2nd VegOil

Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines

Workpackage 2

Engine development

Deliverable N° 2.5:

Report on tests of stage 3B engine

Publishable Summary

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List of Acronyms

ASTM	American Society for Testing and Materials
CLD	Chemiluminescence detector
CO	Carbon monoxide emissions
DB	Durability built
DK	Diesel fuel
DOC	Diesel oxidation catalyst
DPF	Diesel particulate filter
ECU	Engine control unit
FID	Flame ionization detector
FLRS	Full load rated speed
JD	John Deere
FB	Feasibility built
HC	Hydrocarbon emissions
HCI	Hydro Carbon Injection
KL	Kaiserslautern
MFDA	Multi Functional Diesel Additivs
NDIR	Non-dispersive infrared
NO_x	Nitrogen oxide emissions
NRSC	Non road stationary cycle
NRTC	Non road transient cycle
NTE	Not to exceed zone
PIN	Product identification number
PM	Particulate matter
PPO	Pure Plant Oil
PVO	Pure Vegetable Oil
2G-PVO-RS	2nd Generation Pure Vegetable Oil based on Rape seed oil
RS	2nd Generation Pure Vegetable Oil based on Rape seed oil
WIPO	World Intellectual Property Organization

1 Summary

Within this document the results of the tests with an EU stage 3B engine powered by different 2nd generation vegetable oil fuels (2G-PVO) are described. Therefore it builds on the 2nd VegOil deliverable N° 2.4.
To fulfil stage 3B emission limits, the engine control software was recalibrated, primarily to reduce NO_x emissions. NRSC and NRTC test results are presented for diesel and 2G-PVO from rapeseed, camelina and jatropha. With the new software the stage 3B emission limits as well as the full load power can be achieved with all tested fuels.

2 Testing environment

The test results presented in chapter 3 refer to the stage 3B engine and testing environment described in the 2nd VegOil deliverable N° 2.4.
The only difference is that the testing environment is also equipped with an engine dynamometer which can run transient tests and therefore now the full results for stage 3B emission testing can be delivered, as PM emissions have to be measured in the Non Road Transient Cycle (NRTC) from stage 3B onwards. For a description of the transient test rig see 2nd VegOil deliverables N° 2.2 and 2.3.

2.1 Test plan

The testing proceedings are based on those applied on the EU stage 3A engine (see 2nd VegOil deliverable 2.2 [5] and 2.3 [3]), including some lessons learned during this first stage of the engine development part of the project. The scheduled test plan for the development of a functional stage 3B vegetable oil engine is listed below. The topics I through XI are discussed in 2nd VegOil deliverable No 2.4.

I. Integration of the engine into the test rig environment.
II. Start up and basic functional testing with diesel fuel.
III. Reference measurements with diesel fuel: full load performance, emission testing, part load map characteristics.
IV. Adaptation of hardware based on experiences from stage 3A engine development.
V. Evaluation of functionality of hardware adaptation (leakage, compliance with engine application requirements, performance).
VI. Switch to vegetable oil by blending diesel fuel step by step with 2G-PVO-RS during engine operation.
VII. Evaluation of functionality of hardware measures with 2G-PVO-RS.
VIII. Reference measurements with 2G-PVO-RS according to III.
IX. Evaluation of differences between diesel and 2G-PVO-RS regarding power, emissions and general performance.
X. Determination of required software modifications for 2G-PVO-RS to achieve the power and emission levels of diesel fuel. (No I vegetable oil software)

XI. Emission testing according to 97/68/EC [10] and 2004/26/EC [11] with No I vegetable oil software.

XII. Further improvement of basic software for transient cycles, regeneration, cold starting.

XIII. Engine test cycles with camelina and jatropha oil.

2.2 Fuels

The same fuels as used on the 3A engine are used on the 3B engine: diesel according to DIN EN 590 and 2G-PVO according to DIN V 51605 (except for the fuel source) with a higher quality regarding the element content. The results of the fuel analysis are displayed in Table 1.

