USE OF WATER-FUEL MIXTURE IN DIESEL ENGINES AT FISHING VESSELS

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Abstract:
The paper presents the laboratory test results determining physical parameters of fuel mixture made up of petroleum diesel oil, rapeseed oil methyl esters (up to 20%) and water (up to 2.5%). The obtained parameters prove that adding bio-components (rapeseed oil methyl esters) and water to fuel does not result in deterioration of their physical and chemical properties and are comparable to base fuel parameters, namely petroleum diesel oil. The mixture was a subject of bench testing with the use of a self-ignition engine by means of pre-catalytic fuel treatment. The treatment process consisted in fuel – catalytically active material direct contact on the atomizer body. At the comparable operational parameters for the engine, the obtained exhaust gases opacity was lower up to 60% due to the preliminary fuel mixture treatment in relation to the factory-made fuel injection system using petroleum diesel oil.

Key words: diesel engine, preliminary fuel treatment, water-fuel mixture

INTRODUCTION

Nowadays, it is quite common to use petroleum fuels with bio-components for transportation purposes during summer period. As far as self-ignition engines are concerned it refers to higher fatty acid oils and their esters, which should correspond to the pumping and atomizing conditions and, consequently, to the oxidation processes along with generating both the maximum amount of heat energy and the minimum possible level of toxic compounds emission in exhaust gases (the required parameters for engines in terms of economic and ecological effectiveness). It should be highlighted here that methyl esters have hygroscopic properties, hence the application of water-fuel mixture, where the fuel itself is a mixture of petroleum fuels with higher fatty acid methyl esters, is a certain method to reduce toxic compound emission in exhaust gases.

The goal of the research conducted at the Maritime University of Szczecin is to obtain the highest operational and ecological parameters for self-ignition engines of the Polish fishing fleet due to the application of petroleum fuels and bio-components mixtures, taking into consideration the amount of water during the preliminary catalytic and thermal fuel treatment.

LABORATORY TESTS

For the purpose of the laboratory test, petroleum diesel oil, rapeseed oil and rapeseed oil methyl esters were used (the volume of the bio-components and water is presented in Table 1). The volume of 1.5-2.5% of water in the mixture was decided to be used since such a water volume is in the fuel tanks at the fishing vessels inspected directly when visiting the ship owners. In order to determine the physical and chemical parameters for the water-fuel mixture, an assay was performed under the following norms and standards:

- PN-EN 22719, Determination of flash point; Pensky-Martens closed cup method,
- PN-EN ISO 10370, Determination of carbon residue – Micro method,
- PN-EN ISO 12156-1, Diesel fuel – Assessment of lubricity using the high-frequency reciprocating rig (HFRR) - Part 1: Test method
- PN-ISO 12156-2, Diesel fuel – Assessment of lubricity using the high-frequency reciprocating rig (HFRR) – Part 2: Limit
- PN-EN ISO 12185, Crude petroleum and petroleum products – Determination of density – Oscillating U-tube method
- PN-EN ISO 3104, Determination of kinematic viscosity and calculation of dynamic viscosity
- ISO 8754, Determination of sulfur content, Energy-dispersive X-ray fluorescence method,
- ASTM D 7170-06, Determination of Derived Cetane Number by means of Constant Volume Combustion Chamber,
- PN-83/C-04523/Ap2:2004, Determination of water by distillation.

The following instruments were used to measure fuel physical and chemical parameters – density meter DMA 4500, PMT Tamson capillary viscometers, a micro carbon residue tester MCRT 160 , an instrument to test trybological properties, Horiba X-ray fluorescence sulfur-in-oil analyzer SLFA-2100/2800, meeting the requirements of PN-ISO 8754 and ASTM D 4294, spectrometer Spectroil M of Spectro Inc, USA to determine metal content in fuels, an instrument to determine DCN PAC Cetane ID 510 (combustion chamber of constant volume). The selected laboratory tests results are presented in Table 1.

Table 1
Laboratory tests results

| No. of sampe | Sample composition | | | | HFRR | | | |
| | Diesel fue | Methyl ester | Rapesees oil | Water v/v | Calorific value Qir | Average of the wear scar | Friction coefficient | Lubricant film |
	v/v [%]	v/v [%]	v/v [%]	[%]	[J/g]	diameter [µm]	[-]	[%]
1	100	0			43443	187	0.137	92
2	90	10			43221			
3	85	15			43092			
4	80	20			41409	181.5	0.117	92
5	98.5			1.5	41289			
6	98			2.0	42989			
7	97.5			2.5	42980	220.5	0.145	71
8	88.5	10		1.5	42967			
9	88	10		2.0	41514			
10	87.5	10		2.5	40589	207	0.137	79
11	83.5	15		1.5	41927			
12	83	15		2.0	41155			
13	82.5	15		2.5	40718	325.5	0.132	80
14	78.5	20		1.5	41593			
15	78	20		2.0	41128			
16	77.5	20		2.5	40955	251	0.13	74
17	90		10		42186	215.5	0.129	93
18	88.5		10	1.5	41677			
19	88		10	2.0	41553			
20	87.5		10	2.5	41120			

As the research result, it was concluded that all fuel samples including the bio-components have properties comparable to the properties of the base fuel (petroleum diesel oil). The properties of the tested samples demonstrate that the tested fuel samples may be classified as DMX fuel under ISO-F-8217:2010.

