2nd VegOil

Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines

Workpackage WP2

Engine development

Deliverable N° 2.8:

Hybrid engine measurements and tests

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1 Introduction

Within the EU funded project „**Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines**“ the Chair of internal combustion engines (Lehrstuhl für Verbrennungskraftmaschinen, LVK) of the Technische Universität München works on the workpackage WP2 “engine development”. The objective of this workpackage is to develop engines able to comply with the EU Stage 4 (for non-road vehicles) emission norms if fuelled with the 2nd generation vegetable oil fuel developed in workpackage WP3. The WP2 consists of the development work regarding in particular exhaust gas aftertreatment systems (responsible: John Deere) in the first project steps. On the other hand, another project goal is to develop a hybrid engine system to achieve future emission limits.
The development work at the engine laboratory of the LVK is done on a hybrid test stand. This test stand was built up in the project months 1 to 9 (please see Deliverable D2.7 for further information). During this period, reference tests and measurements with mineral diesel fuel were executed, which are briefly described in this document.

2 Reference to project planning: key partners, scope of the key partners, timetable and milestone

In terms of testing and the first measurements the key partner is John Deere, who delivered the combustion engine for the hybrid test stand. All information regarding the JD 6068 HL481 diesel engine, like application requirements and default parameters for the engine operation, provides John Deere.
The scheduled time for testing and measuring is 8 months (month 2 to 9). Task 2.8 “Measurements and tests” ends with the milestone M2.2H (“Acquisition of all necessary engine parameters is finished”). The present deliverable summarises the results of the reference measurements and tests with mineral diesel fuel.

3 Test stand testing and first measurements

For the 2nd VegOil project a certain range of tractor models was selected for the fleet demonstration. These models are the 6830 Premium, 6930 Premium, 7430 Premium and 7530 Premium tractors of John Deere. Those models are powered by the 6068 Powertech Plus engine at different power levels. The 6830 Premium and 6930 Premium tractors have got the CD6068HL481 engine and the 7430 Premium and 7530 Premium the CD6068HL482. Those two engine models differ for example in the stability of the crankshaft, but not in major technological properties like air or fuel system. The different power levels are implemented by different ECU software versions. The 6068 Powertech Plus engines are four-valve en-

gines with a high pressure common rail system for fuel injection. They are turbocharged and have an external exhaust gas recirculation (EGR) system including cooler to control NO_x emissions.
Those tractor models were selected as they are the largest and most powerful tractors produced at the John Deere Werke Mannheim (JDWM). After evaluation of the market demand it is clear that mostly owners of large tractors with numerous operating hours demand a plant oil powered tractor. In that case the highest saving potential is achieved and the investment in the engine technology is profitable.
For the test stands the CD6068HL481 was selected.

The LVK test stand simulates a hybrid system, thus allowing studying experimentally different hybrid engine configurations. This simulation is done with a four-quadrant-machine, which is able to drive, respectively to consume, the power of the combustion engine. With this test stand, the development of an engine operation strategy on the basis of hybrid operation will be developed whereby the disadvantageous combustion engine operation points regarding vegetable fuels can be avoided.
To get all necessary engine data, the Diesel fuelled combustion engine was measured with an operational test increment measurement (not least for later comparisons with the vegetable oil operation measurement data). Fig. 1 shows the operation points (measurement status: May 2009)