Table 1 Analysis results of the used vegetable oils

	Limit DIN V 51605 (rapeseed oil)	Rapeseed oil *Brassica napus* L.	False flax oil *Camelina sativa* L.	Jatropha oil *Jatropha curcas* L.
Density @15°C (kg/m³)	900…930	919	926.4	918
Calorific value (MJ/kg)	36.0	37.6	37.2	37.2
Cinematic viscosity @40°C (mm²/s)	max. 36	35.0	29.8	34.2
Ignitability	min. 39	47.6	47.3	55.9
Flashpoint (°C)	min. 220	280	254	229
Carbon residues (% m/m)	max. 0.40	0.29	0.28	0.24
Iodine number (g Iodine/100 mg)	95…125	110	148	99
Sulfur content (mg/kg)	max. 10	4.0	3.2	<1
Total contamination (mg/kg)	max. 24	3	-	15
Acid number[1] (mg KOH/g)	max. 2.0	0.99	3.46	11.20

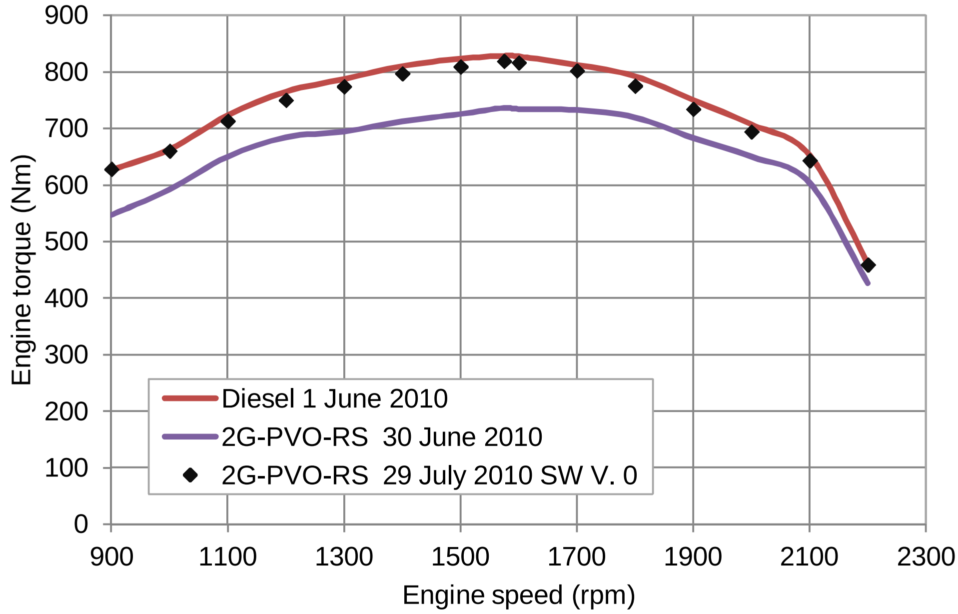
[1] The acid number of false flax as well as jatropha oil exceeded the limit of 2 mg KOH/g. This quality reducing property was accepted for the short term engine testing. For a long term, durable engine operation the high acid number would not be accepted, as it causes corrosion that can lead to a total damge of the engine. At the same time the oxidation stability of the jatropha oil is very high, though it

Oxidation stability (h)	min. 6	7.4	1.3	37.6
Phosphorous content (mg/kg)	max. 12	0.8	<0.5	<0.5
Calcium +magnesium content (mg/kg)	max. 20	1.2	<0.5	<0.5
Oxide ash (% m/m)	max. 0.01	<0.001	<0.001	0.001
Water content (mg/kg)	750	586	823	668

3 Results

3.1 Full load performance

The goal of the following engine adaptation, especially of the software calibration, is to hit this curve (as a reference the full load curve with diesel fuel on the 1 June 2010 was selected) with 2G-PVO fuels.



should be reduced at such a high acid number. Teh oxidation stability was improved by a fuel additive, which was dosed ccording to the supplier's recommendation, but was obviously too high.

