The Effect and Comparison of Biodiesel-Diesel Fuel on Crankcase Oil, Diesel Engine Performance and Emissions

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Biodiesel is an alternative fuel for Diesel engines made from new/used vegetable oils and animal fats. It is bio-degradable and has lower hydrocarbon emission levels and similar performance characteristics compared to conventional Diesel fuel. After modifying its molecular structure through a transesterification process, biodiesel (rapeseed oil methyl ester – RME) can be used as an alternative fuel in compression ignition engines without any modification. Modern internal combustion engines must have longer oil drain periods to decrease operating costs and environmental pollution levels. Related studies indicate that biodiesel fuel has a potential for reducing engine wear. This experimental study investigates the effect of commercial Diesel fuel and RME on lubricating oil performance and the exhaust emissions. Performance, emissions and long-term wear tests were carried out and discussed on a single cylinder marine Diesel engine for both Diesel fuel and 100 % RME. Results indicated that the RME has a deteriorating effect on lubricating oil performance by decreasing oil viscosity degree and base number. Ferrous element is the main evidence of the engine wear and it was increased depending on lowering viscosity relating to the fuel dilution and rising running period. Although carbon monoxide and hydrocarbon pollutants in exhaust gas decreased with RME, nitric oxides raised significantly as well as performance results which remained similar except for specific fuel consumption.

Keywords: *biodiesel, lubrication oil, wear elements, exhaust emissions.*

1. INTRODUCTION

Internal combustion engines are the pioneer energy conversion machines. The idea of operating compression ignition (Diesel) engine with a renewable source of energy can contribute to solution of environmental problems and operation costs [1].

Vegetable oils are promising alternative energy sources for compression ignition engines depending on their high heat content and similar combustion related properties with respect to Diesel fuel. Although vegetable oils create various long-term problems in engine components and wear such as ring sticking, injector and combustion chamber cooking and forming deposits, insufficient atomization, lubricating oil dilution. Vegetable oil viscosity is significantly higher than Diesel fuel, also volatility and molecular structure different from Diesel fuel [2-5]. Fatty acid methyl esters can be produced by modifying the molecular structure of straight vegetable oils, edible and non-edible, recycled waste vegetable oils and animal fat which is commonly called biodiesel. Chemical processes such as transesterification, supercritical, catalyst-free process etc. can be applied to vegetable oils to change their fluid properties [6-8]. Biodiesel does not require any changes in the fuel distribution infrastructure and can be used as blends with petro-Diesel or neat (100 %) form. EN 14214 and ASTM D6751 standards are described specifications of biodiesel fuel.

The heating value of biodiesel is lower (approx. 10 %) than conventional Diesel fuel that results in higher brake specific fuel consumption (BSFC). Harmful emissions from combustion of Diesel fuel are tending to decrease with biodiesel. The nitric oxide (NO_x) emissions are increasing because of advancing phenomenon of the injection start that originates from the physical properties of the biodiesel. The total hydrocarbon (THC) and carbon monoxide (CO) emissions are tending to decrease because of the oxygen content and the enhanced cetane number of biodiesel fuel which helps for a more complete combustion [9-14].

Engine lubricating oil is designed to: facilitate enough oil film layer between sliding surfaces, protect engine parts from corrosion, transfer the combustion heat from surfaces and reduce total wear and friction of the engine. Wear of the engine parts is the main limiter of the lifetime of an engine. One can easily indicates the wear rate of engine with determining presence of a metallic element in a used oil sample by using appropriate technique, for instance, atomic absorption spectrometry. However, a certain amount of wear metals (also known as trace metals) in used oil is expected because of normal engine wear. In every internal combustion engine, there will be a certain amount of

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unburned fuel or the products from complete and incomplete combustion of fuel that passes through the piston rings and cylinder finally goes into the lubricating oil. Abnormal fuel dilution in engine oil which is the evidence of fuel delivery system malfunction that results in thinning of oil, also small amount of fuel dilution increase oxidation, and hence oil viscosity increases more than normal rates. Biodiesel requires approx. 50 °C higher temperature to vaporize when compared to equal mass of Diesel fuel, so evaporation of biodiesel fuel in engine oil is relatively small [4].