PRELIMINARY FUEL TREATMENT

By the examination of a diesel engine indicator diagram, it may be stated that the basic period, directly affecting economic and ecological parameters for the engine, is a self-ignition delay period, the reduction of which may result in the reduction of both pressure increase degree and maximum temperatures in the combustion chamber when upholding effective work area [2]. The self-ignition delay period depends on the factors such as the pressure and the temperature in the combustion chamber, the rotational frequency of the shaft and the kinematics of the engine and the activation energy amount. It should be noted that when considering the possibilities to improve the economic and ecological operational parameters, both for newly built and the existing engines, it is impractical to change the pressure, temperature and structural parameters. However, one possible effect on the said self-ignition engines' parameters is to reduce the amount of activation energy.

For polyatomic systems (which firstly include hydrocarbon fuels), the activation energy is determined as minimum kinetic energy by which the potential energy of the system should be increased in order to enable chemical reaction to take place. Since the activation energy depends on the particles structure and the strength of chemical bonds [1], an example of a paraffinic hydrocarbons C_nH_{2n+2} reaction is presented hereunder. In the hydrocarbons, bond-dissociation energy for C–H bonds is higher than for C-C bonds. Therefore, along with the increase of the carbon atoms numbers, lower activation energy is needed to cleave the partition. This may be an explanation for high stability of the isooctane C_8H_{18}, used as a base fuel to determine octane number for fuel. In order to enable to overcome the energy barrier related with the activation energy, one may either provide more energy to the environment (e.g. heating) or use a substance that easily react with a substrate (low activation energy), and the new compound is converted into a final product (also low activation energy). The substance, which enables the conversion from substrates to products is a catalyst, which completely reproduces upon the transition process of substrates into products. This implies that the presence of a catalyst is required (e.g. platinum group metals) and its contact with fuel prior to its injection into the combustion chamber.

The presence of a catalyst in the fuel system is justified. The chemical properties of fuels used in diesel engines, where the most numerous are paraffinic hydrocarbons, may be modified due to the dehydrogenation of paraffin. To be exact, in the presence of the catalyst, certain reactions may occur resulting in the transformation of paraffin into olefin hydrocarbons C_nH_{2n} along with the separation of hydrogen molecule. Then, hydrogen, due to a high diffusion coefficient, high ignition capacity and burning rate, and a wide range of mixture flammability limits, conduces to the reduction of self-ignition period in the conditions within the combustion chamber.

As it is well known, catalyst efficiency may be increased by high temperature and turbulent fuel flow along the surfaces where the catalyst is applied [2, 3, 4, 5]. Therefore, it has been suggested to make "preliminary fuel treatment" involving the application of a catalytically active material on the surface of the atomizer needle as the most thermally loaded engine element, while the needle surface itself has to have appropriately located channels allowing for turbu-

lent fuel flow. For the purpose of the primarily fuel treatment, a surface of the needle connecting the precise surface and the closing cone. This solution, both the application of a catalyst (e.g. by electro-spark alloying) and making turbulising channels, does not encounter any technological problems and may be applied in the production process of new atomizers and on already existing ones. An example of an atomizer needle for preliminary fuel treatment is presented in Figure 1.

Fig. 1 Needle and body of fuel injector in a self-ignition engine with preliminary fuel treatment

BENCH TESTS

The bench tests were conducted on a six-cylinder self-ignition engine with a direct fuel injector, 359 type. It is a four-stroke engine of 6.842 dm^3 displacement volume, 17 compression ratio and 110 kW of nominal power. It should be highlighted that engine atomizers are equipped with a long, non-working part of the needle. It is possible to apply on that surface a catalytic material along with a turbulisation system. The term "non-working" part of the needle refers to the needle part which connects the precise elements such as the rail and the closing cone.

