

Research on Emissions and Engine Lube Oil Deterioration of Diesel Engines with BioFuels (RME)

2011-01-1302

Published
04/12/2011

Zbigniew Stepień, Wiesława Urzędowska and Stanisław Oleksiak
Institute of Petroleum Processing

Jan Czerwinski
Univ. of Applied Sciences Biel-Bienne

Copyright © 2011 SAE International

doi:[10.4271/2011-01-1302](https://doi.org/10.4271/2011-01-1302)

ABSTRACT

In the Diesel sector the fatty acid methyl esters (FAME's) - in Europe mostly RME *) (rapeseed methyl ester) and in US mostly SME (soja oil methyl ester) - are used as a various share, % volume blends with the Diesel fuel (B5, B7, B10, B20, Bxx).

The present joint project focuses on RME being the most important representative of the biofuels of 1st generation in Europe. The influences of RME blend fuels on emissions and on lube oil deterioration are emphasised.

Emissions were investigated on a modern engine with exhaust gas aftertreatment devices like SCR and (DPF+SCR).

Beside the legally limited exhaust emission components some non-legislated like NO₂, N₂O, NH₃ and nanoparticles were measured at stationary and dynamic engine operation.

The most important findings are:

- the increased percentage of RME w/o aftertreatment causes an increase of NO_x by higher engine load and reduction of CO & HC; at transient operation (ETC) these tendencies are less pronounced and only B100 shows an increase of NO_x,

- with SCR alone there are no differences of NO_x and of NO_x reduction rate (KNO_x) with increasing RME portion; there is lowering of CO & HC,

- with DPF+SCR KNO_x-values are slightly higher, than with SCR alone, due to the production of NO₂ in the catalytic DPF (upstream of SCR),

- there is excellent count filtration efficiency of DPF, up to 99.9%; with SCR alone there is usually a small reduction of nanoparticles concentrations (in the range of 10-20%, similar like an usual oxidation catalyst).

The paper describes as well significant problems related to the influences of biofuels on engine lube oils deterioration demonstrated by monitoring the engine lube oil aging during its operation in heavy duty (HD) and modern high speed direct injection (HSDI) light duty (LD) engine through the bench tests.

Subject to the long run durability engine tests were both: mineral and synthetic engine lube oils with different improved additives packages and viscosity ranges and with different RME-blending ratios in fuel.

The research methodology used: standard analysis as well as in house developed innovative methods, extensive analysis of engine lubricants oxidation stability - thin lubricant film oxidation tests and bulk lubricant oxidation tests.

*) Abbreviations see at the end of this paper

It can be stated that:

- the presence of bio-components in the fuel has significant impact on multidirectional hastening of engine lube oil destruction processes,
- kind of base lube oil, lube oil additives components and RME-portion, as well as engine design and its operating conditions are very essential factors influencing the engine lube oil performance,
- the processes taking place in an engine lubricant, influence adversely the limited possibilities of bio-components evaporation from engine lube oil and contribute to initiation of accelerated, deeper engine lube oil oxidation and degradation.

INTRODUCTION

The removal of NO_x from the lean exhaust gases of Diesel engines (also lean-burn gasoline engines) is an important challenge.

Selective catalytic reduction (SCR) requires and uses a supplementary substance - reduction agent - which in presence of catalysts produces useful reactions transforming NO_x in N_2 and H_2O .

The preferred reduction agent for toxicological and safety reasons is the water solution of urea (AdBlue), which due to reaction with water (hydrolysis) and due to thermal decomposition (thermolysis) produces ammonia NH_3 , which is the real reduction substance.

A classical SCR de NO_x system consists of 4 catalytic parts:

- precatalyst converting NO to NO_2 (with the aim of 50/50 proportion)
- injection of AdBlue (with the intention of best distribution and evaporation in the exhaust gas flow)
- hydrolysis catalyst (production of NH_3)
- selective catalyst (several de NO_x reactions)
- oxidation catalyst (minimizing of NH_3 slip)

The main de NO_x -reactions between NH_3 , NO and NO_2 are widely mentioned in the literature [1, 2, 3, 4]. They have different rate according to the temperatures of gas and catalysts, space velocity and stoichiometry. All these influences cause a complex situation of reactions during the transient engine operation.

Additionally to that there are temperature windows for catalysts and cut off the AdBlue-injection at low exhaust gas temperatures to prevent the deposits of residues.

Several side reactions and secondary substances are present. An objective is to minimize the tail pipe emissions of:

ammonia NH_3 , nitrous oxide N_2O , isocyanic acid HNCO and ammonium nitrate NH_4NO_3 (also known as secondary nanoparticles).