The aim of this study is to investigate the effect of biodiesel on engine performance, exhaust emissions and wear. An experimental performance and durability tests were carried out on a single cylinder Diesel engine. EN590 convenient Diesel fuel and EN14214 convenient rapeseed methyl ester were used as fuels.

2. EXPERIMENTAL SETUP

The tests were carried out on a single cylinder, four strokes, swirl chamber, air cooled marine type Diesel engine. Table 1 shows engine specifications and Figure 1 shows the scheme and image of test bench.

Table 1. Technical specifications of test engine

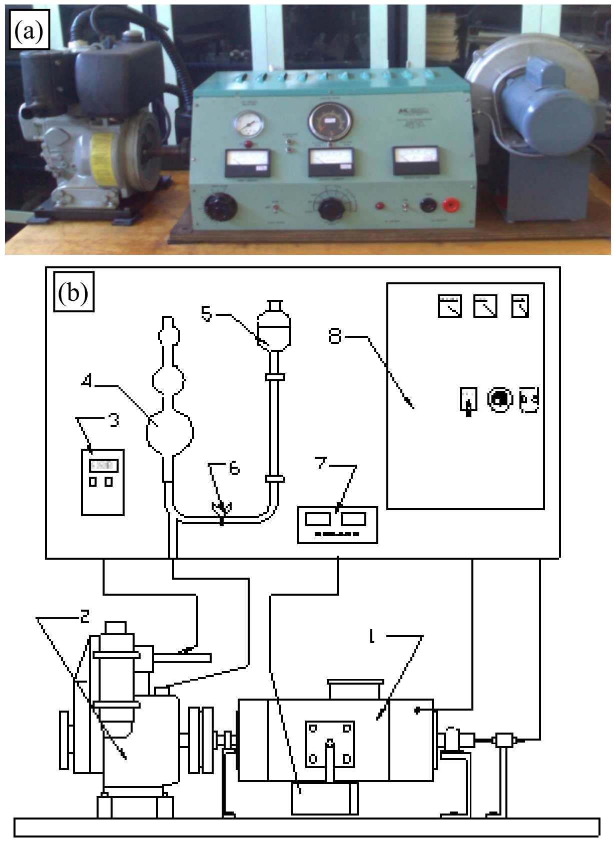
Engine manufacturer	Hatz Diesel Co. Germany
Model	E673 LHK
Type	4-stroke air-cooled Diesel
Aspiration	naturally aspirated
Number of cylinders	1
Bore x stroke [mm]	73 × 67
Cylinder volume [cm^3]	280
Compression ratio	19:1
Lub. oil capacity max/min [l]	1.0 / 0.35
Speed range min – max [rpm]	1000 – 3300
Fuel injection pressure [bar]	134
Rated power DIN ISO 3046 [kW]	4

Test bench was manufactured by Megatech Corporation and model description is MEG310 [15]. Performance and emissions test were performed via varying the load from control panel. During long-term durability tests, engine operated at 1910 rpm corresponding to approx. 85 % of full load. This load point was determined by considering the stable operation of engine. Engine test conditions are shown in Table 2.

Table 2. Engine test conditions

Speed [rev/min]	1910
Load [%]	86
Lubricating oil temprature [°C]	87
Ambient temprature [°C]	24
Duration [h]	150

An EN14214 convenient rapeseed methyl ester (RME) and EN590 mineral Diesel fuel used as test fuels, specifications of both fuels are shown in Tables 3 and 4. Infrared method was implemented to measure exhaust gas emissions, Bilsa Ltd. Company MOD2210 type of gas analyzer is used for this purpose [5]. Smoke measurements were made with Bosch BEA 370 smoke meter.