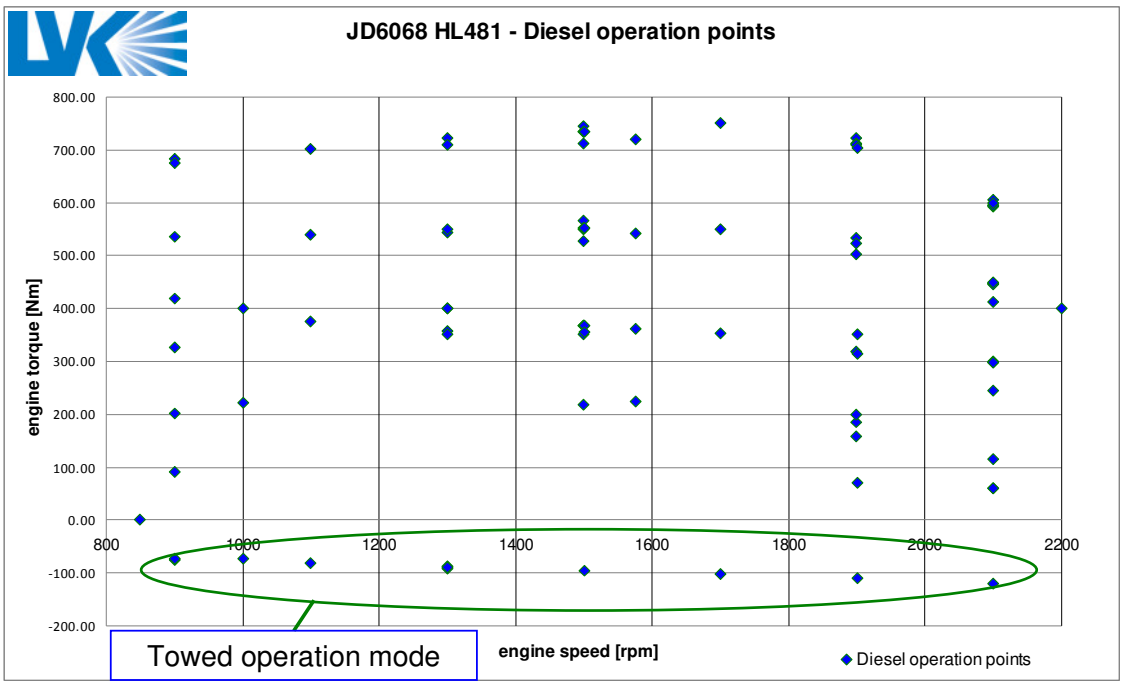

Fig.1: Measured diesel operation points

Description of the measured engine data

For developing a hybrid engine operation strategy that complies with future emission limits for non-road diesel engines (e.g. tractor engines), it is important to know as much as possible about the combustion engine`s operation data. Examples therefore are:

- engine speed
- power output / torque
- combustion – air ratio (respectively air-fuel ratio)
- air mass flow
- fuel consumption
- fuel temperature
- air intake temperature / pressure
- cylinder head temperature
- cylinder liner top dead centre / bottom dead centre temperature
- exhaust temperature / pressure before and after the turbine
- cooling fluid temperature
- lubricant temperature / pressure
- exhaust gas recirculation temperature / mass
- cylinder pressure curve over one degree crank angle
- variable turbine geometry position

All data will be used for later comparison with the vegetable oil operation data. The diesel measurements provide reference data which mark the state-of-the-art at the beginning of the project measurements (please see the annexed extract as an example for one data file). Furthermore, the data are used as input parameters for the (thermodynamic) simulation of the combustion engine. The latter allows saving time in the development process through iterative simulation of single operation modes without the test stand. The data are also used for validating the output of the simulation.

Diesel measurement – results

Figure 2 shows the torque and power curve for the diesel operation (Diesel fuel DIN 51628 with a maximum rate of fatty acid methyl ester of 7 vol. %).

Fig. 2: Torque and power curve (Diesel operation)

The engine achieves the torque and power output stated by the OEM (John Deere).
Besides the above-written, the emission limits for this engine development stage (EU STAGE 3A) have to be kept. For this reason, the pertinent emission cycle (NRSC: **N**on **R**oad **S**tationary **C**ycle, specified by the EU - directive 2004/26/EG) was executed with the Diesel fuelled engine. This cycle consists of eight steps. The following table shows the engine speed and the engine load at the different steps:

step	engine speed	engine load	duration	weighting factor
[-]	[rpm]	[%]	[sec.]	[%]
1	2100	100	600	15
2	2100	75	600	15
3	2100	50	600	15
4	2100	10	600	10
5	1575	100	600	10
6	1575	75	600	10
8	850	0	600	15

