 | 32.8 | 289 |
| | 60 | 17.7 | 152 | 341 | 468 | 2.4 | 0.376 | 5.03 | 6.5 | 33.7 | 278 |
| | 70 | 16.9 | 196 | 441 | 605 | 2.9 | 0.417 | 5.29 | 7.5 | 37.4 | 270 |
| | 80 | 14.8 | 223 | 667 | 916 | 4.5 | 0.470 | 5.46 | 7.5 | 38.4 | 269 |
| MDO +5 % RME | 25 | 17.3 | 112 | 313 | 430 | 2.7 | 0.221 | 4.14 | 6.8 | 32.4 | 392 |
| | 40 | 17.5 | 162 | 288 | 395 | 2.5 | 0.278 | 4.55 | 6.7 | 32.3 | 314 |
| | 50 | 17.8 | 182 | 280 | 384 | 2.3 | 0.320 | 4.71 | 6.5 | 31.9 | 310 |
| | 60 | 17.6 | 179 | 314 | 431 | 2.4 | 0.364 | 4.91 | 6.8 | 33.0 | 298 |
| | 70 | 16.8 | 154 | 446 | 612 | 3.0 | 0.406 | 5.13 | 6.8 | 36.6 | 290 |
| | 80 | 14.7 | 185 | 664 | 912 | 4.6 | 0.459 | 5.32 | 7.7 | 37.9 | 293 |
| MDO +10 % RME | 25 | 17.3 | 100 | 303 | 416 | 2.7 | 0.222 | 4.18 | 7.0 | 32.6 | 370 |
| | 40 | 17.4 | 138 | 305 | 419 | 2.6 | 0.267 | 4.46 | 6.8 | 32.6 | 303 |
| | 50 | 17.9 | 116 | 283 | 388 | 2.2 | 0.318 | 4.70 | 6.8 | 32.5 | 290 |
| | 60 | 17.5 | 233 | 336 | 461 | 2.5 | 0.364 | 4.93 | 6.8 | 34.5 | 286 |
| | 70 | 17.3 | 143 | 397 | 545 | 2.7 | 0.403 | 5.16 | 7.5 | 37.2 | 272 |
| | 80 | 15.6 | 181 | 602 | 827 | 3.9 | 0.447 | 5.29 | 6.3 | 38.2 | 270 |

for different loads, three kinds of the applied fuels, and a given rotational speed set constant.

Analysis of the results indicates a noticable influence of combustion of the used MDO/RME mixtures on the engine's working parameters and its exhaust gas content against those obtained during combusting the MDO alone.

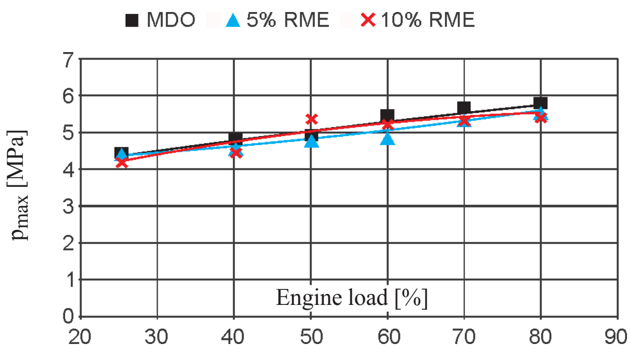
Within the entire range of the set loads and for both rotational speeds of the engine (220 and 320 rpm) a small drop of the maximum combustion pressure $p_{max}$ , namely by about 3% only (see Fig.1 and 2), can be observed. Simultaneously, a small increase of the respective angle of occurrence of $p_{max}$ , measured from the top dead centre (TDC) of engine's piston, (in Tab.1 and 2 this is the quantity $\alpha p_{max}$), can be observed. The phenomenon may reveal a somewhat longer time of combustion process of the applied biofuels against that of the MDO alone.

