2nd VegOil

Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines

Workpackage 2

Engine development

Deliverable N° 2.6:

Functional stage 4 plant oil engine

Publishable Summary

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List of Acronyms

ASTM	American Society for Testing and Materials
ATD	(Exhaust) Aftertreatment device
CLD	Chemiluminescence detector
CO	Carbon monoxide emissions
DB	Durability built
DEF	Diesel exhaust fluid (“AdBlue”): 32.5% urea, 67.5% water
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
PSX	John Deere Engine Model (stage 3B)
RS	2nd Generation Pure Vegetable Oil based on Rape seed oil
SCR	Selective Catalytic Reduction
WIPO	World Intellectual Property Organization
2G-PVO-RS	2nd Generation Pure Vegetable Oil based on Rape seed oil

1 Summary

A PowerTech PSX engine was tested with different vegetable oil fuels for its power and emission performance. The tested fuels were diesel and 2nd generation vegetable oil from rapeseed, jatropha and false flax. The engine was equipped with a DOC and DPF system, as well as an SCR system to reduce PM and NO_x emissions to fulfil EU stage 4 emission limits.

Within this document the development and first results of the tests with an EU stage 4 engine powered by different 2nd generation vegetable oil fuels (2G-PVO) are described. Therefore this document continues the 2nd VegOil deliverables N° 2.4 and 2.5.

The emission limits could be fulfilled with all the tested fuels due to modifications of the engine control software for the vegetable oils.

2 Testing environment

The test results presented in chapter 3 refer to the same testing environment as described in the 2nd VegOil deliverable N° 2.5.

2.1 Engine

For the stage 4 engine development a JD PowerTech PSX engine was used. The engine includes an exhaust aftertreatment device (ATD) consisting of a diesel oxidation catalyst (DOC), a diesel particle filter (DPF) and a selective catalytic reduction catalyst (SCR). As the DOC and the DPF are the same as on the stage 3B engine, only the SCR will be described in the following part.

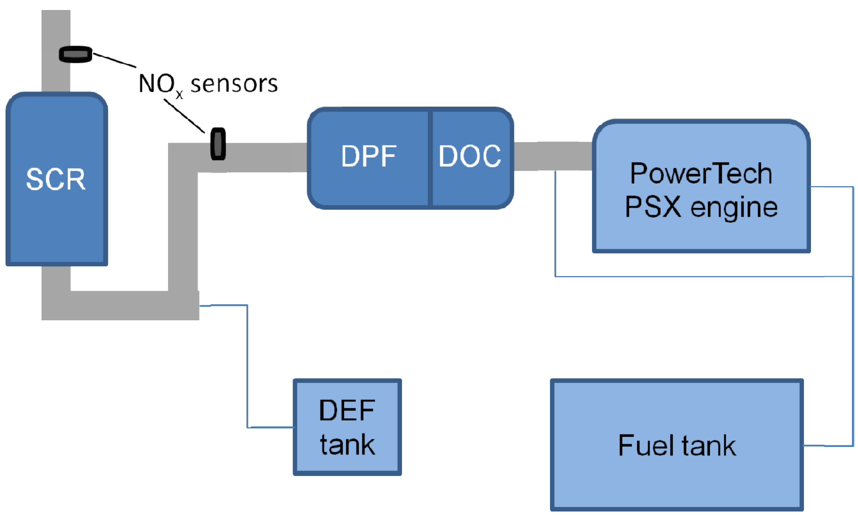

Figure 1 Schematic engine layout PowerTech PSX with exhaust aftertreatment devices

After the exhaust gas leaves the DPF, DEF is injected into the exhaust gas where it is hydrolysed into ammonia (NH_3) and water[1]. Within the SCR, NO and NO_2 is reduced into N_2. The required amount of DEF is calculated by the ECU software, based on the outputs of two NO_x sensors before and after the SCR catalyst. To make sure that no excessive NH_3 slips trough the SCR catalyst, the NH_3 emissions are measured with a spectroscope.

2.2 Test plan

I. Start up and basic functional testing with diesel fuel.
II. Reference measurements with diesel fuel: full load performance, emission testing, part load map characteristics.
III. Reference measurements with 2G-PVO-RS
IV. Evaluation of differences between diesel and 2G-PVO-RS regarding power, emissions and general performance.
V. Determination of required software modifications for 2G-PVO-RS to achieve the power and emission levels of diesel fuel. (No I vegetable oil software)
VI. Emission testing according to 97/68/EC [12] and 2004/26/EC [13] with No I vegetable oil software.
VII. Further improvement of basic software for transient cycles, regeneration, cold starting.
VIII. Engine test cycles with false flax and jatropha oil.