1 – Dynamometer; 2 – Test engine; 3 – Thermometer; 4 – Flowmeter; 5 – Fuel tank; 6 – Fuel line; 7 – Field voltage and current monitor; 8 – Control panel

Figure 1. (a) engine test rig and (b) scheme of test bench

Two main types of tests were applied; these are performance tests (including emissions tests) and engine durability tests. Both tests were employed for neat biodiesel (B100) which was produced from rapeseed methyl ester (RME) and mineral Diesel fuel (D). Durability tests consist of 150 hours of operation for each test fuel. Specifications of lubricating oil are listed in Table 5.

Test engine was dismantled and cleaned before each test. The first durability test was carried out with Diesel fuel. After 150 hours of operation with Diesel fuel, the lubricant and the oil filter were replaced with the new one, and then engine operated with B100 for 150 hours. Lubricating oil samples were drawn from the engine crankcase with equal intervals of 25 hours. Total crankcase oil quantity was decreased by 100 ml for every sampling period and any top-up was not added. Then samples were analyzed by Total company test laboratories.

3. RESULTS

3.1 Performance and emission test results

According to performance test results in Figure 2 the RME showed similar performance with respect to Diesel fuel but BSFC is increased by 6 %.

Table 3. Specifications of rapeseed oil methyl ester

Specification	Result	Method	Min	Max	Unit
Ester content	99.3	EN14103	96.5		% (m/m)
Specific gravity at 15 °C	882	EN ISO 12185	860	900	kg/m^3
Viscosity at 40 °C	4.83	EN ISO 3104	3.5	5	mm^2/s
Flash point	178.5	EN ISO 3679	120		°C
Cold filter plug. point	– 15	EN 116			°C
Sulphur content	7.46	EN ISO 20884		10	mg/kg
Carbon residue (% 10)	0.25	EN ISO 10370		0.3	% (m/m)
Cetan index	53	EN ISO 5165	51		
Sulfated ash content	0.01	ISO 3987		0.02	% (m/m)
Water content	51	EN ISO 12937		500	mg/kg
Total contamination	18	EN 12662		24	mg/kg
Copper strip corrosion	1a	EN ISO 2160	Class 1		
Oxid. stab. at 110 °C	11	EN 14112	6		h
Acid value	0.19	EN 14104		0.5	mgKOH/g
Iodine number	109	EN 14111		120	gIodine/100 g
Linolenic acid methyl ester	7.6	EN 14103		12	% (m/m)
Methanol content	< 0.01	EN 14110		0.2	% (m/m)
Free glycerol	0	EN 14105		0.02	% (m/m)
Monoglyceride content	0.42			0.8	% (m/m)
Diglyceride content	0			0.2	% (m/m)
Triglyceride content	0.01			0.2	% (m/m)
Total glycerol	0.11			0.25	% (m/m)
Phosphorus content	0.5	EN 14107		10	mg/kg
Alkaline metals I (Na+Ka)	< 1.5	EN 14108		5	mg/kg
Metals II (Ca+Mg)	1.8	EN 12662		5	mg/kg

Table 4. Specifications of mineral Diesel fuel

Specification	Result	Method	Min	Max	Unit
Density at 15 °C	838	ASTM D 4052	820	845	kg/m^3
Flash point	66	ASTM D 93	55		°C
Water content	98	ASTM D 6304		200	mg/kg
Sulphur content	1471	ASTM D 2622		7000	mg/kg
Copper strip corrosion	1a	ASTM D 130	Class1		3 h, 50 °C
Cetan index	51.4	ASTM D 4737	46		calc.
Viscosity at 40 °C	2.812	ASTM D 445	2.0	4.5	mm^2/s

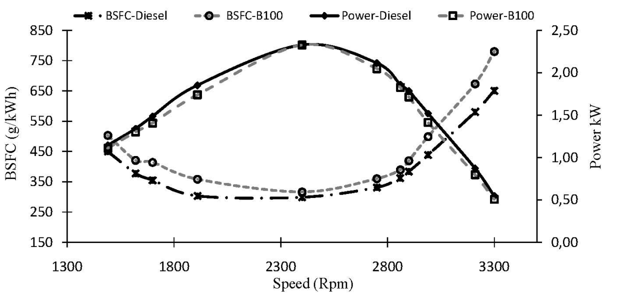


Figure 2. Diesel and RME power and brake specific fuel consumption curves as a function of the engine speed

