RESEARCH ON POSSIBLE SUPPLYING SHIP DIESEL ENGINES WITH ALTERNATIVE FUELS

Kazimierz Witkowski

Gdynia Maritime University, Mechanical Faculty
Morska Street 83, 81-225 Gdynia
phone: 081 69 01 332
e-mail: wika@am.gdynia.pl

Abstract

The paper presents introduction to the research on possible supplying ship diesel engines with mixtures of diesel oils and vegetable oils or their esters with accounting for ecological aspects – exhaust gas purity. Characteristics of vegetable oils and their esters are compared with those diesel oils.

Consequences of their application to diesel engines, mainly for their working process and exhaust gas content, are indicated. Also, influence of combusting mixtures of diesel oil and vegetable oils or their esters, are discussed in the same context.

The paper presents results of experimental tests which were carried out on a ship diesel engine supplied with marine diesel oil(MDO) and the oil and rape oil methyl esters mixed (MDO/RME) in different proportions (i.e. 5% RME in MDO, 10% RME in MDO and 20% 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. It was paid to influence of combustion of the mixtures of diesel oil and rape oil methyl esters on working parameters of the engine, including noxious components capacity.

Keywords: *tests, combustion, alternative fuel, fuel oils, rape oil methyl esters, exhaust gas content*

1. Introduction

Contemporary main diesel engines of sea-going ships are commonly supplied with heavy oil fuels. This very often concern also auxiliary engines, especially electric generating sets.

However on many ships the electric generating sets are still fed with marine diesel oils (MDO). Also, most of diesel engines installed on small ships are run on MDO. Permanently increasing demand of diesel oils, increase of their prices, increasing ecological requirements make that more and more attention is paid to the alternative fuels called also substitute, renewable or conventional. Another reason of the growing interest to the fuels is the increasing probability of dropping worldwide output of crude oil due to different causes. Moreover the problem of the hazard to natural environment, associated with mining, transport, processing and combusting the oil products are today brought up more and more strongly.

All energy sources other than crude oil products may be deemed unconventional ones [1]. As is results from the diagram presented in Fig.1. there is a wide range of possible media for supplying diesel engines. However today most of the unconventional fuels are not used in practice of operation of diesel engine, including ship engines.

2. Application of vegetable oils for supplying diesel engines

In the northern zone of moderate climate rape oil, flaxseed oil and corn oil are mostly taken into account. In other climatic zones it can be soybean, sunflower, palm, cotton, sesame, peanut or coconut oil. Vegetable oils are esters of glycerol and fatty acids containing from 14 to 22 carbon atoms [5]. In Tab.1.[1] some properties of diesel oil and selected vegetable oils are compared.

Results of research on application of vegetable oils for supplying diesel engines [2-4, 6, 7] show worse cylinder filling, worse spraying, greater lengths of injected oil jets, associated with their large viscosity and density. Engines supplied with rape oil operate with a lower total efficiency mainly due to its lower calorific value in comparison with that of diesel oils, as well as due to worse spraying, process resulting in a longer combustion.

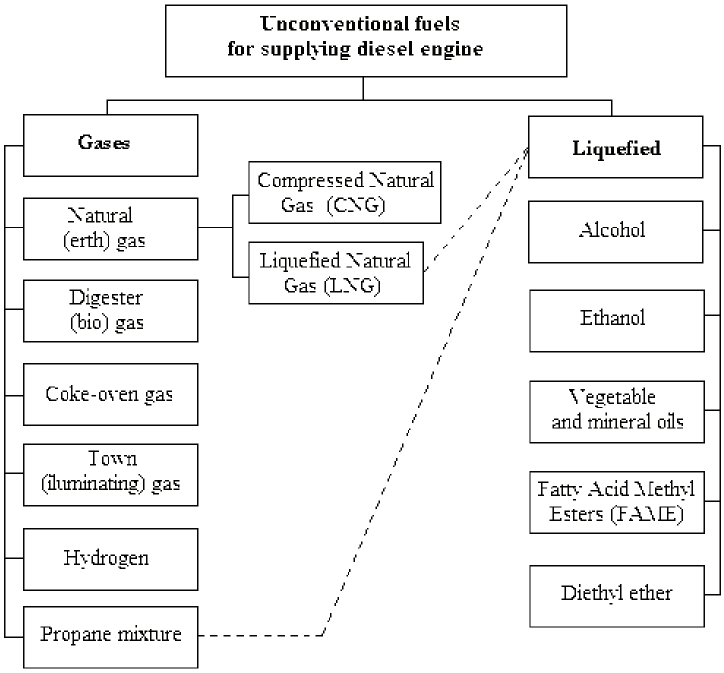

Fig. 1. Scope of unconventional fuels for supplying diesel engines [1]