The combination of particle filtration (DPF) and of the most efficient de NO_x technology (SCR) is widely considered as the best solution, up to date, to minimize the emissions of Diesel engines [5].

Biodiesel, especially in form of biodiesel fuel blends, as an alternative, renewable fuel is a partial replacement of petroleum Diesel as a pathway to energy diversity and reduced petroleum dependency in the transportation sector. Due to numerous, well known advantages as for example renewability, high lubricity, high flashpoint, low sulphur content and no aromatics, good biodegradable property, non-toxic, relatively high cetane number, lower particulate exhaust emissions and life cycle CO_2 emissions in comparison with Diesel fuel derived from mineral oils, biodiesel is regarded as a fuel of the nearest future. In Europe rapeseed methyl ester (RME) is the most common sort of fatty acid methyl ester (FAME), which according to newest standard EN 590:2009 can be blended with standard Diesel fuel in a portion of up to 7% (V/V).

For use of biocomponents the limiting of impurities and phosphorus in biofuels according to the present standards is an obligatory prerequisite for successful operation.

Unfortunately beside undoubted advantages, biodiesel has many disadvantages, a part of which is related to dilution of engine lube oil, requiring more frequent oil change than in standard Diesel fuelled engines. Excessive lube oil dilution leads to several problems, such as reduced oil performance and durability. Usually the oil breakdown is promoted by oxidation and polymerization of unsaturated fuel constituents. So, a serious danger is the possibility that unburnt biodiesel entering the oil sump may be oxidized, thus promoting lubricant degradation and thickening sometimes by severe sludge precipitation and significant loss of its dispersion. On the other hand, oil thinning may be due to fuel dilution or share of polymers used as viscosity modifiers. Apart from that, certain metals such as copper and lead become leached from bearings due to biodiesel fuel in the lubricating engine oil. Since the state of oil deterioration depends also on operation conditions, oil performance grade, engine type and its service, the life span of engine oil is until now not well understood.

There are limited data concerning how the FAME might interact with lubricating oil additives either in the bulk of the lubricant or in thin film on metal surfaces influencing the lubricating oil performance changes. Possibility of incompatibility problems between the crankcase lubricants and the biofuels additives should be also further clarified by

studying the complicated physicochemical processes between modern engine lube oils and biofuels [6, 7, 8].

The present paper shows some results of research of SCR-and (DPF+SCR)-systems with different rates of biocomponents (RME). Taking into account the above indicated issues a research program about the impact of biofuels on engine lube oils deterioration was performed.

TESTED ENGINES, FUELS, LUBRICANTS

Table 1a. Specifications of tested engine IVECO

Specification	Test engines
	IVECO
Type	F1C Euro 3
Displacement	3.00 Litres
Max. speed	4200 rpm
Rated power:	100 kW at 3500 rpm
No. of cylinders	4 cylinder in-line
Combustion process	direct injection
Injection system	Bosch Common Rail 1600 bar
Supercharging	Turbocharger with intercooling
Emission control	none

Table 1b. Specifications of tested engine MAN

Specification	Test engines
	MAN
Type	D 0826 LOH. 18 Euro 2
Displacement	6.87 Litres
Max. speed	2500 rpm
Rated power:	191 kW at 2300 rpm
No. of cylinders	6 cylinder in-line
Combustion process	direct injection
Injection system	Bosch in-line pump
Supercharging	Turbocharger with intercooling
Emission control	none

Table 1c. Specifications of tested engine FORD

Specification	Test engines
	FORD
Type	Duratorq 2.0 TDCi Euro 4
Displacement	2.0 Litres
Max. speed	4200 rpm
Rated power:	96 kW at 3800 rpm
No. of cylinders	4 cylinder in-line
Combustion process	direct injection
Injection system	DEPLHI Common Rail 1600 bar
Supercharging	Turbocharger with intercooling
Emission control	DOC + DPF

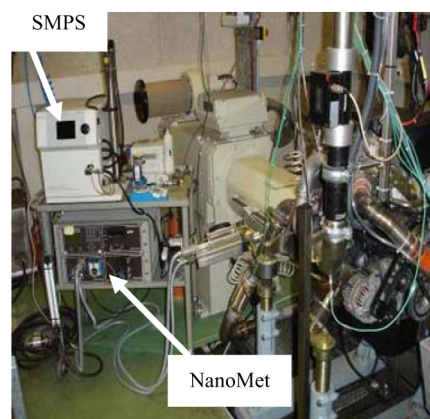


Fig. 1a. Tested engines. IVECO and apparatus for nanoparticle analytics SMPS & NanoMet at the University of Applied Sciences, Biel-Bienne, Switzerland