Table 5. Specifications of lubricating oil

Specification	Initial values
SAE Grade	SAE 10W-40
API service class	API CF, ACEA E4/E7
TBN	15.6 mgKOH/g
Viscosity at 40 °C	85.6 mm^2/s
Viscosity at 100 °C	13.1 mm^2/s
Viscosity index	113
Flash point	224 °C
Pour Point	– 33 °C
Specific gravity at 15 °C	0.871 g/cm^3
Glycol content	0 ppm
Water content	0 ppm

The CO and THC emission results are shown in Figures 3 and 4, unburned hydrocarbon emission of RME was lower than Diesel fuel but difference between them varied with engine speed. The CO emission behaviour of the engine was similar to the THC emission.

The RME increased NO_x emissions significantly when compared to Diesel fuel, as it is shown in Figure 5. The RME exhaust NO_x quantity almost double Diesel exhaust at high loads. Smoke opacity trend of RME is opposite to the NO_x which is lower than Diesel fuel. Also, smoke opacity and NO_x showed different variation with load, the difference obtained from smoke opacity measurements at high load is proportionally smaller than NO_x emission difference.

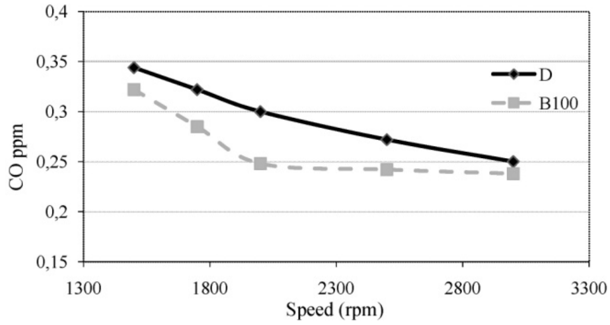


Figure 3. CO emission variation as a function of the engine speed

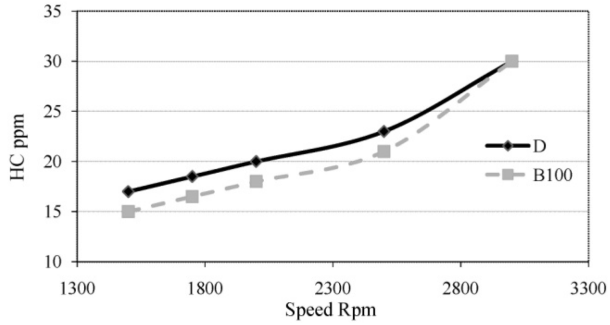


Figure 4. Total HC emission variation as a function of the engine speed

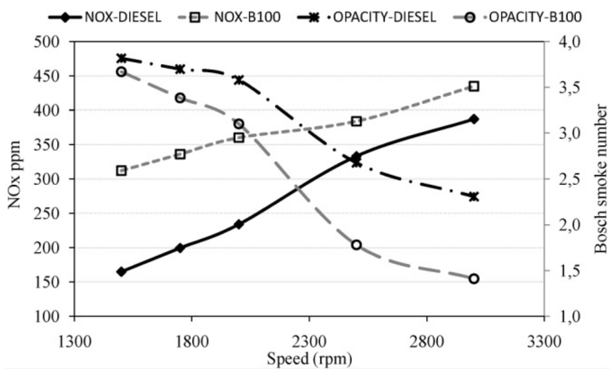


Figure 5. NO_x emissions and smoke opacity variation as a function of the engine speed

3.2 Durability test results

After engine run during 150 h period for each fuel at certain load, total wear element data collected from engine oil is shown in Figure 6 according to Table 6.

