

500 Hours Endurance Test on Biodiesel Running a Euro IV Engine

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ABSTRACT

A 500 hours endurance test was performed with a heavy duty engine (Euro IV); MAN type D 0836 LFL 51 equipped with a PM-Kat®. As fuel 100% biodiesel was used that met the European specification EN 14214. The 500 hours endurance test included both the European stationary and transient cycle (ESC and ETC) as well as longer stationary phases. During the test, regulated emissions (carbon monoxide, nitrogen oxides, hydrocarbons and particulate matter), the particle number distribution and the aldehydes emission were continuously measured. For comparison, tests with fossil diesel fuel were performed before and after the endurance test.

During the endurance test the engine was failure-free for 500 hours with the biogenic fuel. There were almost no differences in specific fuel consumption during the test, but the average exhaust gas temperature increased by about 15°C over the time.

Emissions changed only slightly during the test. Carbon monoxide, hydrocarbons and aldehydes were effectively eliminated by the oxidation catalyst as part of the PM-Kat®. The concentration of hydrocarbons was partially under background level and the emissions of hydrocarbons as well as carbon monoxide were well under the regulatory requirements. Nitrogen oxides emissions increased, as expected, by 10 % when using biodiesel instead of fossil diesel fuel. So they slightly exceeded the legal limit of Euro IV. During the test small increases of nitrogen oxides, particulate matter and particle numbers were observed.

In all, the endurance test demonstrated clearly that the engine can be driven with 100% biodiesel and the biogenic fuel has

no effect on the continuously operating PM-Kat®. However, the exhaust gas system might have some optimization potential for biodiesel.

INTRODUCTION

The replacement of petroleum-derived fuels by biogenic fuels from renewable resources has become of worldwide interest and is being researched for its environmental costs and benefits [1,2]. The reduction of atmospheric greenhouse gas (GHG) is especially important and is being addressed. The combustion of vegetable oil-derived fuels reduces net GHG emissions in comparison to fossil diesel fuel [3].

Fatty acid methyl esters (FAME) or, more generally, fatty acid alkyl esters, are proven as a suitable alternative to fossil diesel fuel (DF) producing similar or even lower emissions [4,5]. They are called biodiesel and are produced from various oil plants, e.g., rapeseed (canola), palm, soybean, sunflower and others. Biodiesel is produced by transesterification of vegetable oil with methanol or another alcohol [4,5], resulting in a fuel with properties similar to mineral oil-derived fuels.

Particulate matter (PM) is recognized as one of the major harmful emissions generated by diesel engines. PM emissions are subject to diesel engine emission regulations worldwide. To achieve these standards of the regulation, particle filters are essential parts of the exhaust line. Besides PM, emissions of fine and ultrafine particles from diesel engines caused a broad discussion in Europe.

Since January 2005 the limit for the emission of fine particles has been tightened in the context of a council directive of the European Union (99/30/EG) [6]. According to this directive

the limit of 50 $\mu\text{g}/\text{m}^3$ particles in ambient air should not be exceeded on more than 35 days per year. The compliance of the limit cannot be guaranteed yet all over in Europe. In 2007, the limit was exceeded in more than 11 European countries. For instance in Germany a violation of the threshold value was recorded on more than 35 days at 34 of the 415 measuring stations [7]. In detail, particles from diesel engines show a bimodal size distribution consisting of a nuclei mode in the size range from 9 nm to 30 nm and an accumulation mode. Nuclei mode particles, which can depose deeply in the lung, dominate the majority of particles but have only little effect on the total mass. Epidemiological and toxicological studies indicated that adverse health effects from exposure to PM may increase with decreasing particle size even if the particles consist of toxicologically inert materials [8, 9]. Ultrafine particles can penetrate into the alveolar region, resting there for months. Here the particles can cause inflammatory reactions leading to bronchitis and asthma [10]. Therefore the determination of the particle number distribution is of the same importance as the regulated PM mass.

In previous investigations at the Johann Heinrich von Thünen-Institut (vTI) it was shown that biodiesel has great potential to reduce most regulated and unregulated emissions in the raw exhaust.

Particle filters are designed for exhaust gas that originates from diesel fuel. The use of biodiesel can effect the efficiency of the filter. Especially long term usage must be examined. In this study the effect of a 500 h endurance run using rapeseed oil methyl ester (RME, biodiesel, B100) on regulated and non-regulated emissions was tested.

MATERIALS AND METHODS

ENGINE

The study was carried out at the emission test facility of the Institute of Agricultural Technology and Biosystems Engineering at the Johann Heinrich von Thünen-Institut in Braunschweig, Germany.

