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INFLUENCE OF BIODIESEL FUELS ON LUBRICITY OF PASSENGER CAR DIESEL ENGINE OILS

Abstract
The present paper will mainly focus on the physical and chemical impact of currently used and future biodiesel components on the performance of a typical low- sulfated-ash-phosphorus-sulfur (low SAPS) passenger car engine oil. Beside a current fatty acid methyl ester (FAME), a next generation hydrotreated vegetable oil (HVO) is also investigated as a biogenic fuel blend component. In a representative modern four-cylinder diesel engine test runs with different biodiesel containing fuels were combined with diesel particulate filter regeneration to reach high loads and stresses on the engine oil. The samples of used engine oils were characterized and compared after the engine test runs.

1. Introduction

Nowadays, the modern passenger car diesel engines are equipped with an adequate exhaust after-treatment system to meet the requirements of emission limits. The most common after-treatment system is a combination of diesel particulate filter regeneration realized by post-injection. Due to post-injection procedure the fuel and its combustion derivates can penetrate to the engine oil sump through the cylinder wall and the piston rings. Depending on their sort, blend apart and quality of used (bio-)diesel components and their degradation products, this dilution can seriously affect the functionality and performance of state-of-art engine oils.

2. Test Engine

The test engine is a modern 4-cylinder passenger car diesel engine. The maximum injection pressure of 1800 bar is reached with a common rail injection system. The designated oil capacity of the engine is 3,6 liter. The test engine also utilizes variable exhaust gas recirculation (EGR) with EGR cooling and a variable turbine geometry (VTG) turbocharger. For the test procedure an oxidation catalyst and a diesel particulate filter (DPF) are used (Figure 1).

The conventional DPF regeneration is realized by post injection after exceedance of a specific difference pressure generated by accumulated particulate matter (PM). To burn accumulated PM in the DPF it is necessary to increase the DPF inlet temperature to about 600 °C. The exhaust gas temperature is reached by post injection. Due to post injection, a high concentration of unburned fuel can reach the oxidation catalyst and increase the DPF inlet temperature to the necessary regeneration temperature. Due to post injection, the fuel is diluting the engine oil through the cylinder wall and the piston rings. The DPF regeneration is realized by manipulation of the engine control unit (ECU). The regeneration time for these tests takes about 20 minutes.

Displacement	1970	cm³
Maximum Power at 4000 rpm	103	kW
Maximum Torque at 1750 rpm	320	Nm
Compression Ratio	16,5	-
Cylinder	4	-
Bore	80,99	mm
Stroke	95,5	mm

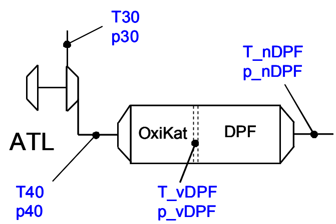


Figure1: Engine specification and exhaust gas after-treatment system with oxidation catalyst and diesel particulate filter.

3. Test Fuels

Different composition of the hydrocarbons in the conventional diesel is leading to a wide boiling area. The chemical composition of the different hydrocarbons, determine the qualities of the fuel as for example lower heat value, density, cetane number and boiling curve. When comparing conventional diesel with FAME, the disadvantage of FAME becomes obvious: FAME has almost one boiling point, not a well rising boiling curve. An increasing boiling curve is beneficial for a good fuel ignition and combustion in the cylinder. Hydrotreated vegetable oil (HVO) a narrow boiling area should be observed. Hydrotreated vegetable oil exists of straight chain paraffinic hydrocarbons that are free of aromatics, oxygen and sulfur, thereby it shows a narrow boiling range (Figure 2).

Table 1 shows the compositions and the essential properties of the tested fuels. As a reference fuel a CEC diesel according to EN590 is used. B30 consist of 30% FAME and 70% CEC EN590. The third test fuel B5X25 contains 5% FAME, 25% HVO and 70% CEC EN590. It can be seen that HVO has several favorable properties, including a high heat value, and consist of no aromatic and oxygen hydrocarbons. The cetane number of HVO is typically high. HVO meets the conventional diesel fuel requirement (EN590), except for low limit of density. In order to prevent the critical density (820 kg/m^3) according to EN590 the amount of the HVO should not be higher than 25%.