Tab. 1. Comparison of some properties of diesel oils, vegetable oils and methyl ester of higher fatty acids of rape oil (RME)

Parameter	Unit	Diesel Oils (DO)	Vegetable oils (VO)		Esters (RME)
			Rape oil (RO)	Palm oil (PO)	
Density at 15^{o}C	kg/m^3	820 ÷ 860	920	899	860 ÷ 900
Kinematic viscosity at: - 40^{o}C - 100^{o}C	Mm^2/s	 1.5 - 4.5 0.75	 30.0 - 43.0 8.0 - 8.4	 39.3 8.4	 4.3 - 6.3 ~ 1.8
Cetane number	-	45 - 55	~ 51	~ 51	49 - 56
Gross calorific value	MJ/kg	42 - 45	37.1 - 37.5	37.3	37 - 39
Flow temperature	^{o}C	<-15	-6	38	-5 - -8
C/H/O ratio	% mass	86/14/0	77/12/11	77/12/11	-
Sulphur content	mg/kg	<350	1	<1	10 - 25

According to [1, 7] 20% addition of diesel oil to rape oil made its viscosity dropping by 30% as well as ignition lag period lowering; engine starting features appeared to be improved. In common operational applications small additions of rape oil or RME to diesel oil (e.g. 5% to 20%) are usually reported. Tests on mechanical vehicles running on a 20% RO/80% DO mixture did not reveal any detrimental consequences [7].

Therefore author has decided to carry out investigations on diesel engines supplied with MDO/RME mixtures initially containing no more than 20% of RME. The basic properties of the MDO and RME and their mixtures selected for the experiments are given in Tab.2. Preparation of such mixture is easy as it does not reveal a tendency to separation. However, such mixtures could be less resistant to ageing process hence they should be consumed in a short time.

Tab. 2. The basic properties of the MDO and RME and their mixtures selected for the experimental tests.

Oils	Density kg/m³	Viscosity °E				Viscosity cSt (mm²/s)			
		20°C	50°C	70°C	80°C	20°C	50°C	70°C	80°C
Fidel oil (MDO)	831	1.31	1.11	1.04	1.01	4.2	2.1	1.4	1.1
Rape oil methyl ester (RME)	883	1.79	1.29	1.13	1.12	9.3	4.0	2.3	2.2
95% MDO + 5% RME	833	1.38	1.15	1.08	1.01	4.7	2.5	1.8	1.1
90% MDO + 10% RME	836	1.38	1.14	1.06	1.03	4.9	2.4	1.6	1.3
80% MDO + 20% RME	840	1.37	1.08	1.02	1.01	4.8	1.8	1.2	1.1

3. Laboratory tests – object of tests, test program, results and their analysis.

The tests were carried out with the use of the one-cylinder, two-stroke, crosshead and longitudinal scavenging supercharged by means of Roots blower. 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 investigating exhaust gas content. The test stand block diagram is shown in Fig.2.

To supply the engine during the tests in question the marine diesel oil (MDO) and its mixtures with rape oil esters (RME) of following proportions, were prepared:
- 5% RME in MDO,
- 10% RME in MDO,
- 20% RME in MDO.

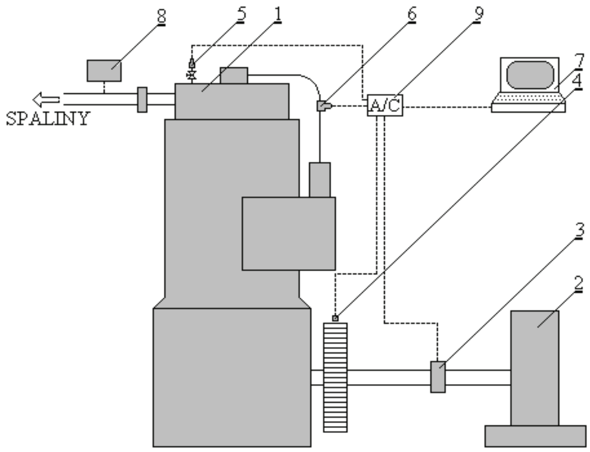

Fig. 2. Test stand block diagram: 1 – L-22 diesel engine, 2 – water brake, 3 – torsiometer, 4 – gauge for crankshaft position marking and rotational speed measuring, 5 – combustion pressure transducer, 6 – injection pressure transducer, 7 – computer, 8- exhaust gas analyzer, 9 – analog/digital converter

The test was 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 at 220 rpm. At the given rotational speed and successively set loads, were realized measurements of the engine's working parameters and exhaust gas content during combusting by the engine: the MDO alone, and the above specified mixtures (i.e. 5% RME in MDO, 10% RME in MDO and 20% 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.