Fig. 3: Survey – NRSC steps for JD6068HL481

For the overall result, the single step emission is multiplied with the weighting factor and summed up with the other single step results.
The overall result after the measurement analysis is listed below:

	emission measured [g/kWh]	emission limit EU Stage 3A [g/kWh]
E_{spezNO_x}	3,31	-
E_{spezCO}	0,71	3.500
E_{spezHC}	0,05	-
$E_{spezNOx+HC}$	3,36	4.000
E_{spezPM}	0,08	0.200

Fig. 4: Results NRSC (Diesel operation), Date: 08.12.2009

All limits were adhered to. Especially carbon monoxide (CO) and particulate matter (PM) are considerably lower than the specified limit. The JD6068HL481 engine complies with the EU Stage 3A.

4 Conclusion and summary

In Task 2.8 the hybrid test stand was validated and reference tests and measurements with mineral diesel fuel were executed. The collected comprehensive measurement data will be used for (1) later comparisons with the vegetable oil measurement data, (2) as input data for the simulation and (3) for validating the simulation results.

5 Annex – example table diesel operation

Name Andreas Hubert
Datum 24.02. - 26.02.2009

n	M	p_{me}	Last n. Anzeige 32	P	Verbrauch n. Anzeige 30	b_e	λ_{alle}	$T_{Öl}$	$T_{Kühlwasser, kl. Kreis}$	$T_{vor Verdichter}$	$T_{Ladeluft, n. Anzeige 31}$	$p_{Ladeluft n. Anzeige 35}$	$p_{Commonrail nach Anzeige 38}$	$T_{Kraftstoff vor Pumpe}$	$T_{Kraftstoff vor Injektor}$	$T_{Zyl.kopf 1}$	$T_{Zyl.kopf 6}$	$T_{Buchse1_UT}$	$T_{Buchse1_OT}$	$T_{Abgas,Zyl 1}$	$T_{vor Turbine}$	$T_{nach Turbine}$	$p_{vor Turbine}$	$p_{nach Turbine}$
[1/min]	[Nm]	[bar]	[%]	[kW]	[l/h]	[g/kWh]	[-]	[°C]	[°C]	[°C]	[°C]	[bar]	[bar]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[bar]	[bar]
1) 50% Lastkennlinie																								
900.0	418.0	7.7	50.0	39.4	8.5	182	1.56	23.00	81.00	18.58	13.00	1.10	540.00	38.81	61.82	124.56	140.12	95.43	119.62	404.89	473.08	410.32	1.43	1.00
1100.0	375.0	6.9	50.0	43.2	10.2	197	1.95	23.00	80.70	18.60	13.00	1.20	685.00	39.95	63.04	123.14	136.95	95.56	118.45	355.44	393.47	332.76	1.82	1.03
1300.0	357.0	6.6	50.0	48.6	12.5	216	2.17	26.00	80.50	18.57	13.00	1.29	925.00	41.65	66.14	123.88	137.90	96.13	121.84	336.23	371.68	305.79	2.08	1.04
1500.0	356.0	6.6	50.0	55.9	14.8	222	1.96	93.00	81.20	19.03	12.00	1.11	1225.00	50.38	76.97	132.25	148.00	97.36	126.51	372.05	442.50	391.83	1.55	1.01
1700.0	354.0	6.6	50.0	63.0	16.9	225	1.89	87.00	81.20	19.16	12.00	1.17	1265.00	52.35	78.13	130.27	144.28	97.46	124.00	373.81	419.13	375.13	1.35	1.01