Fig. 1b. Tested engines. MAN engines used for lube oils aging at the Oil and Gas Institute, Krakow, Poland



Fig. 1c. Tested engines. FORD, engines used for lube oils aging at the Oil and Gas Institute, Krakow, Poland

For the research of Diesel biofuels influence on emissions of a Diesel engine with SCR were used four blend fuels containing different percentage of RME (B7, B20, B30 & B100). Following base fuels were used for preparation of above fuels:

- Shell Formula Diesel fuel Swiss market summer quality (10 ppm S) according to SN EN 590
- Rapeseed Oil Methyl Ester RME from Flamol, Berne, CH

For testing of Diesel biofuels influence on engine lube oils deterioration was used a typical polish commercial low sulfur (up to 10 ppm S) Diesel fuel meeting requirements of EN 590 standard and containing 3,5 % (V/V) RME meeting requirements of EN 14214 standard. This fuel has been utilized to prepare three test blend fuels containing different share of RME (B7, B20 & B30). Quality diversification in respect of oxidation and thermo-oxidation stability has been assumed as a selection criterion of engine lube oils tests. The engine lube oil quality determined by above performance properties is both dependent on oil base stock composition and properties of improver additives package. Selected lubricating oils met tested engines Original Equipment Manufacturers (OEM) requirements. So, for tests have been received engine lube oils as follows:

- For HD Diesel engine (MAN D 0826. LOH 18) has been selected fully mineral lubricating oil SAE 15W-40 blended in API Group I base stock and fulfilled the requirements of ACEA A2-96/B2-98/E2-96; API CG-4/SJ; CCMC D4/PD-2/G4 standards. That lubricant is identified as “OM”. The second lubricating oil for this HD engine was fully synthetic lube oil SAE 5W-40, blended in API Group IV (PAO) base stock, and fulfilled the requirements of ACEA E5/E4/E3; API CI-4 PLUS/CI-4/CH-4/CG-4/CF/SL/SJ; JASO DH-1 standards. That lubricant is identified as “OS”.

- For LD HSDI Diesel engine (FORD Duratorq 2.0 TDCi) two lubricating oils have been selected for tests. The first was mineral lubricating oil SAE 5W-30 blended in API Group II⁺ base stock (from hydrocracking) and fulfilled the

requirements of ACEA A-1/B-1; API SL; ILSAC GF-3 standards. That lubricant is identified as “OMH”. The second lubricating oil for this LD engine was synthetic oil SAE 5W-30, blended in mixed API Group IV (PAO) base stock (25%) and API Group III base stock (75%), and fulfilled the requirements of ACEA A-1/B-1 standards. That lubricant is identified as “OSS”.

INSTRUMENTATION FOR EMISSIONS TESTING

Engine dynamometer and test equipment for emissions measurements

Fig. 2 represents the special measuring systems installed on the engine, or in its periphery for analysis of the regulated and unregulated emissions. Laboratory equipment employed:

- Dynamic test bench
- Volatile components: CO₂, CO, HCIR, O₂, HCFID, NO, NO_x, CLD
- FTIR (Fourier Transform Infrared) Spectrometer with the possibility of simultaneous, time-resolved measurement of approx. 30 emission components - among those validated are: NO, NO₂, NO_x, NH₃, N₂O.

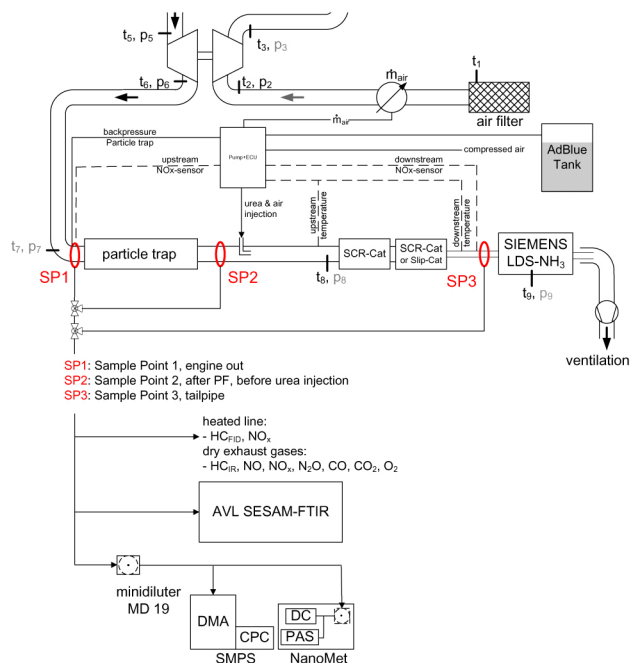


Fig. 2. Emission measuring equipment on engine dyno

The particle size and number distributions were analysed with SMPS - Scanning Mobility Particle Sizer, TSI (DMA TSI 3071, CPC TSI 3025 A).