Also, the mean indicated pressure $p_i$ drops to a small degree only. A more distinct drop, by about 3% on average, can be observed during running the engine on the mixture (MDO + + 10%RME) at the engine's speed of 220 rpm, and by about 4% on average at the speed of 320 rpm (see Fig.3 and 4). The small drop of $p_i$ resulted also in a small increase of the specific fuel oil consumption $f_e$. However in some cases the changes exceeded the measurement error limits only insignificantly.

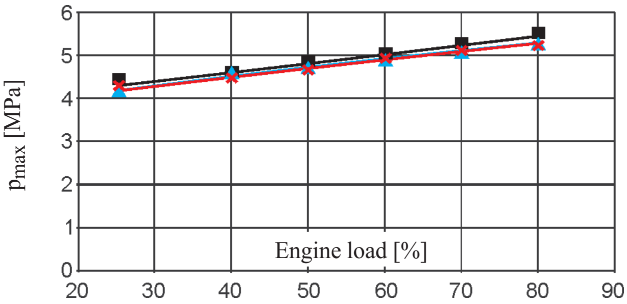
During the tests the course of pressure in the engine's injection system was recorded. Regardless of a kind of fuel, changes of the pressure for both the engine's speed were small. It is not possible to state a.o. any significant influence of the tested fuels on change of the maximum injection pressure $p_{max,in}$ (see Fig.5 and 6).

On the basis of the exhaust gas analysis it can be stated that combustion of MDO with 5% addition of RME caused on average the drop of $NO_x$ content by over 6%, and that during combusting the MDO with 10% addition of RME the drop on average exceeded 8% (see Fig.7 and 8). However ambiguous are changes of CO content in exhaust gas. As, depending on engine's load, both either a distinct increase or a drop of CO content in exhaust gas, can be observed. For instance, in the case of using both the mixtures at 220 rpm engine speed the drop of CO content in exhaust gas exceeded 15% at the load levels of 40 and 70% $M/M_r$ , but at the load levels of 25, 50, 60 and 80% $M/M_r$ the increase of CO content in exhaust gas by a few to a dozen or so percent see Fig.9 and 10) was observed.

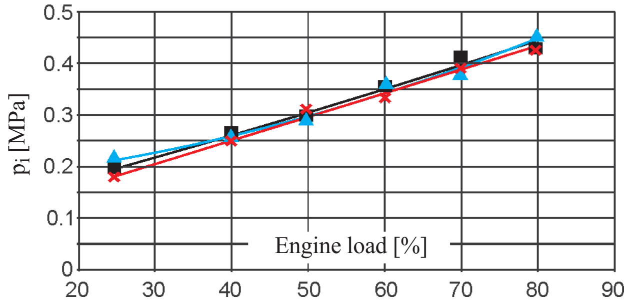
Explanation to Figs 1÷10 :



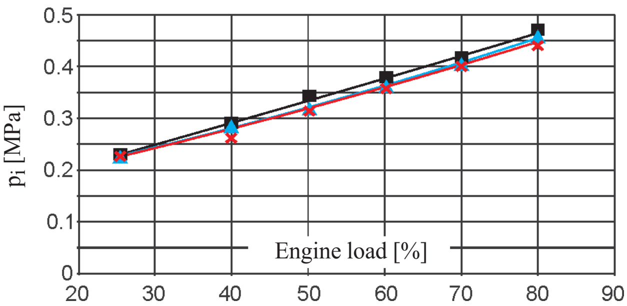

***Rys. 1.** Maximum combustion pressure $p_{max}$ in function of engine load for different kinds of fuel at constant engine rotational speed n = **220** obr/min*



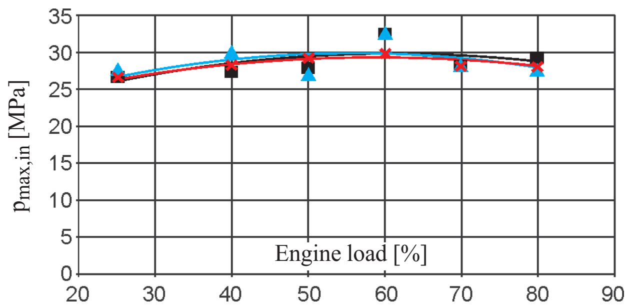

***Rys. 2.*** *Maximum combustion pressure $p_{max}$ in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***320*** *obr/min*