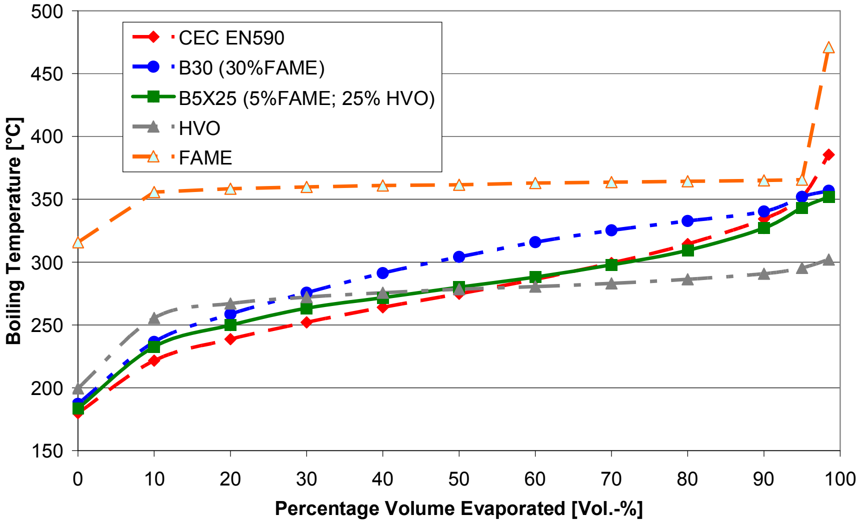


Figure 2: Distillation curves of the test fuels, HVO and FAME

Table 1: Characterisation of the test fuels, HVO and FAME

Fuel Characteristics	Reference Fuel	Test Fuels		Fuel Components	
	CEC EN590	B 30	B5X25	FAME	HVO
Density (15°C) [kg/m^3]	836.2	849.4	824.5	883.5	778.5
Initial boiling point [°C]	179.9	187.2	183.7	315.8	199.5
Final boiling point [°C]	385.5	356.8	351.9	471.0	302.1
Cetane number [-]	54.0	53.2	60.0	53.1	>75
C [% m/m]	86.4	83.5	85.5		84.9
H [% m/m]	13.3	13.5	14.0		15.0
Oxygen [%]	<0.1	3.3	0.6		<0.1
Heating value [MJ/kg]	42.9	41.1	42.8		43.8
Heating value [MJ/dm^3]	35.9	34.9	35.3		34.1
Total aromatic hydrocarbons [% m/m]	24.3	16.7	17.4		0.1

4. Test Engine Oil

The used low SAPS engine oil is a synthetic passenger car engine oil, specially designed for engines with diesel particulate filter, meeting the specifications ACEA A3/B4 and VW 504 00 / 507 00. It belongs to the viscosity class SAE 5W-30. The typical properties of the test engine oil are presented in Table 2.

Table: Typical properties of the test engine oil

Oil properties	Values	Unit
Density at 15 °C	850	kg/m^3
Flash point COC	231	°C
Viscosity Grade	5W-30	SAE
Viscosity at 40 °C	70.80	mm^2/s
Viscosity at 100 °C	11.60	mm^2/s
Viscosity index	160	-
CCS at -30 °C	6277	mPa.s
Pour Point	<-39	°C
Sulfated Ash	0.80	%wt
Sulfur content	2200	mg/kg
Phosphor content	750	mg/kg

5. Test Procedure

To outline the impact of the given fuel qualities on engine oil performance, the engine test cycles included a combination of diesel particulate filter regenerations and high load endurance test runs. During the test procedure 12 DPF regenerations were initiated. The overall test procedure took about 50 hours per test fuel. Samples were taken before and after DPF regeneration.

6. Results and Discussion

An irreversible oil dilution appeared in the engine oil sump, as a result of DPF regeneration. The cause of these is the higher boiling range and distinguishing distillation characteristics of biodiesel blends compared to the conventional diesel fuel (Figure 3). Hence, it comes with the endurance test with B30 to an oil dilution of about 11 percent. The dilution level of the reference fuel CEC lies with approximately 5 percent lower. By the substitution of FAME with HVO the oil dilution is reduced to about 8 percent. The explanation is the lower boiling range of synthetic bio-fuel compared to FAME. Due to the oil refill at the middle of the endurance test the oil level rises. Figure 3 shows the oil dilution rates above the test run.

Excessive oil dilution can cause engine lubrication problems due to reduced oil performance and additive concentration, and undesirable chemical interactions. At a minimum, oil dilution can reduce the service intervals between oil changes, as well as the wear protection efficiency of functional additives. Acceptable and usual maximum rates of fuel dilution can achieve a range up to 2-5%.

