EMISSION CHARACTERISTICS OF NEW VEGETABLE OIL COMPATIBLE EXHAUST GAS STAGE IIIA TRACTORS

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ABSTRACT: Rapeseed oil fuelled tractors gain more and more importance in Germany. Since 2008 series produced vegetable oil compatible tractors are on the market and have a technical release for rapeseed oil due to DIN V 51605. However, the emission characteristics of those new exhaust gas stage IIIA tractors are widely unknown. Objects of investigation were two commercially available Fendt 820 Vario^{greentec} tractors equipped with a two-tank-system with fuel-management. As fuels diesel, rapeseed oil and for one tractor sunflower oil has been used. Emission testing was done for all possible operation modes the driver can choose. The carbon monoxide (CO), hydrocarbon (HC) and particle mass (PM) emissions were lower with rapeseed oil than with diesel fuel, whereas the nitrogen oxides (NO_X) emissions were higher. The lowest CO and PM emissions were reached, when the fuel-management system was enabled and in operation mode "AUTO". Sunflower oil showed the same emission behaviour like rapeseed oil and from this point of view seems promising for being used as a fuel in vegetable oil compatible engines. Further research on the long-time behaviour of sunflower oil in tractors must be done and a fuel quality standard has to be set up like for rapeseed oil.
Keywords: liquid biofuel, emissions, engine, rapeseed oil, sunflower oil

1 INTRODUCTION AND PROBLEM

Rapeseed oil fuelled tractors gain more and more importance in Germany during the last decade. Besides environmental benefits, a reduction of costs can be achieved in many cases. The 100-tractor-demonstration program in Germany (Hassel et al. (2005) [4]), the 35-tractor-programm in Austria (Rathbauer et al. (2008) [3]) and a study from Thuneke et al. (2009) [5] showed that tractors can be reliable operated with rapeseed oil.

Since 2008 a series produced vegetable oil compatible engine from Deutz with a two-tank system is available for agricultural machinery. Fendt and Deutz-Fahr integrated this engine in their tractors and are on the market since almost two years. A single-tank system was developed by John Deere and is currently under evaluation within the "2nd VegOil" demonstration project. However, the emission characteristics during rapeseed oil fuel operation for those new exhaust gas stage IIIA tractors are widely unknown.

In Germany, the dominating vegetable oil for fuel is rapeseed oil. For this vegetable oil a fuel standard (DIN V 51605) is available, where important quality parameters are defined. The current available series produced vegetable oil compatible tractors are only allowed to be operated with rapeseed oil due to DIN V 51605. But especially for other European countries different vegetable oils may be from interest to be used as a fuel.

Thus, it is the aim of a present research project to determinate the exhaust gas emissions of stage IIIA rapeseed oil fuelled tractors and to research the influence of sunflower oil on the emission behaviour of the tractors to evaluate the feasibility of using it as a fuel.

2 APPROACH

Objects of investigation are two commercially available Fendt 820 Vario^{greentec} tractors with a DEUTZ TCD 2012 engine with exhaust gas recirculation. The series equipment of the tractors is a two-tank-system with fuel-management. They are equipped with a 100 l tank for diesel fuel and a 340 l tank for rapeseed oil fuel. In dependence of the rapeseed oil fuel temperature and the torque of the engine the fuel management system switches automatically between diesel and rapeseed oil fuel operation. The driver of the tractor can choose between three operation modes:

- **DIESEL:** the fuel-management-system is deactivated and the engine operated with 100 % diesel
- **AUTO:** the fuel-management-system switches between diesel and rapeseed oil fuel
- **100 %:** the fuel-management-system is deactivated and the engine operated with 100 % rapeseed oil

The usual operating mode is "AUTO", but before shutting down the engine, the driver has to switch to the "DIESEL" mode to flush the injection system with diesel fuel. The engine is then started with diesel fuel again. For the case e.g. that the tractor ran out of diesel fuel, the driver can also switch to the "100%" mode to force the engine to use rapeseed oil. The emission testing with tractor 1 is done in all three operation modes. Figure 1 shows tractor 1 and in Table I the technical data of the tractors is listed.