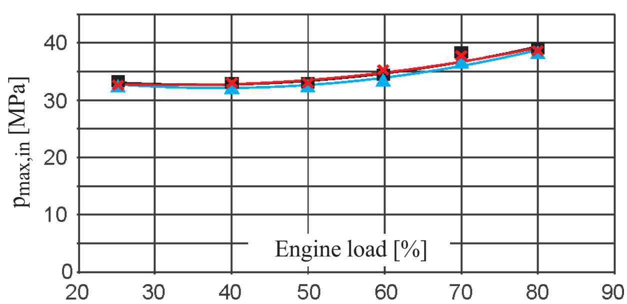

***Rys. 3.*** *Maximum mean indicated pressure $p_i$ in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***220*** *obr/min*



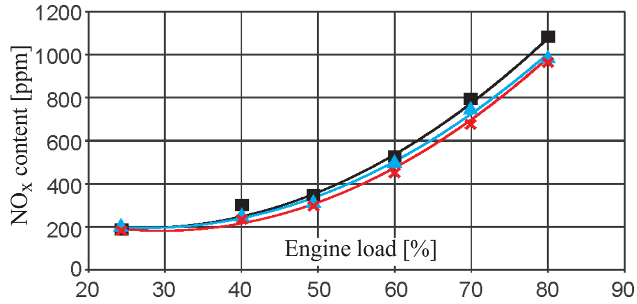

***Rys. 4.*** *Maximum mean indicated pressure $p_i$ in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***320*** *obr/min*



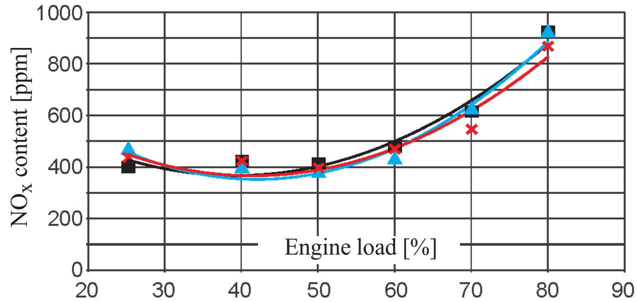

***Rys. 5.*** *Maximum fuel injection pressure $p_{max,in}$ in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***220*** *obr/min*



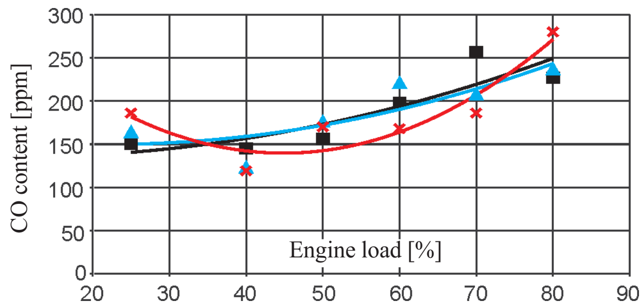

***Rys. 6.*** *Maximum fuel injection pressure $p_{max,in}$ in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***320*** *obr/min*