In terms of viscosity, the behavior of engine oil in the middle and at the end of the endurance test is an early decrease due to mechanical shear and oil dilution with fuel, followed by an increase caused by aging products and evaporation of low volatile oil fraction. The biggest effect is seen by the B30 test fuel, which consists of 30% FAME. All together the physical influence after the endurance test seems not to be critical (Figure 4).

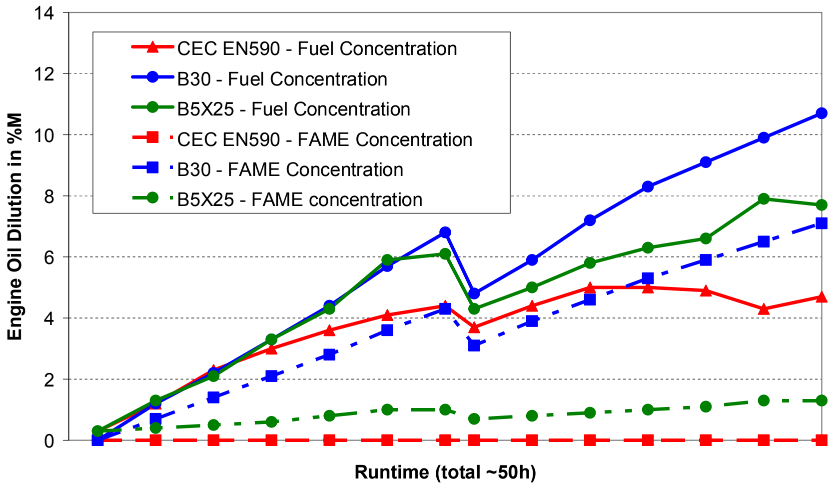


Figure 3: Engine oil dilution with different test fuels during the endurance test

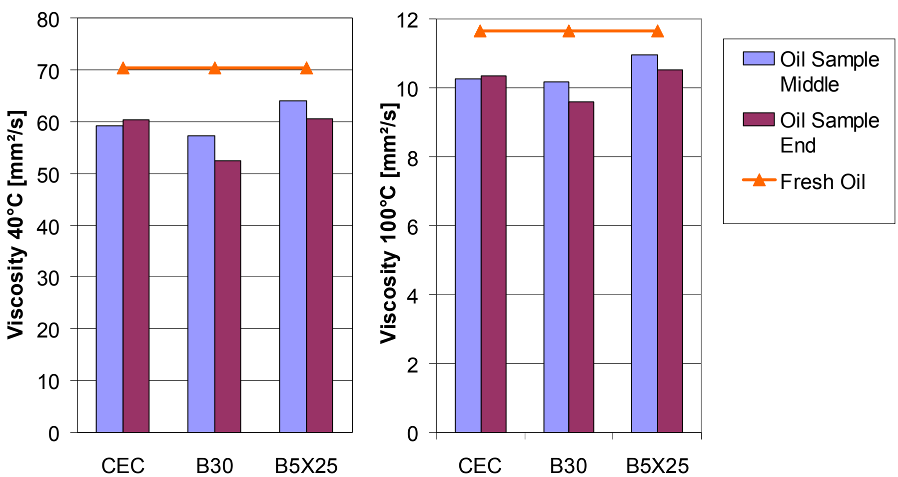


Figure 4: Viscosity of the low SAPS oil at the middle and end of the endurance test

Figure 5 shows the main chemical indicators of oil aging, as oxidation and nitration numbers (determined by FT-IR spectroscopy, according to DIN 51453), at the middle and at the end of the endurance test. Oil dilution by B30 leads to accelerated aging of the engine oil. By the substitution of FAME with HVO the oxidation number is reduced. The reason for that effect is that HVO is oxygen free. In case of nitration number a higher value was found in case of HVO containing test fuel (B5X25).

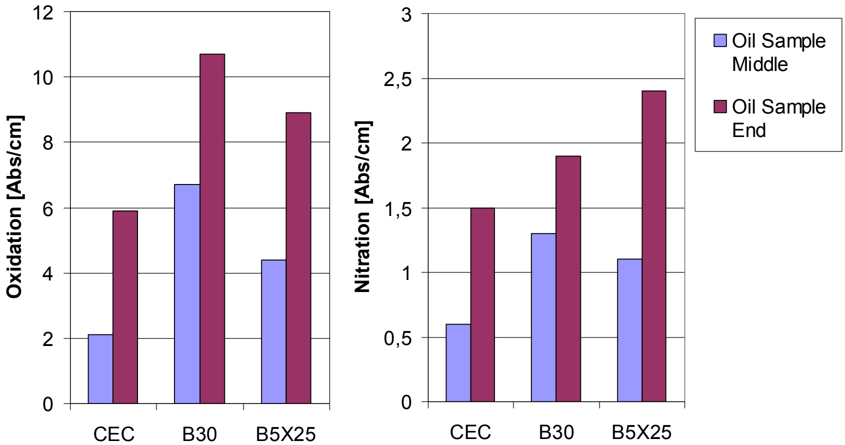


Figure 5: Oxidation and nitration number of the low SAPS oil at the middle and end of the endurance test

There is varying, but no critical effect to see by the TBN (total base number) and TAN (total acid number), see Figure 6.