2.3 Fuels

The same fuels as used on the 3A and 3B engine are used for the stage 4 engine: diesel according to DIN 51628 and 2G-PVO according to DIN V 51605 (except for the fuel source) with a higher quality regarding the content of P, Ca and Mg. 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/m^3)	900…930	919	926.4	918
Calorific value (MJ/kg)	36.0	37.6	37.2	37.2
Cinematic viscosity @40°C (mm^2/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 resi-	max. 0.40	0.29	0.28	0.24

[1] For further details regarding SCR principles see [3], [7].

dues (% m/m)				
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[2] (mg KOH/g)	max. 2.0	0.99	3.46	11.20
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 full load performance was measured with diesel, false flax and rapeseed oil. This was done with the series control software to verify the differences between the fuels. On average both 2G-PVO-RS and 2G-PVO-CS delivered about 8% less power than diesel fuel.

[2] 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 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.

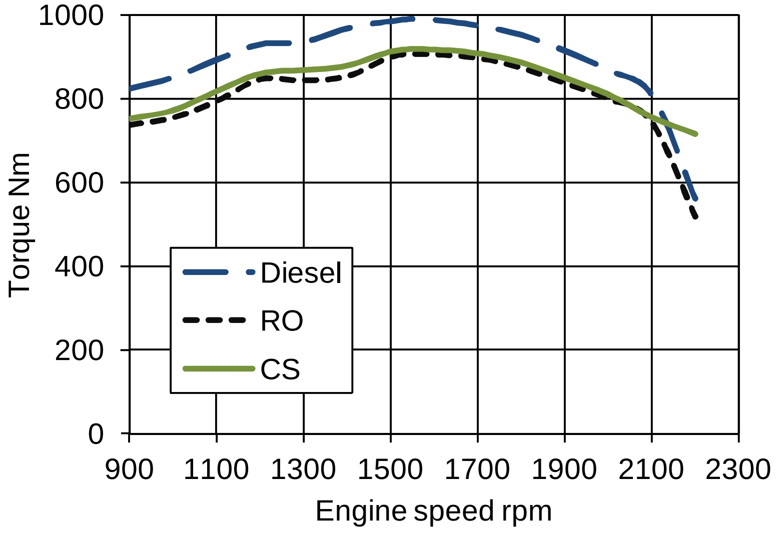

Figure 2 **Full load curves of the PowerTech PSX engine**

For further tests the software was adjusted to achieve the same full load power with the vegetable oils as with diesel fuel. The measures to achieve the required power were deduced from the stage 3B engine development (see 2nd VegOil deliverables No 2.4 and 2.5). To verify the effectiveness of these changes, the engine power in the full load modes of the NRSC are displayed in Table 2 for all the tested fuels.

Table 2 **Full load power in mode 1 and mode 5 of the NRSC with different fuels. Series software for diesel fuel, modified engine software for the biofuels.**

Fuel	Mode 1 (kW)	Mode 5 (kW)
Diesel	176	161
Rapeseed oil	177	162
Jatropha oil	176	162
False flax oil	176	160

3.2 Emissions

3.2.1 NRSC

Initially the engine was tested with diesel fuel and series software. Table 3 shows the results of the NRSC after the complete exhaust aftertreatment device (ATD).

Table 3 **Results of the NRSC with series software and diesel fuel**

	Limit of stage 4	after ATD
CO (g/kWh)	3.5	0.02
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	0.4	0.33
PM (g/kWh)	0.025	0.007

The first test with 2G-PVO-RS was conducted with series software of which the results are listed in Table 4. The engine raw emissions (before ATD) were consistent with the results measured in the NRSC with the stage 3A and stage 3B engine, which showed a tendency to increase CO and NO_x with 2G-PVO compared to diesel, as well as a reduction of PM and HC. Behind the ATD the emissions were on a similar level as with diesel fuel after the ATD, though NO_x emissions exceeded the stage 4 limit by 0.02 g/kWh.

Table 4 Results of the NRSC with series[3] software and 2G-PVO-RS

	Limit of stage 4	after ATD
CO (g/kWh)	3.5	0.03
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	0.4	0.42
PM (g/kWh)	0.025	0.007

As the NO_x emissions were only a small fraction above the stage 4 limit, the software was not modified for the second tested fuel, false flax oil (2G-PVO-CS). The reason was to find out if this tendency was persistent. The results for 2G-PVO-CS emissions in the NRSC with series software (power output adjusted) are displayed in Table 5. CO and HC emissions are on the same level as diesel and rapeseed oil fuel, while PM are reduced and NO_x even increased compared to rapeseed oil. Therefore the engine control software was adjusted to reduce the NO_x emissions with false flax oil. As the engine raw NO_x emissions are higher with the vegetable oils, the amount of diesel exhaust fluid (DEF) was increased for those fuels. The results measured with the modified software are presented in Table 6. With the modified software all emission limits were met with false flax and jatropha oil. Rapeseed oil was not tested again, as its engine raw emissions already were below the raw emissions of false flax and jatropha and therefore can easily be met with those modifications.