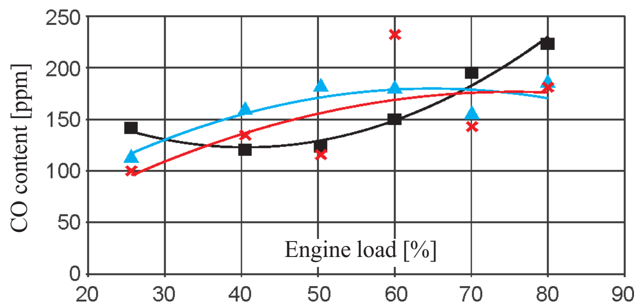

***Rys. 7.*** *$NO_x$ content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***220*** *obr/min*




***Rys. 8.*** *$NO_x$ content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***320*** *obr/min*




***Rys. 9.*** *CO content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***220*** *obr/min*




***Rys. 10.*** *CO content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed n =* ***320*** *obr/min*

## CONCLUSIONS

❖ Running the engine on the MDO/RME mixture made the pressures $p_{max}$ and $p_i$ dropping – especially when using MDO/10% RME fuel – at simultaneous maintaining the engine's speed and torque load constant. It shows that combustion of the fuel proceeded mildly. Most probably, the combustion proceeded more orderly and less dynamically than in the case of combustion of MDO alone. It can be explained by the greater cetan number of RME relative to that of MDO. The increase of cetan number makes the ignition-lag shorter and the work of the engine „soft" , i.e. at a more moderate increase of combustion pressure. The described probable course of combustion process led to only a small rise of specific fuel consumption.

- The observed , however small, drop of $NO_x$ content seems to confirm the thesis on a more moderate course of combustion process of the fuels containing esters. It may go to show that the maximum combustion temperature was somewhat lower.
- The ambiguous changes of CO content in exhaust gas are difficult to explain in the present phase of the research. It is known that the excess air factor of diesel engines highly varies along with engine's loading. It is favourable that for MDO/RME mixtures CO content in exhaust gas significantly drops at high engine's loads : namely at n = 220 rpm it starts to occur beginning from 75%, and at n = 320 rpm from 70% rated load. It goes to show that the loss due to incomplete combustion appears lower, which indirectly confirms the above formulated theses. This is especially important for ship diesel engines which usually operate under 80÷100% rated load.
- Lack of important differences between values of the maximum fuel injection pressures should be justifed positively, as it shows that a little greater viscosity of RME against that of MDO does not detrimentally influence operation of fuel injectors.
- In the light of the above presented analysis and resulting conclusions it seems reasonable to continue the tests with the MDO/RME mixtures which would have even greater content of the esters.

**NOMENCLATURE**

CO – carbon monoxide
$CO_2$ – carbon dioxide
° CSR – crank angle [deg]
$f_e$ – specific fuel consumption
M – set torque of engine
$M_r$ – rated torque of engine
$NO_x$ – nitrogen oxides
$O_2$ – oxygen
$P_i$(MIP) – mean indicated pressure
$p_{max}$ – maximum combustion pressure
$P_{max,in}$ – maximum fuel injection pressure
TDC – Top Dead Centre of engine piston
$\alpha_{p\ max}$ – angle of $p_{max}$ occurrence – measured as crank angle relative to TDC

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## Conferences

# SemEko 2004

For already three years the SemEko scientific meetings have been organized by Prof. L. Piaseczny, Head of Mechanic-Electric Faculty, Polish Naval University, within the frame of activity of Maritime Technology Unit, Section of Transport Means, Transport Committee, Polish Academy of Sciences.

In the last year two seminars of the kind had place during which the following papers were presented :

- *Camless electro-magnetic timing gear for four-stroke combustion engine* – by K. Zbierski (Łódź University of Technology)
- *Optimization problems of control of piston combustion engines* – by Z. Chłopek (Warsaw University of Technology)

and two papers prepared by J. Pielecha (Poznań University of Technology) :

- *Investigations of emission of noxious components contained in exhaust gas during starting the engine*
- *On possible lowering $NO_x$ emission from diesel engines*.

## Conference

# ZTM Closing the 2004-year activity

On 4 November 2004 members of the Marine Technology Unit (acting within the Transport Technical Means Section, Transport Committee, Polish Academy of Sciences) met in Maritime University of Szczecin to held its plenary scientific session.

During the scientific part of the meeting two papers were presented :

- *Ship routing on oceans* – by B.Wiśniewski (Maritime University of Szczecin)
- *Ultimate strength analysis of ship hull* – by M.Taczała (Technical University of Szczecin)

After discussion on the presented papers the Unit's members adopted the report on the Unit's activity in 2004, presented by Prof. Jerzy Girtler (Gdańsk University of Technology), the Chairman of the Unit, as well as some proposals to the program of the Unit's activities in 2005 were submitted.