1900.0	315.0	5.8	50.0	62.7	17.5	235	2.11	93.00	80.90	19.20	13.00	1.19	1255.00	44.81	73.85	128.16	145.62	96.04	125.34	340.29	426.45	365.67	1.65	1.06
2100.0	245.0	4.5	50.0	53.9	16.5	257	3.54	95.00	80.50	19.17	20.00	1.84	1250.00	46.68	74.36	118.13	130.54	95.89	112.40	278.30	307.81	202.05	4.78	1.16
2) 75% Lastkennlinie																								
900.0	535.0	9.9	75.0	50.4	12.7	211	1.35	91.00	80.90	19.00	14.00	1.17	780.00	44.51	68.04	135.03	150.55	98.50	131.52	466.50	508.45	433.53	1.62	1.00
1100.0	539.0	10.0	75.0	62.1	15.3	206	1.56	91.00	81.40	19.15	13.00	1.34	890.00	44.70	68.24	136.86	151.74	98.35	128.90	449.10	489.03	403.83	2.08	1.03
1300.0	543.0	10.1	75.0	73.9	18.2	207	1.77	91.00	80.70	19.02	14.00	1.51	1070.00	46.95	71.69	137.18	152.91	97.78	129.03	411.73	470.78	376.12	2.48	1.06
1500.0	567.0	10.5	75.0	89.1	22.0	207	1.58	92.00	81.60	19.43	14.00	1.40	1200.00	51.73	77.67	143.66	161.04	99.64	134.90	451.08	540.08	462.70	1.87	1.04
1700.0	550.0	10.2	75.0	97.9	25.0	214	1.66	95.00	81.50	19.78	15.00	1.47	1240.00	54.00	81.22	143.13	161.60	99.78	136.44	441.83	558.14	475.24	1.97	1.09
1900.0	523.0	9.7	75.0	104.1	26.5	214	1.85	96.00	81.40	19.74	16.00	1.55	1260.00	54.20	82.19	141.41	158.94	100.62	131.58	407.99	514.01	424.55	2.25	1.12
2100.0	413.0	7.6	75.0	90.8	25.0	231	2.02	96.00	81.10	20.05	15.00	1.40	1295.00	55.72	84.29	135.71	153.22	100.26	128.85	378.61	475.43	397.99	2.06	1.11
3) 100% Lastkennlinie																								
900.0	684.0	12.7	100.0	64.5	16.9	220	1.13	90.00	81.20	18.81	18.00	1.31	975.00	46.91	72.55	149.04	165.17	102.11	145.56	555.47	617.18	525.28	1.82	1.00
1100.0	701.0	13.0	100.0	80.7	20.3	211	1.35	94.00	83.00	19.14	16.00	1.51	960.00	47.70	72.96	147.44	164.47	99.90	144.61	519.85	590.67	489.54	2.26	1.03
1300.0	723.0	13.4	100.0	98.4	24.1	206	1.59	93.00	81.20	19.43	18.00	1.78	1065.00	48.78	74.52	147.64	164.27	100.27	143.22	461.60	554.65	436.84	2.85	1.08
1500.0	745.0	13.8	100.0	117.0	29.5	212	1.50	94.00	81.50	19.57	19.00	1.80	1085.00	47.90	75.52	153.48	170.16	100.78	144.15	516.31	622.78	503.60	2.41	1.09
1700.0	750.0	13.9	100.0	133.5	33.6	211	1.61	94.00	81.90	19.91	21.00	1.92	1155.00	50.19	78.12	154.29	172.09	102.05	143.25	510.81	612.98	496.16	2.57	1.16
1900.0	722.0	13.4	100.0	143.7	35.3	206	1.70	95.00	81.60	20.06	21.00	1.91	1250.00	53.27	81.52	153.87	172.35	103.44	144.26	469.50	577.56	461.66	2.73	1.18
2100.0	605.0	11.2	100.0	133.0	33.0	208	1.89	100.00	81.70	20.14	21.00	1.80	1300.00	52.74	81.57	148.61	167.54	103.30	137.28	426.19	524.96	415.14	2.77	1.18
2200.0	400.0	7.4	80.0	92.2	25.5	232	2.11	99.00	80.90	20.24	17.00	1.41	1270.00	55.68	83.42	135.45	152.43	99.94	129.40	373.72	463.71	381.28	2.17	1.13