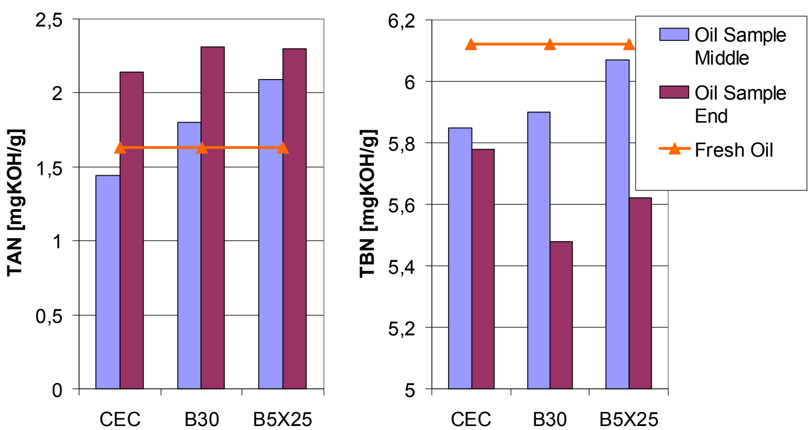
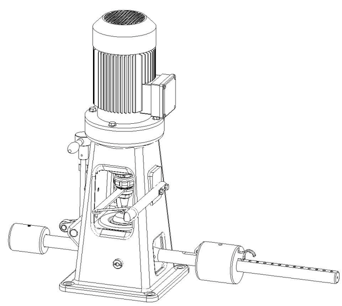


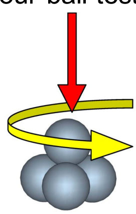
Figure 6: Total Base Number (TBN) and Total Acid Number (TAN) of the low SAPS oil at the middle and end of the endurance test

Besides changing the viscometric properties of the lubricant, bio-fuel and its degradation products could also interact with the lubricant additives and impact their performance. The partially oxidize components may compete with ZDDP antiwear additives on metal surfaces. The wear characteristics of the bio-fuel contaminated oil are investigated using four-ball tester as well as high-frequency, linear-oscillation (SRV) test apparatus.

The four-ball is a testing device standardized in DIN 51350 Part 1 and is used to determine welding and metal loads (DIN 51350 Part 2 and 3) as well as different friction and wear characteristics of lubricants (DIN 51350 Part 4 and 5). A roller-bearing ball rotates under pressure and at constant speed on three fixed steel balls. The gradual increase of the normal force (contact pressure) enables determination of the weld load, anti-wear protection, and friction coefficients of a lubricant. Wear is determined by optically measuring the formed wear scar diameter, the worn depression area (Figure 7).



Four-ball tester



Specimen Geometry

Test Parameters

Rpm
- 10 to 5800 1/min

Load
- 100 to 12000 Newton

Temperature
- -30 to 150 °C

Movement types
- Sliding, rolling

Friction states
- Mixed friction, EHD

Contact geometry
- Point contact

Measurements
- Friction torque, temperature, transition resistance, wear scar diameter

Figure 7: Four-ball testing device and specific test parameters

Investigating the load capacity of the engine oil after the endurance test, the B30-blend leads to increased engine wear, which is shown in a higher wear scar diameter, see Figure 8. This effect is reduced by the operation with the hydrotreated vegetable oil (HVO) bio-fuel component (B5X25).

The second standard test method to investigate the wear protection potential of the low SAPS oil at the end of the endurance test is the so called SRV test procedure (High-Frequency, Linear-Oscillation). The SRV test apparatus is designed to simulate very small displacements under well known conditions of load, speed and environmental control. Test methods cover procedures for determining the coefficient of friction of a lubricating oil and its ability to protect against wear when subjected to high-frequency, linear-oscillation motion at a test load of 50 to 1600 N, frequency of

50 Hz, stroke amplitude of 1.0 mm, duration of 2 h, and temperature within the range of -40°C to 280°C (DIN 51834-2). In this case an upper oscillating specimen with defined parameters on a fixed lower specimen was used and a point contact was selected.

