

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_T , 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	Content of exhaust gas					Values of selected engine working parameters				
		M/M _r	O ₂	CO	NO _x	CO ₂	p _i	p _{max}	αp _{max}	p _{max.in}	f _c
		%	ppm	ppm	ppm	mg	%	MPa	MPa	°CSR	MPa
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

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

Analysis of the results indicates a noticeable 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 αp_{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_c . However in some cases the changes exceeded the measurement error limits only insignificantly.

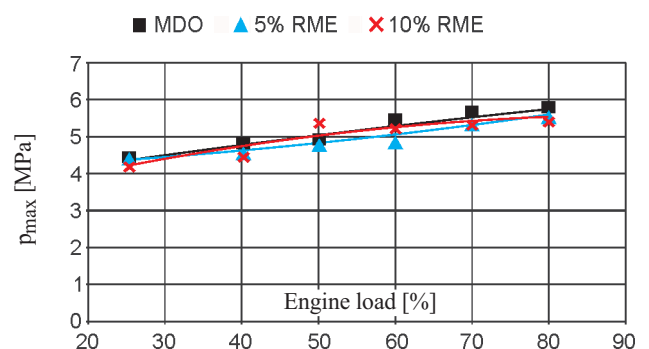
During the tests the course of pressure in the engine's injection system was recorded. Regardless of a kind of fuel, changes of the pressure for both the engine's speed were small. It is not possible to state a.o. any significant influence of the tested fuels on change of the maximum injection pressure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

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

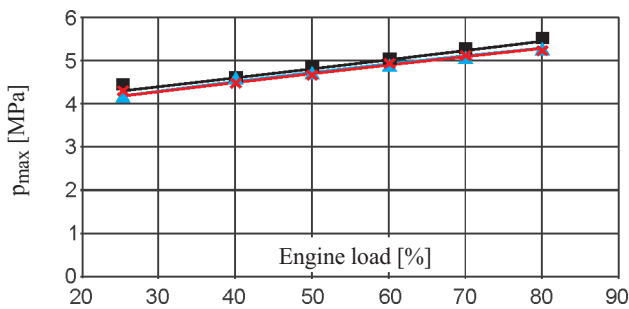
Kind of fuel	Loading level	Content of exhaust gas					Values of selected engine working parameters				
		M/M _r	O ₂	CO	NO _x	CO ₂	p _i	p _{max}	αp _{max}	p _{max.in}	f _c
		%	ppm	ppm	ppm	mg	%	MPa	MPa	°CSR	MPa
MDO	25	17.4	141	288	395	2.6	0.224	4.29	4.5	32.8	384
	40	17.4	121	305	419	2.6	0.284	4.57	6.0	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

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.

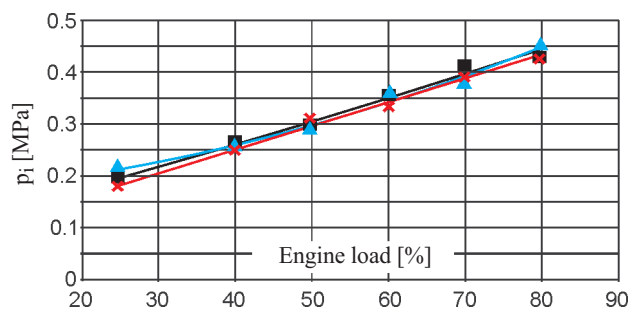
Explanation to Figs 1÷10 :



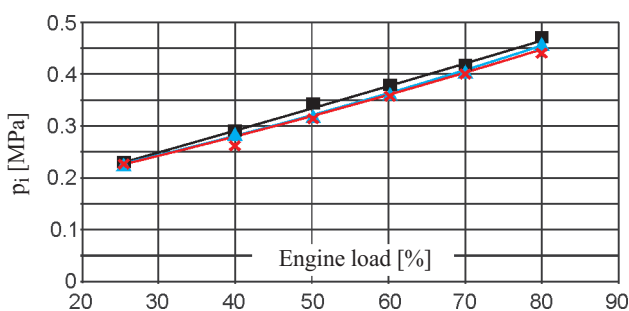
Rys. 1. Maximum combustion pressure p_{max} in function of engine load for different kinds of fuel at constant engine rotational speed $n = 220$ obr/min



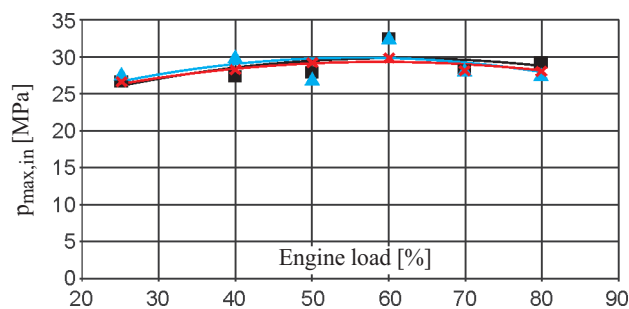
Rys. 2. Maximum combustion pressure p_{max} in function of engine load for different kinds of fuel at constant engine rotational speed $n = 320$ obr/min