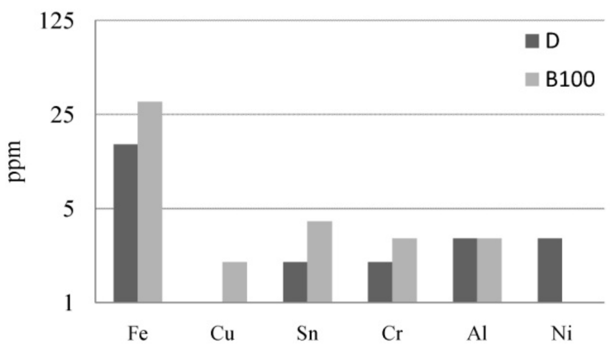


Figure 6. Quantity of trace metals in used lubricating oil after 150 hours engine operation

According to Figure 6, iron concentration raised from 15 ppm to 31 ppm with RME fuel although aluminium metal concentrations are at equal quantities at the end of the test. On the other hand, lead element quantities in wear debris were very small and neglected. The RME fuelled test oil were containing higher copper, tin and chromium.

Table 6. Wear metals results of used lubricating oil

Element [ppm]	Fe		Al		Cu		Ni		Sn		Cr	
Operating hour	D	B 10 0	D	B 100	D	B 100	D	B 100	D	B 100	D	B 100
0	2	2	1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
25	8	11	3	6	< 1	< 1	2	< 1	< 1	2	< 1	< 1
50	10	20	3	4	< 1	1	1	< 1	< 1	3	< 1	1
75	12	21	2	9	< 1	1	3	< 1	< 1	3	1	2
100	10	25	5	7	< 1	2	3	< 1	< 1	3	1	2
125	12	27	3	4	< 1	2	3	< 1	2	4	2	2
150	15	31	3	3	< 1	2	3	< 1	2	4	2	3

Figure 7 shows the TBN values of used oil as a function of time at the end of RME and Diesel fuel durability tests. The TBN reduced with increasing engine operation time also the RME fuelled test results showed dramatic decrease with respect to Diesel fuelled test.

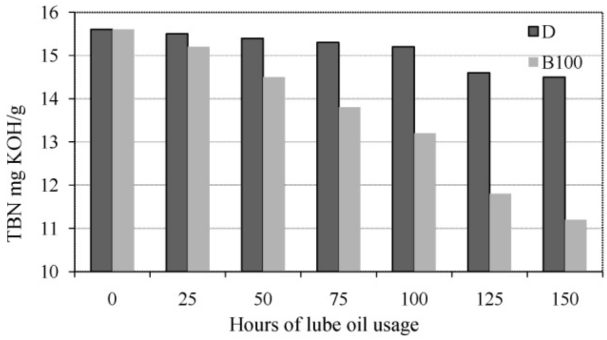


Figure 7. Total base number of used lubricating oil as a function of operating time

Figure 8 shows the TAN variation in used lubricating oil as a function of time. Diesel fuel showed considerably lower test results than the RME test.

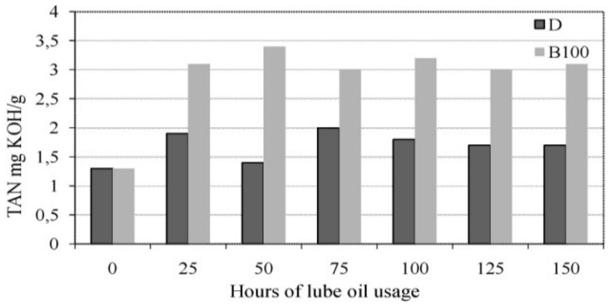


Figure 8. Total acid number of used lubricating oil as a function of operating time

Fuel dilution in used engine lubricant is shown in Figure 9. Dilution percentage of biodiesel in the engine oil reached 3.5 % at the end of the 150 hours of test period, while Diesel test results remained below the measuring range of the analyzer.