The test results are presented in Tab.3 and changes of values of selected working parameters of the engine, and exhaust gas content are graphically shown in Fig. 3–6 for different loads, 4 kinds of the applied fuels and a given rotational speed set constant.

Tab. 3. Test results – exhaust gas content and values of selected working parameters of the engine In 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_n	O_2	CO	NO_x	NO_x	CO_2	p_i	p_{max}	αp_{max}	$p_{max,in}$	g_e
	%	ppm	ppm	ppm	mg	%	MPa	MPa	°CA	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
95% 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
90%MDON +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
80%MDO +20 % RME	25	19.5	171	167	229	1.0	0.119	4.15	5.0	25.0	424
	40	19.5	164	184	252	1.0	0.186	4.48	6.0	27.4	353
	50	19.4	293	214	294	1.1	0.228	4.85	6.0	27.2	336
	60	19.2	311	253	347	1.3	0.261	5.00	7.0	27.6	319
	70	18.3	299	341	468	1.9	0.314	5.30	6.5	27.7	321
	80	17.2	324	427	586	2.7	0.358	5.45	6.5	28.2	315

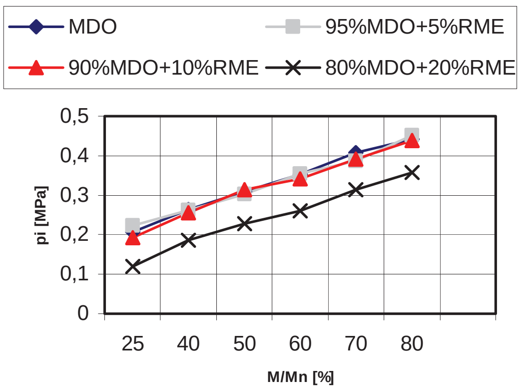

Fig. 3. Mean indicated pressure pi in function of engine load for different kinds of fuel at constant engine rotational speed 220 rpm

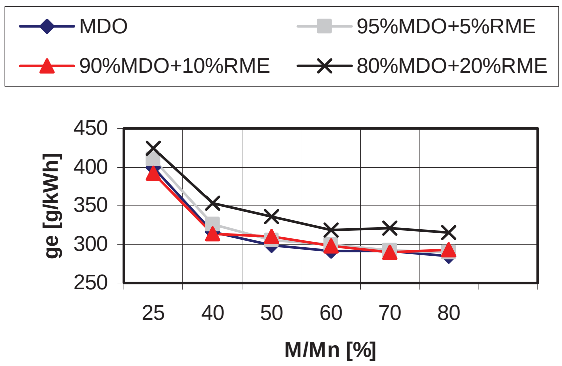

Fig. 4. Specific fuel consumption ge in function of engine load for different kinds of fuel at constant engine rotational speed 220 rpm

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 speed engine (220 rpm) a small drop of the maximum combustion pressure pmax, namely by about 3% only (see Tab.3. – pmax), can be observed. Simultaneously, a small increase of the respective angle of occurrence of pmax, measured from the top dead centre (TDC) of engine's piston (in Tab.3 this is the quantity αpmax), 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 pi drop. A more distinct drop, by about 3% on average, can be observed during running the engine on the mixture (MDO+10% RME) and by about 20% on average, can be observed during running the engine on the mixture (MDO+20% RME) at the engine's speed of 220 rpm (see Fig. 3). The drop of pi resulted also in an increase of the specific fuel oil consumption ge - by about 10% on average, can be observed during running the engine on the mixture (MDO+20% RME) (see Fig.4).

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 Tab. 3 – $p_{max,\ in}$).

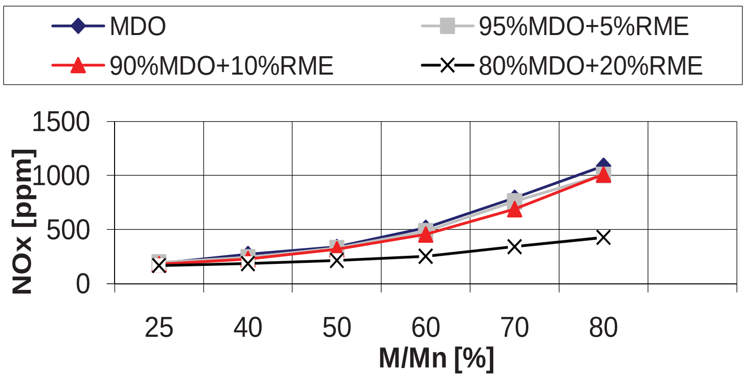

Fig.5. NOx content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed 220 rpm

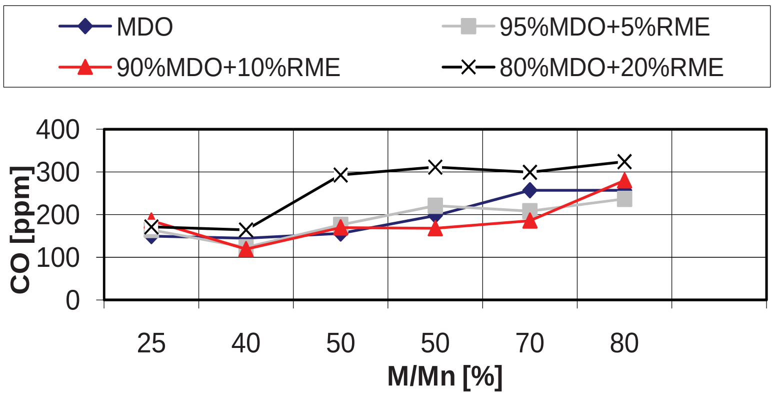

Fig. 6. CO content in exhaust gas in function of engine load for different kinds of fuel at constant engine rotational speed 220 rpm

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 NOx content by over 6%, that during combusting the MDO with 10% addition of RME the drop on average exceeded 8% and that during combusting the MDO with 20% addition of RME the very large drop in nitrogen oxides, particularly for 80% M/Mn (see Fig. 5). However ambiguous are changes of CO content in exhaust gas. As, depending on engine's load, can by observed, both either a distinct increase of

CO content in exhaust gas (combustion of MDO with 20% addition of RME) or a small drop of carbon oxides content in exhaust gas for other combustion mixtures (see Fig. 6).

4. Conclusions

Running the engine on the MDO/RME mixture made the pressures p_{max} and p_i dropping especially when using MDO/20% 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 drop of NOx 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. As, depending on engine's load, can by observed, both either a distinct increase of CO content in exhaust gas (combustion of MDO with 20% addition of RME) or a small drop of carbon oxides content in exhaust gas for other combustion mixtures.

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.

References

[1] Baczewski, K., Kałdoński, T., *Paliwa do silników o zapłonie samoczynnym*, Wydawnictwo Komunikacji i Łaczności, Warszawa 2004.

[2] Bouche, T., Hinz, M., Hieber, D., Tschöke, H., *Einfluß verschiedener Pflanzenöl – Eingeschaften auf Verbrenung und Schadstoffbildung in einen direkteinspritzenden Dieselmotor*, MTZ, Nr 3 (58), 1997.

[3] Cisek, J., *Wpływ oleju rzepakowego i jego mieszanin z olejem napędowym na własności silnika wysokoprężnego*, Praca doktorska. Politechnika Krakowska, 1998.

[4] Cisek, J., Szlachta, Z., *Correlation Between Autoignition Delay and Cetane Number of Rape Fuels at Varied Diesel Engine Work Conditions.* 27st International Scientific Conference on Combustion Engines KONES'2001, Jastrzębia Góra 2001.

[5] Górski, W., Ostaszewski, W., Wiślicki, B., *Krajowe oleje roślinne surowcem dla paliw silnikowych i olejów smarowych.* Paliwa, Oleje i smary w eksploatacji, Nr 90, 2001.

[6] Sagerer, R., *Einsatz regenerativer Brennstoffe im Motor.* MTZ, Nr 11 (57), 1996.

[7] Szlachta, Z., *Zasilanie silników wysokoprężnych paliwami rzepakowymi.* Wydawnictwo Komunikacji i Łączności, Warszawa 2002.