A Euro IV engine MAN D08 36 LFL51 with turbocharger, intercooler, exhaust gas recirculation system, and particle filter was used for this study. Technical data are listed in [table 1](#). For exhaust aftertreatment a continuously operating particle filter, a PM-Kat®, was attached. This filter, added to a stainless steel muffler, works without plugging and is maintenance free. It doesn't need any additional lubricants and should reduce particulate matter by 60%. The PM-Kat® incorporates an oxidation catalyst, which should eliminate hydrocarbons [11].

Table 1. Technical data of MAN engine D08 36 LFL51

Rated power	206 kW
Rated speed	2300 min^{-1}
Maximum torque	1100 Nm at 1200-1800 min^{-1}
Number of cylinders	6
Piston stroke	125 mm
Bore of cylinder	108 mm
Stroke volume	6871 cm^3
Injection	Common Rail
Compression ratio	18.0:1

The engine was coupled to a dynamometer DynoRoad 205/3,5 SL from AVL, Graz, Austria. The regulation of the accelerator was done by an actuator from Froude-Hoffmann. This actuator was controlled by a circuit developed in the vTI.

The input signal for this circuit is optionally taken from the EM-CON device (AVL controller), or from an SPS controller developed in the vTI.

The AVL controller was well adapted for constant torque as it appears in ESC tests. The ETC test has fast changes in load, so the engine could not follow the course of the test all the time. The speed of the engine is controlled primarily by the dynamometer, this followed the course of the reference quite well. The torque needed more time to adjust. As the minimal adjusting time of engine and accelerator is a fixed value, the controller calibration could be changed simply. A new PID controller was implemented on SPS. This SPS controller was much faster and the course of the torque followed the reference much better ([figure 1](#)). On negative reference torque values the engine works in towed operation.

The power curve was determined with diesel fuel according to EU guideline 88/77 [12]. As RME has a lower specific energy content, the maximum torque was not achieved. It was 12 % lower using RME instead of diesel fuel. [Figure 2](#) shows the difference between both fuels in the ETC test.

TEST PROCEDURES

The test was running over 22 days (500 hours) using 100% biodiesel. Only small stops were done to sample motor oil. In the night time constant modes were performed. During the day up to 20 ETC and ESC tests were carried out. A typical course of speed and torque during 24 hours is presented in [figure 3](#). Before and after the 500 h endurance test regulated and non-regulated emissions were measured using reference diesel fuel.

FUELS

During the 500 h endurance test two charges of RME were used. The fuels met the standard DIN EN 14214 and were delivered by Bio-Ölwerk Magdeburg GmbH, Magdeburg, Germany. The reference DF meeting the EU standard EN590

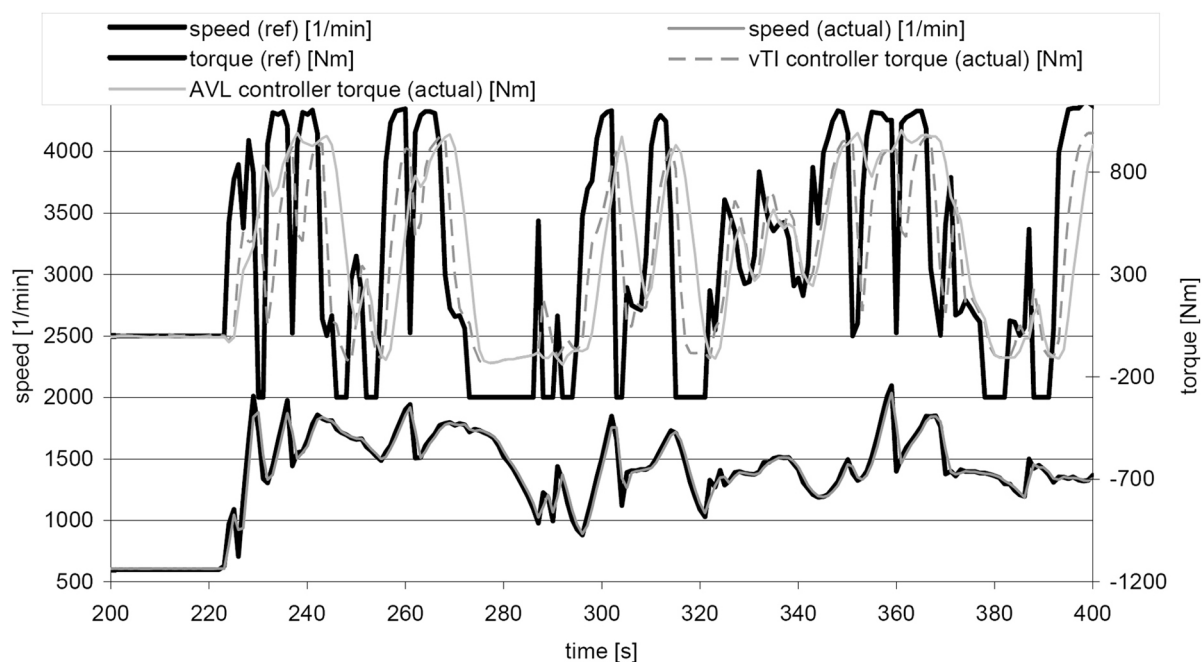


Figure 1. Reference and real course of speed and torque in the ETC test between 200 and 400 s with different controllers (diesel fuel)

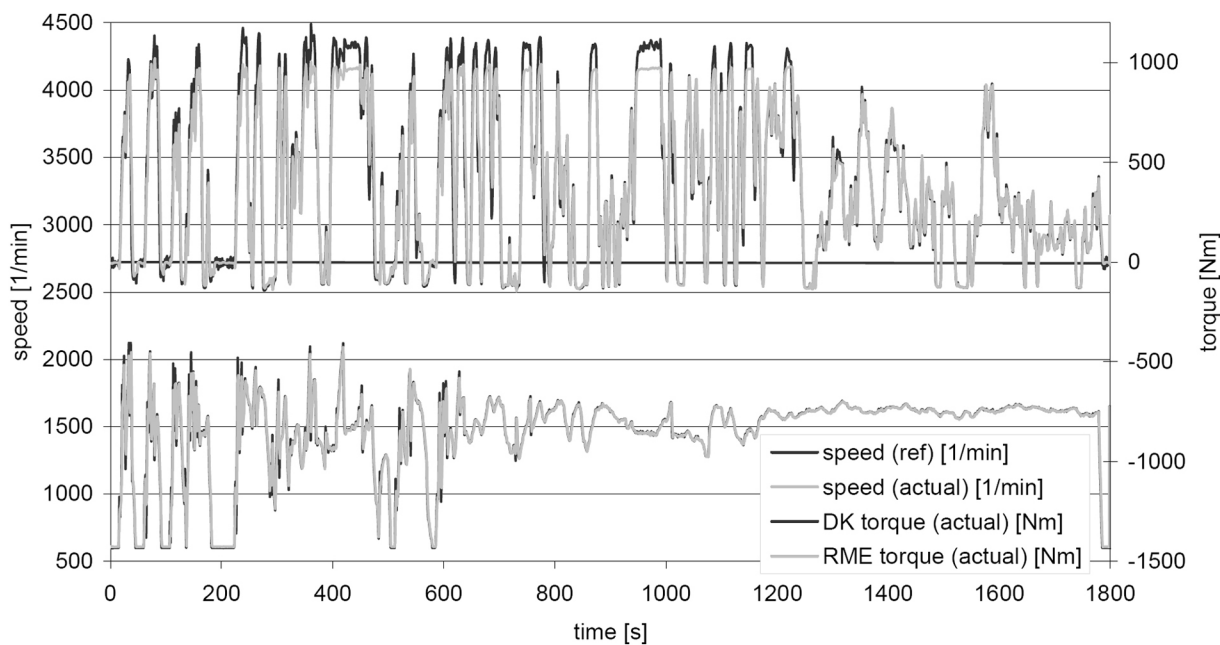


Figure 2. Course of speed and torque during the ETC test with RME and diesel fuel.

was delivered by Haltermann Products, Hamburg, Germany. Properties of the fuels are listed in [table 2](#).

DETERMINATION OF REGULATED EXHAUST EMISSIONS

Regulated gaseous compounds carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) were sampled

each second from the raw exhaust gas stream and determined with commercial gas analyzers.

Hydrocarbons (HC) were determined with a gas analyzer RS 55-T (Ratfisch, Poing, Germany), which measures the electrical signal gained from ionization of carbon fragments as the filtered exhaust gas passes a hydrogen flame (FID). Carbon monoxide (CO) was measured by means of an

