500 HOURS ENDURANCE TEST ON BIODIESEL RUNNING A EURO IV ENGINE

Jürgen Krahl[1], Axel Munack[2], Yvonne Ruschel[2], Olaf Schröder[2], C. Pabst[2]
[1] Coburg University of Applied Sciences, D-96406 Coburg, Germany
[2] Johann Heinrich von Thünen-Institut (vTI), Institute of Agricultural Technology and Biosystems Engineering, D-38116 Braunschweig, Germany

ABSTRACT

A 500 hour endurance test was performed with a heavy duty engine (Euro IV) MAN type D 0836 LFL 51 equipped with a PM-Kat®. As fuel biodiesel was used that met the European specification EN 14214. The 500 hour endurance test included both of the European stationary and transient cycles (ESC and ETC) as well as longer stationary phases. During the test, regulated emissions (carbon monoxide, nitrogen oxides, hydrocarbons and particulate matter) and the particle number distribution 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 consumption during the test, but the average exhaust gas temperature increased by about 15 °C over the time. The exhaust gas pressure before catalyst was measured in two engine modes and showed a small rise.

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.

As expected, Nitrogen oxides emissions increased 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 biodiesel. 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 [Hill et al., 2006]. The reduction of atmospheric greenhouse gas (GHG) is of particular importance, whereby the combustion of vegetable oil-derived fuels leads to a reduction of net GHG emissions in comparison to fossil diesel [Koonin, 2006]. 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 [Mittelbach and Remschmidt, 2004]. 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 [Mittelbach and Remschmidt, 2004], resulting in a fuel with properties similar to fuels that are derived from mineral oil.

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 comply with the regulated limits, particle filters are essential parts of the exhaust line. Besides PM, emissions of fine and ultrafine particles from diesel engines have 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). According to this directive the limit of 50 µg/m³ of 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 transgression of the threshold value was recorded on more than 35 days at 34 of the 415 measuring stations. 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 [Seaton et al., 1995]. Ultrafine particles can penetrate into the alveolar region, resting there for months. Here the particles can cause inflammatory reactions leading to bronchitis and asthma [Mayer, 2005]. 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 affect 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) 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 vTI in Braunschweig, Germany.
A 6 cylinder Euro IV engine MAN D08 36 LFL51 with turbocharger, intercooler, exhaust gas recirculation system, and common rail injection was used for this study. The engine has a rated power of 206 kW and a stroke volume of 6871 cm^3. 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.
The engine was coupled to a dynamometer DynoRoad 205/3,5 SL from AVL, Graz, Austria. The power curve was determined with diesel fuel according to EU guideline 88/77. As RME has a lower specific energy content, the maximum torque was not achieved. It was 12 % lower when using RME instead of diesel fuel.

TEST PROCEDURES

The test was running over 22 days. Only short stops were allowed in order to sample motor oil. During night time constant modes were performed. During the days up to 20 ETC and ESC tests were carried out.

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 was delivered by Haltermann Products, Hamburg, Germany.

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). Carbon monoxide (CO) was measured by an analyzer Multor 710 (Maihak, Reute, Germany) that uses the non-dispersed infrared light process. Nitrogen oxides (NO_x) were analyzed with a CLD 700 EL ht chemical luminescence detector (Eco Physics, Munich, Germany). 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 30 nm to 10 µm). 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.

RESULTS

The exhaust gas backpressure was measured in front of the particle filter. The value indicated a particle filter clogging during the test. The maximum didn't exceed 75 hPa. During the endurance test the exhaust gas backpressure increased by about 10 %. This increased pressure was also observed after the endurance test using diesel fuel.

Carbon monoxide and hydrocarbons were effectively eliminated by the oxidation catalyst that is integrated in the particle filter. Carbon monoxide was only observed at idle mode. In this mode the exhaust gas temperature wasn't high enough for oxidation. In course of the endurance test no aging of the oxidation catalyst was observed.

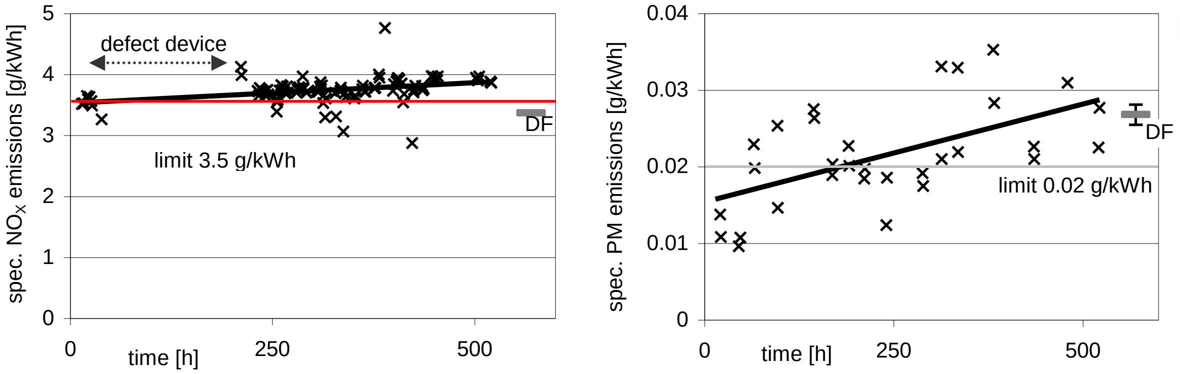

Figure 1: Specific nitrogen oxides emission (left) and specific particulate matter emission in the ESC test during the endurance test

In idle mode the concentration of NO_x was low due to the low combustion temperatures. Furthermore, at low exhaust gas temperature in idle mode the NO_x consisted to more than 95% of nitrogen oxide. Along with increasing exhaust gas temperature and catalyst temperature the percentage of nitrogen dioxide increased to 1/3 of the emission. The emissions of NO_x in the ESC test using diesel fuel were just under the limit (Euro IV) of 3.5 g/kWh. With RME, the emissions increased by about 10% and exceeded the limit of Euro IV (figure 1). During the endurance test the measurement device had to be repaired twice, so between 30 and 200 hours and between 455 and 495 hours no results are available. In course of the endurance test the emission increased slightly.

Particulate matter was sampled during the ESC test from diluted exhaust gas. The dilution tunnel was designed after European guidelines ECE-R 49 (1992) and EWG 88/77 (1992). Due to the low emissions of the Euro IV engine and an insufficient dilution air treatment, the measurement had a high systematic error. A maximum of 20% or 0.004 g/kWh of the particulate matter can be caused by the dilution air. Nevertheless, an increase of PM emissions in the course of the endurance test was observed. The emissions using RME were in the range of the limit of Euro IV and comparable to diesel fuel.

The measurement of the particle number distribution was performed with an Electronic Low Pressure Impactor (ELPI) using diluted exhaust gas. The particle number distribution is shown in Figure 2. The distribution over the stages of the impactor was constant over 500 hours. The absolute value for the single stages showed an increasing trend. The particle number of all stages had also an increasing trend (figure 2), although after 125 and 250 hours the particle number stepped back to the start level. The particle number using diesel fuel is twofold higher compared to RME (not shown here).

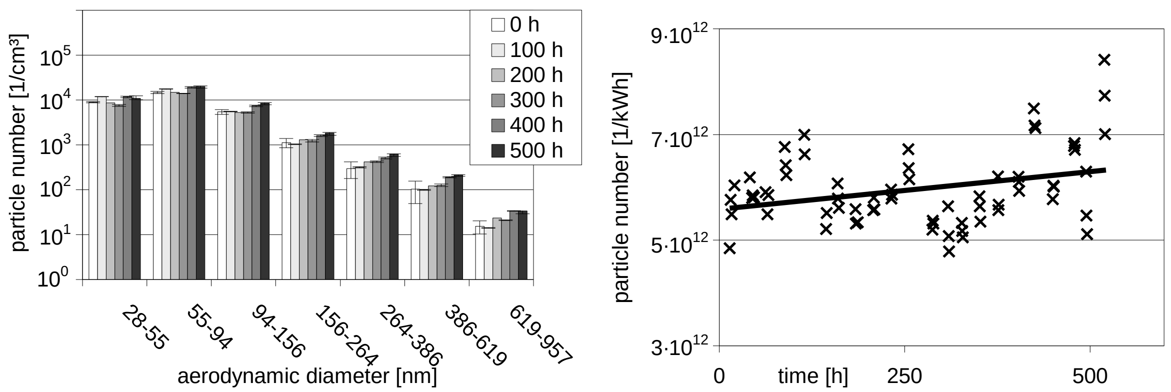

Figure 2: Particle number distribution and particle number (ELPI, ESC test) during the endurance test using RME

REFERENCES

1. Hill J, Nelson E, Tilman D, Polasky S, Tiffany D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proc Natl Acad.Sci 2006; 103(30): 11206–10.
2. Koonin SE. Getting serious about biofuels. Science 2006; 311:435.

3. Mittelbach M, Remschmidt C. Biodiesel – the comprehensive handbook. Graz, Austria; 2004.
4. Seaton, A., MacNee, W., Donaldson, K. Godden, D. (1995). Particulate Air Pollution and Acute Health Effects. Lancet 345 (8943), 176-178
5. Mayer, A. (2001). Particles. [online]. http://www.akpf.org/pub/particle_glossary_2001_10.pdf [quoted at 18.05.2006]

ACKNOWLEDGMENTS

Part of this research work was funded by the Verband der Deutschen Biokraftstoffindustrie e.V. (VDB). For this support of their work the authors like to express their gratitude.