The selection of this engine type was non-random, since the structure analysis of the fishing fleet engines had showed that such a combustion chamber and injecting instruments structures is most commonly used in the engines dedicated for fishing vessels. The tests were conducted at the test benches (Fig. 2a) equipped with a set of essential measurement instruments. The main attention was drawn to exhaust gases opacity generated during the combustion process of the water-fuel mixture using the preliminary fuel treatment as this is a parameter that may prove that the fuel is combusted completely in the combustion chamber of a self-ignition engine. For the purpose of the measurement, a MAHA MDO-2 opacimeter with the measurement

accuracy of the absorption coefficient equalled to (k) 0,01 m^{-1} was used (Fig. 2b).
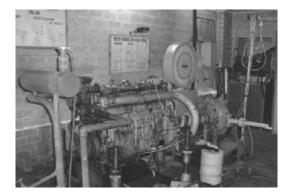
a)

b)

Fig. 2 Test bench with an engine of 359 type (a) and MAHA MDO-2 opacimeter (b)

Figures 3, 4, 5 present the selected tests results of comparative bench tests (in relation to the engine with a factory-made unit of injection instruments supplied with a pure petroleum diesel oil – ON). The results are shown as velocity characteristics for exhaust gases opacity when the engine is supplied with water-fuel mixture with additives (volume fractions) of rapeseed oil (OR), rapeseed oil methyl esters (RME) and water (H_2O).

The bench tests results show a reduction of the exhaust gases opacity in terms of loads when using water-fuel mixture along with preliminary fuel treatment. It refers to the application of both rapeseed oil and its methyl esters in the form of a bio-components mixture. However, when the loads are lower, an increase of water content in the mixture affects more the reduction of exhaust gases opacity.
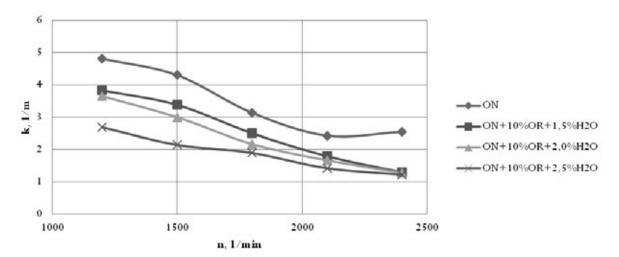

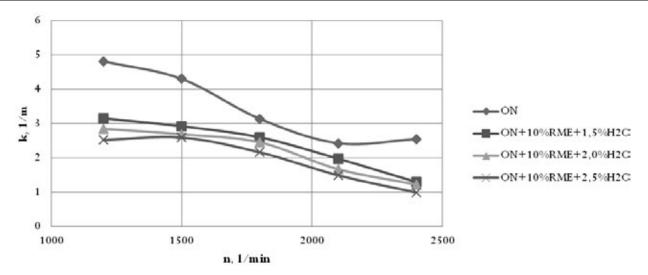**Fig. 3 Exhaust gases opacity when adding 10% OR into the water-fuel mixture**

Fig. 4 Exhaust gases opacity when adding 10% RME into the water-fuel mixture
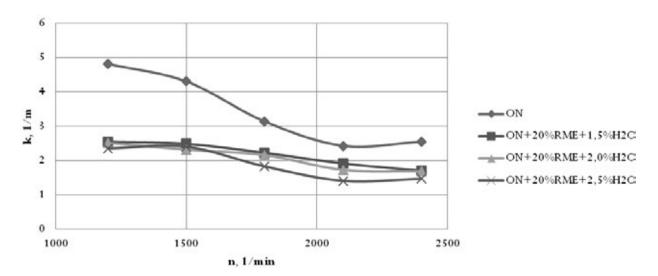

Fig. 5 Exhaust gases opacity when adding 20% RME into the water-fuel mixture

It may be mainly explained by a presence of oxygen molecule in bio-components and by the preliminary fuel treatment, which, apart from the above mentioned catalytic and turbulisation phenomena, may lead to a homogenisation phenomenon. All this allows for the mixture components to be mixed more thoroughly and for the emergence of the dehydrogenation phenomenon, which as a consequence deteriorates the cracking conditions for drops of the injected and combusted fuel, and hence the reduction of exhaust gases opacity.

SUMMARY

On the grounds of the conducted tests, the following conclusions may be drawn:
1. A presence of bio-components in petroleum diesel oil to some extent reduces the calorific value of the mixture. The same refers also to the water content in this mixture.
2. Every sample of water-fuel mixture containing rapeseed oil or rapeseed oil methyl esters has comparable properties to base fuel properties (petroleum diesel oil). The properties of the tested fuel samples may be classified as DMX fuel under ISO-F-8217:2010.

3. The bench tests, conducted on the self-ignition engine with direct fuel injector, showed that by preliminary fuel treatment consisting in direct fuel-catalyst material contact at turbulent flow in an injector body, at comparable values of engine operational parameters, exhaust gases opacity is reduced (absorption coefficient k) in the entire velocity characteristics of the engine.
4. It is advisable to continue research in that direction using a mixture of petroleum fuels and synthetic fuels, and determining an impact of preliminary fuel treatment on the emission volume of nitric oxides and carbon oxides in exhaust gases from self-ignition engines.

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