The nanoparticle results represented in this paper are obtained with sampling at tail pipe with MD19 tunable minidiluter and with thermoconditioner (300°C).

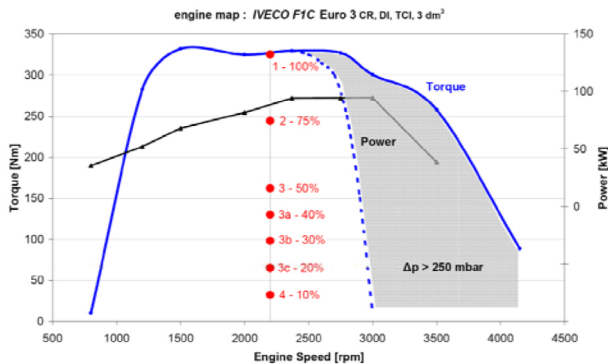


Fig. 3a. Engine test operating conditions. Limited engine map of the IVECO engine and 7 points test for investigations of emissions

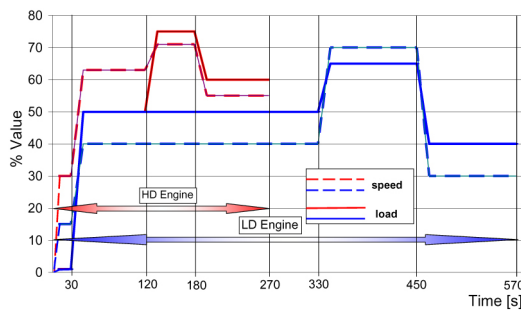


Fig. 3b. Engine test operating conditions. Engine test cycles for aging of investigated lube oils

TEST PROCEDURES

EMISSIONS

In the present work a 7 steps-test at 2200 rpm was used, Fig. 3a. The operating points were chosen in such way that the urea switch-on was included in the test (between 20% and 30% load).

As sampling position (SP3) was used (see Fig. 2) for all variants with/without exhaust gas aftertreatment.

The dynamic testing was performed according to ETC (European Transient Cycle), which in this work was defined on the basis of the non limited engine operation map (NEM).

The tests were driven after a warm-up phase, when the engine coolant temperature and lube oil temperature reached their steady-state values (stationary points tests).

Before the start of each dynamic cycle the same procedure of conditioning was used to fix as well as possible the thermal conditions of the exhaust gas aftertreatment system.

The conditioning was: 5 min pt. 1 and 0.5 min idling.

The test program consisted of:

- test procedures: steps-test at 2200 rpm and ETC (NEM);
- aftertreatment systems: without, with (DPF+SCR), or with SCR only.

LUBE OILS

Taking into account the necessity of creation of conditions promoting lubricating oil aging, a HD Diesel engine, which favors oil deterioration, was chosen.

The used LD Diesel engine applied common rail injection system. The late injection events used as a regeneration strategy for DPFs, increased the opportunity for unburned fuel to reach the cylinder walls, to enter the lubricating oil and to promote its deterioration.

The total time of engine oil aging test for both engines was similar. It has been established for about 200 hours taking the oil consumption quantity into consideration. During endurance engine tests, oil was sampled at regular intervals which were concentrated closer to the end of the test.

Simulating tests for both engines were configured as a repeatable four mode tests conducting for different engine loads and speeds, reflecting engine operating conditions during city driving. The endurance engine tests cycles are given on the Fig. 3b.

TESTED EXHAUST GAS AFTERTREATMENT SYSTEMS

The combined exhaust gas aftertreatment system (DPF+SCR) was installed on the IVECO research engine in the ICE-laboratory in Biel, CH. This system is designed for dynamic on-road applications.

The filters and catalysts are exchangeable modules, for SCR alone the DPF modulus was removed.

The investigated combinations were: a coated Cordierite DPF upstream and Vanadium based SCR catalyst downstream of the urea injection point (see scheme Fig. 2).

Additionally to the elements in the engine exhaust system an Ad Blue-tank and Ad Blue injection unit with pump, sensors and electronic control were installed in the laboratory.

There are following sensors, which enable the open-loop control of urea dosing: