

Emission Reduction Using Hydrotreated Vegetable Oil (HVO) With Miller Timing and EGR in Diesel Combustion

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ABSTRACT

Several high-speed diesel engine test runs were carried out during 2010 in Aalto University using a single-cylinder research engine. The main focus was on miller cycle and exhaust gas recirculation (EGR) tests using hydrotreated vegetable oil (HVO) as fuel. But also reference tests were run using both HVO and regular EN590 diesel in normal engine configuration and running parameters.

The miller tests included a sweep of three different intake valve closing timings and also a sweep with advanced start of injection. The results showed a reduction in both nitrous oxides (NO_x) and smoke emissions.

EGR tests showed a significant decrease in NO_x emissions as was expected. The lower smoke emissions of HVO compared to EN590 enable higher EGR percentages with similar PM emission and hence bigger NO_x emission reduction.

INTRODUCTION

Hydrotreated vegetable oil (HVO) is a renewable, high quality, high cetane number alternative fuel for diesel engines. Properties of HVO are very similar to gas to liquid (GTL) fuels and biomass to liquid (BTL) fuels produced by Fischer-Tropsch synthesis [1, 2, 3].

Previous HVO studies at Aalto university include 1D-simulations of the fuel injection system [4], 3D-simulations of HVO fuel sprays [5], and analysis on the nature of the soot particulate emissions of HVO compared to standard EN590 diesel fuel [6].

In this study the aim was to see how HVO is suited to the use of miller timing and EGR regarding nitrous oxides (NO_x) and particulate matter (PM) emissions. The problem of using EGR is the negative effect it has on PM emissions. In previous studies HVO has been found to produce significantly less PM emissions compared to standard EN590 diesel and also less NO_x emissions [1,7]. As the use of HVO reduces the base level of PM emissions, the benefits of EGR in reducing NO_x emissions can be utilized.

These test runs are a part of a larger research project going on in Aalto University, where the target is to find ways to utilize the strengths of HVO as fuel compared to normal EN590 diesel. Simple software optimization (of things like fuel injection timing) can lead to promising results [1,8]. Software optimization together with hardware changes such as a different compression ratio and use of different valve timings promise even more emission reductions.

EXPERIMENTAL SETUP

The experimental setup consists of a single cylinder research engine, dynamometer, emission measurement equipment, cylinder pressure sensor and various other measurement devices.

TEST ENGINE

The single-cylinder research engine (Figure 1) is based on a commercial 6-cylinder common rail direct injection diesel off road engine. The research cylinder uses the original commercial cylinder head and piston. The five "empty" cylinders have pistons for balancing purposes. Balancing pistons have holes in them so no compression work is done. Basic engine data is shown in Table 1. The engine uses an electric motor together with a frequency converter as a dynamometer.

Table 1 Basic engine data

Parameter	Value	Unit
Number of cylinders	1	#
Cylinder diameter	111	mm
Stroke	145	mm
Compression ratio	17:1	

Charge air is supplied by an external air compressor. The system is capable of producing charge air pressures up to 6 bar. Exhaust back pressure can be adjusted using a control valve in the exhaust pipe. The charge air system also has an air heater and a cooler to adjust the charge air temperature. The mass flow is

measured with a Micro Motion coriolis mass flow meter and controlled by a control valve.

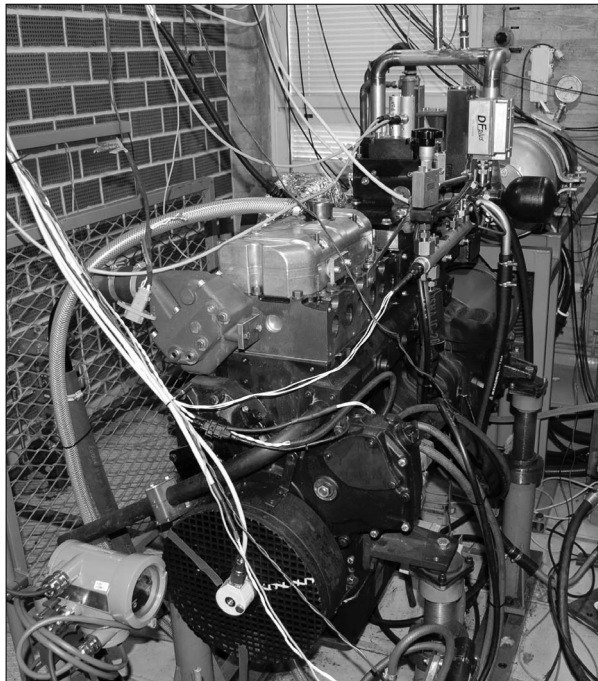


Figure 1 The single-cylinder test engine

Fuel injection parameters, such as injection pressure, injection timing, and injection duration can be adjusted freely. The system is capable of injection pressures up to 1600 bar.

The engine has an electro hydraulic valve actuator system (EHVA) which allows total freedom over gas exchange valve timings and use of different maximum lifts. EHVA makes the engine very well suited for valve timing test runs.

CONTROL AND DATA ACQUISITION SYSTEM

Control and data acquisition system in the engine is designed in house at Aalto University. The system is built on dSPACE real-time system and is based on a PowerPC powered computer with analog and digital I/O cards. The system is operated with a graphical user interface residing in a host PC. Same system is used for engine control and engine measurements excluding emission measurements.

All common engine variables are measured. Some of the sensors are from the original engine but others are from 3rd parties. Most important 3rd party sensors are cylinder pressure sensor and absolute encoder.

EGR SYSTEM

EGR in these test runs was simulated by using neat nitrogen gas. The gas is supplied to charge air before the air mass flow meter and charge air heater (Figure 2). The amount of nitrogen used is controlled by a Bürkert type 8626 inline mass flow controller.

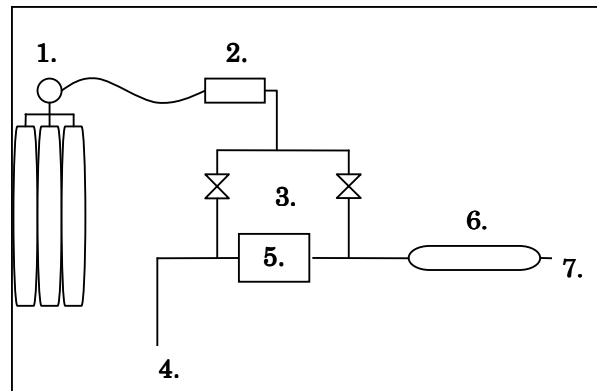


Figure 2 Charge air and EGR system: 1. Nitrogen bottles, 2. Nitrogen mass flow controller (Bürkert), 3. Closing valves, 4. Charge air from the compressor, 5. Charge air mass flow meter (Micro Motion), 6. Charge air heater, 7. To the engine

EMISSION MEASURING

The main focus in emission measuring was in particulate matter emissions and nitrous oxides emissions. In these test runs PM emission was evaluated based on smoke emission measurements. Filter smoke number (FSN) was measured using AVL 415S variable sampling smoke meter and NO_x using Eco Physics CLD 822 S h analyzer.

TEST FUELS

Test fuels used in these test runs were from Neste Oil. Commercial summer grade EN590 diesel fuel was used as reference fuel. Miller and EGR test runs were run on 100 % HVO. The most important properties of the fuels are presented in Table 2.

Table 2 Analyses of the test fuels

Quantity	Unit	EN 590	HVO
EN 590 diesel fuel	vol-%	100	0
HVO	vol-%	0	100
Carbon	wt-%	85,9	84,8
Hydrogen	wt-%	13,5	15,2
C/H-ratio ⁽¹⁾		6,4	5,6
Sulfur	mg/kg	3,6	<3,0
Nitrogen	mg/kg	2	
Total aromatics	wt-%	18,7	0,3
Monoaromatics	wt-%	17,5	0,3
Diaromatics	wt-%	1,1	<0,1
Triaromatics	wt-%	<0,10	<0,10
Polyaromatics ⁽²⁾	wt-%	1,1	<0,1
Ash	wt-%	<0,001	<0,001
Water	mg/kg	17	20
Density	kg/m ³	837,3	779,9
Flash point	°C	73	88
Cloud point	°C	-1	-12
Viscosity (at 40°C)	mm ² /s	3,587	2,985
Lubricity (HFRR)	µm/60°C	309	351
Cal. heating value	MJ/kg	46,038	47,216
Eff. heating value	MJ/kg	43,173	43,991
	MJ/l	36,149	34,308
Cetane number (IQT)		56	88,2
Distillation			
5 vol-%	°C	210	260
50 vol-%	°C	293	281
90 vol-%	°C	348	293
95 vol-%	°C	361	298
Final boiling point	°C	365	309

⁽¹⁾ Calculated from carbon and hydrogen content

⁽²⁾ Sum of di- and tri+ aromatics according to the European regulation

TEST MATRIX

All test runs were run under steady state conditions with a warmed up engine running at the speed of 1500 r/min.

REFERENCE TESTS

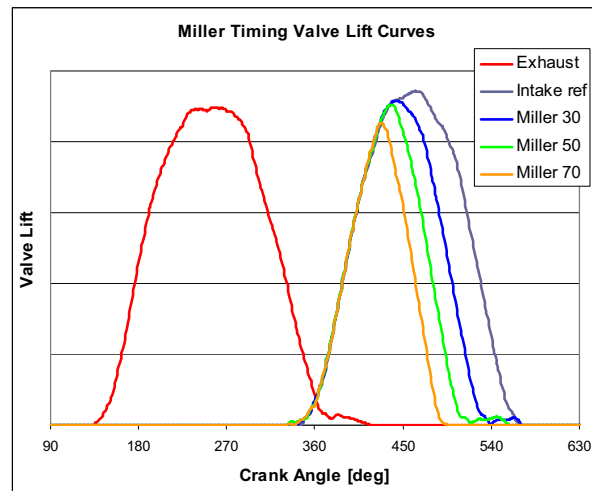
Reference tests were run with both fuels to establish a base level for emissions. The engine was run on commercial engine running parameters. Parameters include charge air pressure, charge air temperature, exhaust back pressure, fuel injection pressure, fuel injection timing, and fuel injection pressure.

Reference test were run at 25 %, 50 %, 75 %, and 100 % loads.

MILLER TIMING

The miller timing test runs were run at 100 % load conditions using only HVO. Miller cycle was achieved by early intake valve closing angle. Three different miller timings were run; 30, 50, and 70 degree miller.

The number stands for the number of crank angle degrees earlier the intake valve is closed compared to normal valve timing. Measured valve curves are presented in Figure 3.

**Figure 3 Measured miller timing valve lift curves**

During the different miller points the air mass flow was kept constant by increasing the charge air pressure. Exhaust back pressure was adjusted according to measurements from the production engine turbo charger to match.

Two test run series with different fuel injection timings were carried out. The first series was run with standard start of injection (SOI), the standard being the timing from the commercial engine. Second series was run with advanced start of injection (ASOI) of 2 crank angle degrees compared with standard timing.

EGR

In these test runs EGR was simulated using neat nitrogen. In this study the given EGR rate is the percentage of N₂ mass flow compared with the total charge air + N₂ mass flow. It is acknowledged that these rates are not the same as the EGR rates using real exhaust gas.

$$EGR\% = \frac{\dot{m}_{N_2}}{\dot{m}_{Air} + \dot{m}_{N_2}}$$

Moderate EGR

Moderate EGR rate test runs were run with HVO at 75 % load. All the engine running parameters were kept constant. The EGR rate was increased from 0 to 10 % with 2,5 % steps.

Extreme EGR

Extreme EGR tests were ran with both fuels at 50 % load. The engine running parameters were kept constant and only the EGR percentage was varied.