Figure 1 **Full load curves of the CD6068R000040 engine with diesel and rapeseed oil with series software and with rapeseed oil and modified software (vegetable oil SW version No 0)**

4 IT4 software calibration for biofuels

4.1 Initial situation

Without any change of the ECU software an NRSC was conducted with 2G-PVO-RS. The most critical limited exhaust components were the NO_x emissions, which were above the stage 3B limit (see also 2nd VegOil deliverable n° 2.4). Therefore the engine calibration for 2G-PVO was carried out with the primary goal to reduce NO_x emissions below the stage 3B limit.

4.2 Engine software calibration

To evaluate the effect of different software parameter modifications, the test plan displayed in Table 2 was conducted. The varied parameters were selected based on experiences from the stage 3A engine development, as well as on the training of JDWM staff at JDPS (engine supplier).

Table 2 **Parameter variation for biofuel software calibration**

Run n°	DiluenttoAirRatio	MainTiming	Railpressure
1	Reference = series SW w/ diesel fuel		
2	+10%		
3	-10%		
4		-5°	
5		+5°	
6			-20 MPa
7			+20 Mpa

These parameters were varied in mode 1, 3 and 4 of the NRSC. While the main focus was on the NO_x emissions, the filter smoke number (FSN), power and fuel consumption were also considered.

5 Test results

The software developed as described in chapter 4.1 was applied on the stage 3B engine with diesel fuel as well as 2nd generation vegetable oil fuel made from rapeseed, camelina and jatropha. The results are listed below for the NRSC and NRTC tests for all tested vegetable oil fuels.

5.1 NRSC

By the change of the engine software the NO_x emissions were successfully reduced with all tested vegetable oil fuels by at least 20%. The other limited emissions PM, CO and HC did not change significantly, as they already were on a very low level.

Table 3 Results of the NRSC with modified biofuel software and 2G-PVO-RS

	Limit of stage 3B	Post DOC/DPF
CO (g/kWh)	3.5	0.03
HC (g/kWh)	0.19	0.02
NO_x (g/kWh)	2.0	1.37
PM (g/kWh)	0.025	0.01

Table 4 Results of the NRSC with modified biofuel software and 2G-PVO-CS

	Limit of stage 3B	Post DOC/DPF
CO (g/kWh)	3.5	0.03
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	2.0	1.22
PM (g/kWh)	0.025	0.01

Table 5 Results of the NRSC with modified biofuel software and 2G-PVO-JA

	Limit of stage 3B	Post DOC/DPF
CO (g/kWh)	3.5	0.04
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	2.0	1.16
PM (g/kWh)	0.025	0.01

5.2 NRTC

To check the compliance with stage 3B particulate (PM) emission limits, the NRTC was run with a cold and warm engine as defined in [11]. The results of all tested fuels are listed in Table 6. The PM limit for EU stage 3B and 4 is 0,025 g/kWh, which is undershot easily with all fuels. As the PM was measured behind the DOC/DPF according to 2004/26/EC [11], there are no significant differences between the fuels.

Table 6 PM emissions with diesel and 2G-PVO in the NRTC

Test	Diesel	Rapeseed	False flax	Jatropha
NRTC cold (g/kWh)	0.015	0.015	0.007	0.012
NRTC warm (g/kWh)	0.004	0.013	0.009	0.017
Weighed result (g/kWh)	0,005	0.013	0.009	0.016

6 Outlook

The software and hardware measures will also be evaluated on a stage 3B tractor. Especially the investigations regarding the DPF regeneration fuel system will be transferred to the tractor, as first tests showed differences between the engine test rig and the tractor. Especially the temperatures of single components are considerably higher under the tractor hood compared to the engine test rig.

For the engine development the next step will be to install an SCR system on the engine with the goal to achieve stage 4 emission limits, where NO_x will be reduced by 80% compared to stage 3B.

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