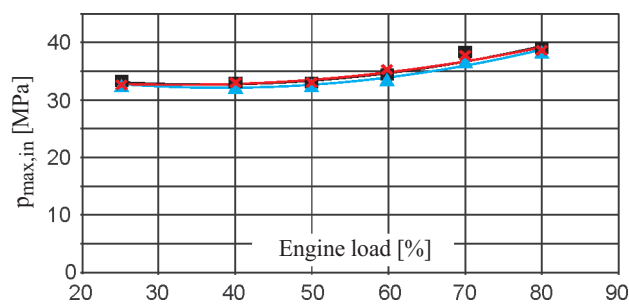
Rys. 3. Maximum mean indicated pressure p_i in function of engine load for different kinds of fuel at constant engine rotational speed $n = 220$ obr/min



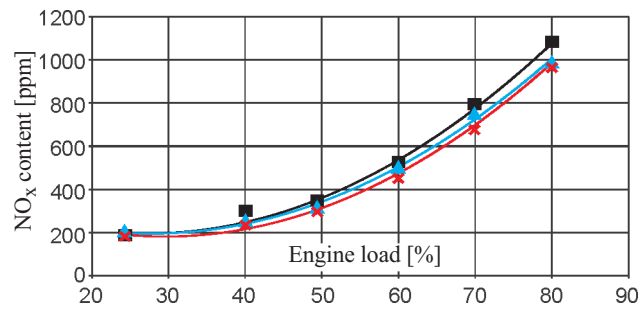
Rys. 4. Maximum mean indicated pressure p_i in function of engine load for different kinds of fuel at constant engine rotational speed $n = 320$ obr/min



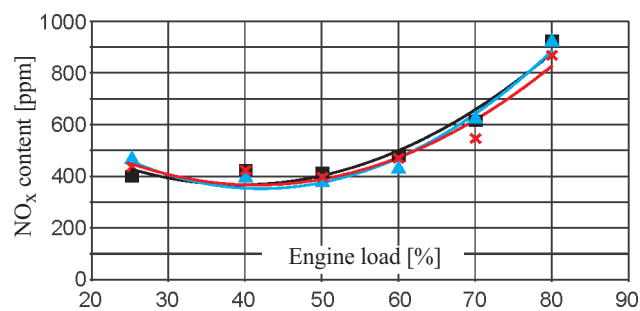
Rys. 5. Maximum fuel injection pressure $p_{max,in}$ in function of engine load for different kinds of fuel at constant engine rotational speed $n = 220$ obr/min



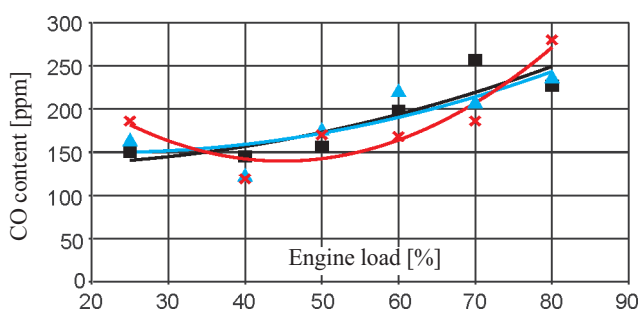
Rys. 6. Maximum fuel injection pressure $p_{max,in}$ in function of engine load for different kinds of fuel at constant engine rotational speed $n = 320$ obr/min



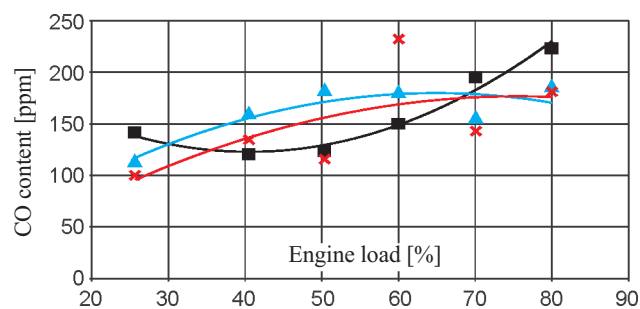
Rys. 7. NO_x content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed $n = 220$ obr/min



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 justified 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
$^\circ \text{CSR}$	– crank angle [deg]
f_c	– specific fuel consumption
M	– set torque of engine

M_r	– rated torque of engine
NO_x	– nitrogen oxides
O_2	– oxygen
$P_i(\text{MIP})$	– mean indicated pressure
p_{max}	– maximum combustion pressure
$P_{\text{max,in}}$	– maximum fuel injection pressure
TDC	– Top Dead Centre of engine piston
$\alpha_{p_{\text{max}}}$	– angle of p_{max} occurrence – measured as crank angle relative to TDC

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C onferences

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.*

C onference

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.