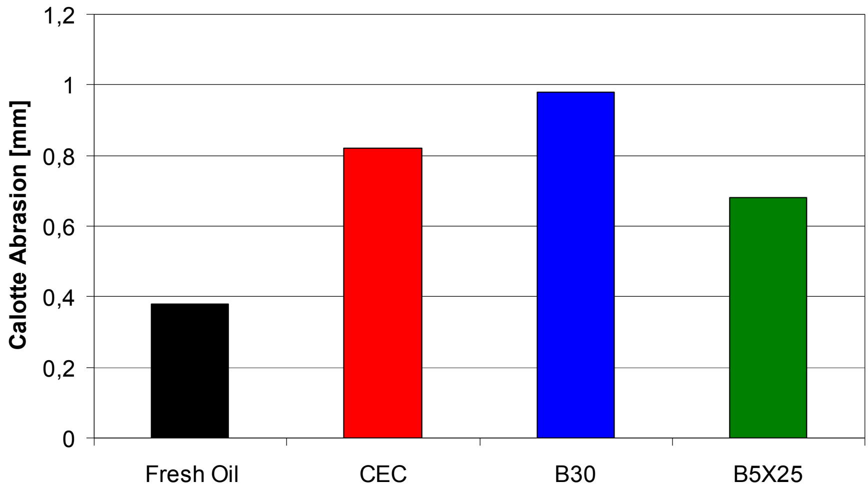


Figure 8: Wear scar diameter of the low SAPS oil at the end of the endurance test

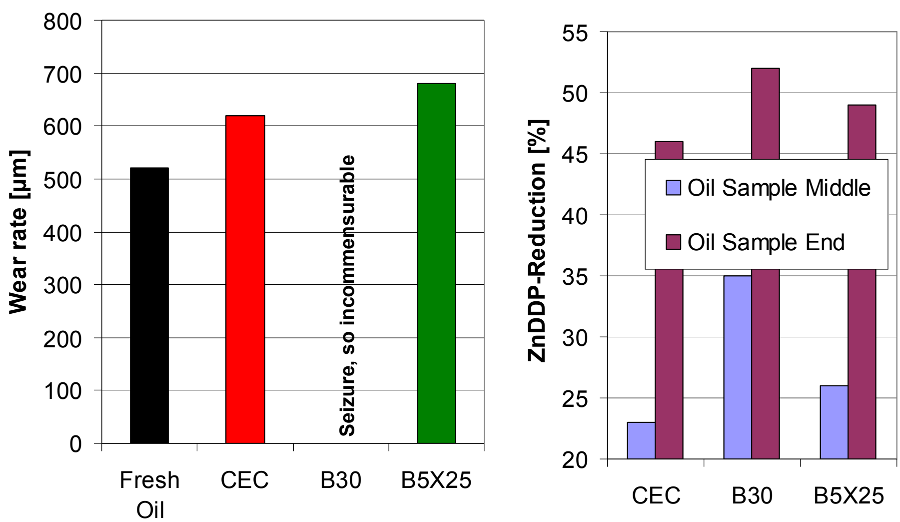


Figure 9: (a) SRV wear test results, (b) Reduction antiwear additives (ZnDDP) in the low SAPS oil at the end of the endurance test

Figure 9 shows the abrasion of the test body shown. B30 shows during the test procedure a so called galling (Figure 9a). Due to chemical reactions of engine oil and absorbed FAME a rapid reduction of antiwear additive is detected and a galling is the consequence during the SRV test procedure. Figure 9b shows the ZnDDP-reduction measured with FT-IR-spectroscopy. By the substitution of FAME with HVO the wear rate is reduced.

7. Conclusion

Due to the higher boiling range of fatty acid methyl esters (FAME), higher fuel dilution in engine oil is to be observed for the FAME containing test fuel in a modern diesel engine with diesel particulate filter, using active diesel particulate filter regenerations realized by post-injection. By the substitution of FAME with hydrotreated vegetable oils (HVO) the fuel dilution can be reduced.

An elevated FAME content can lead to potential performance losses of the low SAPS engine oils. Thereby an accelerated consumption of oil additives and a reduction of wear protection capabilities can be detected. This effect can be softened by the substitution of fatty acid methyl esters (FAME) with hydrotreated vegetable oils (HVO).

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