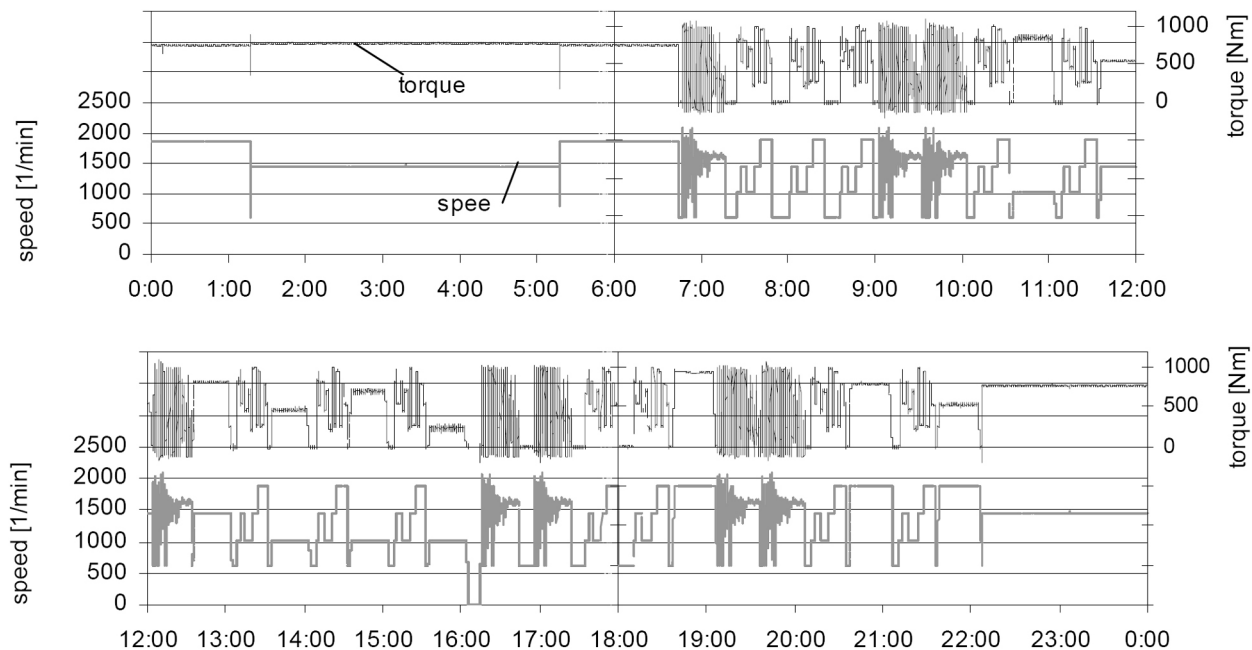


Figure 3. Typical course of speed and torque during 24 hours

analyzer Multor 710 (Maihak, Reute, Germany) that uses the non-dispersed infrared light (NDIR) process. The differential heating of a reference cuvette and the measuring cuvette eventually containing CO causes a flow, which is measured by a micro flow sensor and recorded. Nitrogen oxides (NO_x) were analyzed with a CLD 700 EL ht chemical luminescence detector (Eco Physics, Munich, Germany). Sampled exhaust gas is split in order to measure the luminescence of genuine NO in one part and of total nitrogen oxides (NO_x , $\text{NO} + \text{NO}_2$) after complete reduction to NO in the other part. Luminescence appears after chemical oxidation of NO with ozone (O_3) generated by the CLD.

All particle measurements were accomplished after dilution of raw exhaust gas in a dilution tunnel. A dilution factor of about 10 is applied for determination of particle mass and ELPI measurements (aerodynamic diameter range from 30 nm to 10 μm), an additional dilution by a factor of 7 is necessary to perform correct measurements via the SMPS instrument (electrical diameter range from 10 nm to 300 nm). Dilution factors are calculated from separate recordings of CO_2 contents in fresh air and diluted exhaust gas.

Particle mass was determined gravimetrically after sampling on teflon coated glass fiber filters (T60A20, Pallflex, diam. 70 mm, Pallflex Products Corp., Putnam, CT, USA), with sampling intervals according to individual weighting factors of each engine mode. Weights of fresh and sampled filters were determined to an accuracy of $\pm 1 \mu\text{g}$ by means of a microbalance M5P (Sartorius, Göttingen, Germany) always preceded by at least 24 h of conditioning in a climate chamber held at 22°C and 45% relative humidity.

Aldehydes were measured using DNPH cartridges. To avoid reaction of oxidizing substances in the exhaust gas with the DNPH, the gas stream was led through potassium iodide cartridges before entering the DNPH cartridges. During the ETC test a constant flow of 0.5 l/min of raw exhaust gas was led through the cartridges.

RESULTS

FUEL CONSUMPTION

Although the maximum torque could not be achieved with RME, the gravimetric fuel consumption during the ESC test was 11% higher using RME instead of diesel fuel. Due to the lower energy content of RME this was an expected result. The specific fuel consumption of RME did not change during the endurance test.

MOTOR OIL

During the endurance test every day the oil level was controlled and a sample was taken. After 340 hours 3 liters of motor oil had to be refilled. The oil temperature was between 70°C after long idle mode phases and 120°C after rated power. During ETC and ESC test the temperature change between 80°C and 110°C only.

The motor oil samples were tested with GC-FID technique. Two changes were observed: During the test RME was accumulated in the motor oil. After 500 hours of operating the concentration was about 2%. The concentration of an additive in the motor oil decreased to 1/4. The additive wasn't determined furthermore.