Table 5 Results of the NRSC with series[3] software and 2G-PVO-CS

	Limit of stage 4	after ATD
CO (g/kWh)	3.5	0.04
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	0.4	0.46
PM (g/kWh)	0.025	0.004

Table 6 Results of the NRSC with modified biofuel software and 2G-PVO-CS

	Limit of stage 4	after ATD
CO (g/kWh)	3.5	0.02
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	0.4	0.36
PM (g/kWh)	0.025	0.007

[3] Series software adjusted for the same power output as with diesel fuel.

Table 7 Results of the NRSC with modified biofuel software and 2G-PVO-JA

	Limit of stage 4	after ATD
CO (g/kWh)	3.5	0.02
HC (g/kWh)	0.19	0.01
NO_x (g/kWh)	0.4	0.34
PM (g/kWh)	0.025	0.005

3.2.2 NRTC

To verify the compliance with stage 4 particulate (PM) emission limits, the NRTC was run with a cold and warm engine as defined in [13]. The results of all tested fuels are listed in Table 8. The PM limit for EU stage 4 is 0.025 g/kWh, which is undershot easily with all fuels. As the PM was measured after the DOC/DPF according to 2004/26/EC [13], there are no significant differences between the fuels. The DPF is working efficiently with all tested fuels.

Table 8 PM emissions with diesel and 2G-PVO in the NRTC

Test	Diesel	Rapeseed	False flax	Jatropha
NRTC cold	0.006	0.017	0.008	0.011
NRTC warm	0.005	0.016	0.012	0.010
Weighed result	0.005	0.016	0.012	0.010

4 Conclusions and Outlook

The functionality of an EU stage 4 engine and its exhaust aftertreatment devices was proven with all tested fuels. To fulfil the stage 4 NO_x limit, the NH_3 flow had to be adjusted for vegetable oil compared to diesel fuel.

For the future the active regeneration of the DPF system needs to be improved, which is currently not satisfactory with vegetable oil fuels. Nevertheless the SCR system, as tested on the engine test rig, was also installed on a stage 3B tractor to run first tests as a stage 4 prototype.

5 References

[1] Birkner, C.: Untersuchung der Eignung von Pflanzenölen als Kraftstoff für Dieselmotoren und Vorstellung eines neuen Pflanzenöl-Motor-Konzeptes. Dissertation. Kaiserslautern, 1995.

[2] Blassnegger, J., M. Knauer, M. Carrara, R. Niesser, M. Urbanek, B. Geringer, W. Schramm, J. Kunze und M. Wörgetter: Untersuchung: Emissionen bei der motorischen Verbrennung von Biokraftstoffen und Kraftstoffmischungen. Endbericht FNR-Forschungsvorhaben FKZ 114-50.10.0077/07-E. Gülzow, December 2009.

[3] Bosch: SCR cactalytic converter. http://rb-kwin.bosch.com/at/en/ powerconsumptionemissions/dieselsysteme/dieselsystem/commercialvehiclesystems/exhaust-gas_treatment/denoxtronic/scrcatalyticconverter.html.

[4] Dieringer, S.: Report 3A. Deliverable No 2.3, EU 2nd VegOil Project. www.2ndvegoil.eu

[5] Geringer, B.: Biokraftstoffe - Herausforderung an die Motoren von morgen. OTTI Symposium. Kloster Banz, 19.11.2009.

[6] Harndorf, H., U. Schümann, V. Wichmann und C. Fink: Motorprozessverhalten und Abgasemissionen alternativer Kraftstoffe im Vergleich mit Dieselkraftstoff. MTZ 07-08/2008, p.640-647. July 2008.

[7] Krüger, M. and N. Breuer: Abgasnachbehandlung. In: Handbuch Dieselmotoren. Springer Verlag. Berlin, Heidelberg, 2007. ISBN 978-3-540-72164-2

[8] Pickel, P., S. Dieringer, M. Lang and G. Rütz: Test stand. Deliverable No 2.2, EU 2nd VegOil Project. www.2ndvegoil.eu

[9] Robert Bosch GmbH, WIPO, WO 2007/012512 A1 (PCT/EP2006/062820)

[10] Thuneke, K.: Untersuchungen zu Abgasemissionen und zum Einsatz von Partikelfiltersystemen bei rapsölbetriebenen Blockheizkraftwerken. Dissertation. Hieronymus Buchreproduktions GmbH. München, 2009.

[11] -,-: Racor® fuel filter / water seperator pump systems, Parker catalogue 2010

[12] -,-: Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery. Official Journal of the European Communities, L 59. Brussels, 27.09.1998.

[13] -,-: Directive 2004/26/EC of the European Parliament and of the Council of 21 April 2004 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery. Official Journal of the European Communities, L 225. Brussels, 26.06.2004.