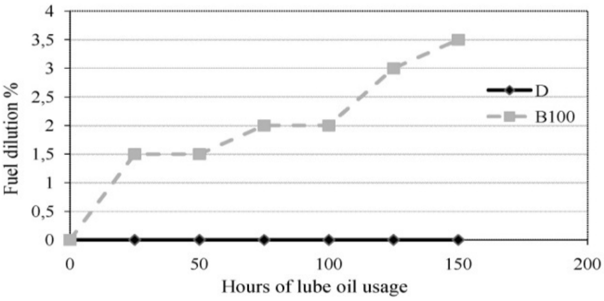


Figure 9. Total percentage of fuel in used lubricating oil as a function of operating time

Measured viscosities of used lubricating oils are shown in Figure 10. Viscosity of oil decreased to the half of the initial value at the end of the RME.

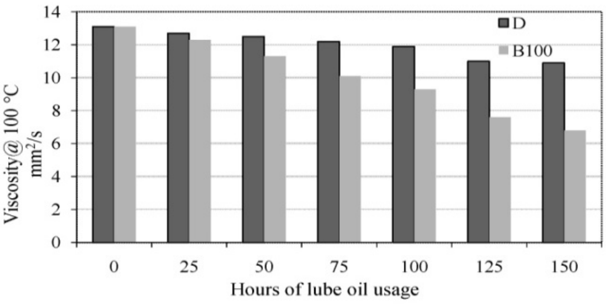


Figure 10. Viscosity of used lubricating oil as a function of operating time

4. DISCUSSIONS

Performance test results indicate that the maximum power obtained from biodiesel is almost equal to Diesel fuel. Although power results of biodiesel varied with engine speed, the results are lower than Diesel fuel by approx. 2 – 9 %. Higher BSFC results of biodiesel shown in Figure 2, indicate more fuel injection quantity per cycle compared to Diesel fuel. This can be related to the heating value of Diesel fuel [12]. Even the test engine was set to constant maximum throttle position; inline fuel injection pump injects more RME than Diesel fuel. This phenomenon can be explained by the specific gravity difference between fuels and pump volumetric efficiency variation. Plunger begins to vaporize the residual fuel in the chamber of pump cylinder when it ends the pumping stroke, lower biodiesel evaporation in pump cylinder surface results in higher volumetric efficiency of fuel injection pump, hence an increase of the injected fuel quantity. This situation can be related to higher distillation temperature curve of biodiesel [4].

The CO and THC emissions depend on combustion quality of the engine. Lower THC and CO emissions of biodiesel are in harmony with aforementioned studies [10-12]. Soot particles form as combustion products produced by the pyrolysis reaction at high gas temperatures. Formed soot particles can partially or completely oxidize by ambient oxygen. By operating of the engine with an oxygenated fuel, such as biodiesel, one can predict the reduced smoke opacity. In Figure 5 the smoke opacity of the engine decreased significantly with the RME and varied with load.

Nitrogen-oxide results showed increasing trend when utilizing RME fuel which, is in harmony with Labeckas and Slavinskas who determined that increasing the mass percent of fuel oxygen, increases the NO_x emissions [9]. Boehman and co-workers investigated the NO_x emissions of Diesel fuel, soy-derived biodiesel and GTL. The authors related higher NO_x emissions of biodiesel to higher bulk moduli of biodiesel fuel (nearly 11 %), which results in early injection than conventional Diesel fuel. The fuel injection timing advanced with increased biodiesel content, hence NO_x emissions of biodiesel, resulted in higher values [16].

Piston, piston ring, cylinder liner, bearings, crankshaft, cam, and tappet and valves, valve seats normally wear during operation of the engine. Analyzing the trace metals (Fe, Cr, Cu and Pb) in engine lubricant, sufficient wear data can be collected to estimate overall engine condition. Also, this method gives good information about lube oil condition; additive amount of aged oil can monitor the affectivity of oil. The wear elements can be related to engine parts, such as: iron reflects the cylinder liners, piston rings valves and gear wear, aluminium reflects piston wear, lead and copper and tin reflects bearings and bushing wear, lead reflects bearing wear and finally chromium and nickel reflect piston ring wear [17].

Earlier injection phenomenon and higher distillation temperatures can increase wall impingement of biodiesel [4,16]. On the other hand, deposit formation on nozzle affect injection parameters. Pehan et al. [18] investigated the effect of the RME utilization on the injection system lubrication and injector discharge coefficient of a six cylinder DI Diesel engine. The discharge coefficient of biodiesel injected used injectors decreased at the end of test sequence. Fraer and co-workers [19] examined the wear and durability analysis with B20 fuel in two different types of engines. Authors reported that injector nozzles of first type of engine were not within specified limits with the biodiesel blend and a replacement was required.

Excessive iron wear, TBN decrease and TAN increase occurred with biodiesel utilization. These results point out the fuel dilution of lubricating oil, as shown in Figure 9. Fuel dilution is in harmony with Baumann and Hubmann [20] who carried out long-term tests with two stationary engines and rapeseed oil methyl ester as fuel. The content of unburned fuel in the engine oil was increased up to 8 % and 10 % during the test period of 1000 hours [21].

5. CONCLUSIONS

The following conclusions may be drawn from the present study:

- Rapeseed methyl ester showed similar performance results with respect to Diesel fuel. However BSFC of engine increased 6 %;
- Rapeseed methyl ester decreased the CO, THC emissions and smoke opacity of exhaust gas while NO_x emissions increased significantly;

- After 150 hours of durability test the RME fuel affected the lubricating oil which aged faster than Diesel fuel. When compared to Diesel results, viscosity and TBN results lowered 60 % and 29 % respectively with biodiesel;
- Iron content increased by more than 100 % when using the RME fuel instead of Diesel fuel. Also engine oil diluted 3.5 % of biodiesel, while no fuel dilution was found with Diesel fuel.

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NOMENCLATURE

B100	neat biodiesel
BSFC	brake specific fuel consumption
CO	carbon monoxide
D	diesel fuel
DI	direct injection
NO_x	nitric oxides
RME	rapeseed methyl ester
TAN	total acid number
TBN	total base number
THC	total hydrocarbon

ПОРЕЂЕЊЕ И УТИЦАЈ БИОДИЗЕЛ И ДИЗЕЛ ГОРИВА НА УЉЕ ЗА ПОДМАЗИВАЊЕ РАДИЛИЦЕ, ПЕРФОРМАНСЕ ДИЗЕЛ МОТОРА И ЕМИСИЈУ ИЗДУВНИХ ГАСОВА

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Биодизел је алтернативно гориво за дизел моторе које се производи од нових или употребљаваних биљних уља и животињских масти. Биодизел је биоразградиво гориво, има мању емисију угљоводоника и даје перформансе сличне конвенционалном дизел гориву. Пошто се изврши промена молекулске структуре процесом трансестерификације, биодизел (метилестер уља уљане репице – PME) може да се користи без модификације као алтернативно гориво за дизел моторе. Савремени мотори СУС морају да имају дужи период замене уља да би се смањили трошкови и загађивање околине. Истраживања показују да биодизел гориво може да смањи хабање мотора. Овај експериментални рад истражује утицај комерцијалног дизел горива и PME на перформансе уља за подмазивање и емисију издувних гасова. Испитивања дизел горива и 100 % PME извршена су на једноцилиндричном бродском дизел мотору, при чему су испитиване перформансе, емисија издувних гасова и хабање током продуженог дуготрајног рада мотора. Резултати показују да PME има неповољан утицај на перформансе уља за подмазивање, јер смањује његову вискозност и базни број. Присуство гвожђа је главни доказ хабања мотора и оно се повећавало са смањењем вискозности, услед разређивања уља горивом, и са временом рада мотора. Количина штетних материја, угљенмоноксида и угљоводоника, у издувним гасовима су се смањиле са коришћењем PME али су се оксиди азота значајно повећали. Резултати перформанси су остали слични, осим потрошње горива.