Figure 1: Fendt 820 Vario^{greentec}

Emission testing is done based on DIN EN ISO 8178-1 [1] with the engine mounted on the tractor and the power taken off at the power take-off (PTO) with a dynamometer. Testing cycle is the stationary 8-mode-test defined in ISO 8178-4 [2] which is shown in Figure 2.

Table I: Technical data of the tractors

Tractor No.	1	2
Number of cylinders	6	6
Rated engine power in kW	152	152
Rated speed in min^{-1}	2100	2100
Engine Type	DEUTZ TCD 2012	DEUTZ TCD 2012
Exhaust gas stage	IIIA	IIIA
Year of Manufacture	2008	2009
Operating hours	approx. 1450	approx. 350

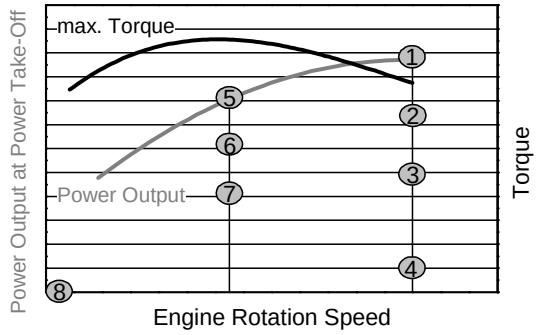

Figure 2: Eight test modes within the engine operating map according to ISO 8178 for emission testing

The recorded exhaust gas components are the limited components carbon monoxide (CO), nitrogen oxides (NO_X), hydrocarbons (HC) and particle mass (PM). The analyzers with measurement principles are listed in Table II. PTO power, torque and fuel consumption were also logged.

Table II: Analyzers for NO_X, CO, HC and PM

Component	model	principle
NO_X	Beckmann Industrial 951A	chemiluminescence detector
CO	Rosemount BINOS 1001	non-dispersive infrared sensor
HC	J.U.M. FID VE 3-100	flame ionization detector
PM	self-made	partial flow dilution with total sampling

Within the 8-mode-test the emission results of every single test stage are added up with specified weighting factors. The emission results over the whole test cycle are stated in g/kWh_{PTO}, if the single modes are considered, the results are shown in parts per million (ppm) on wet basis for the gaseous emission components and in mg/m^3 on dry basis for the particle mass emissions.

As test fuels for tractor 1 reference diesel of the quality RF-06-03, and cold-pressed rapeseed oil (RO) complying DIN V 51605 are used.

For the experiments with tractor 2 cold-pressed rapeseed oil (RO) complying DIN V 51605 and refined sunflower oil (SO) have been the fuels used. Except for cetane number and oxidation stability the sunflower oil meets also the requirements of DIN V 51605. Table III shows the properties of the used vegetable oils.

Table III: Properties of the used rapeseed oil (RO) and sunflower oil (SO)

Property	Unit	RO	SO
Density (15 °C) (ISO 12185)	kg/m^3	920.2	922.7
Flash point (ISO 2719)	°C	274	235
Kin. Viscosity (ISO 3104)	mm^2/s	34.5	32.7
Calorific value (DIN 51900-2)	MJ/kg	37.1	37.5
Cetane number (IP 498)	-	47.1	37
Coke residue (ISO 10370)	mass-%	0.26	0.29
Iodine value (EN 14111)	g Iodine/100g	111	125
Sulphur (ISO 20884)	mg/kg	<1	1
Acid value (EN 14104)	mgKOH/g	1.3	0.05
Oxidation stability (EN 14112)	h (110°C)	7.0	3.1
Phosphorous (EN 14107)	mg/kg	8.2	<0.5
Mg+Ca content (EN 14538)	mg/kg	16.3	<0.5
Water content (ISO 12937)	mg/kg	442	62
Carbon (ASTM D 5291)	mass-%	77.3	77.4
Hydrogen (ASTM D 5291)	mass-%	11.7	11.6
Oxygen (ASTM D 5291)	mass-%	10.2	11.7

3 RESULTS

3.1 Emissions of tractor 1 in different operation modes

Figure 3 gives on overview of the results with tractor 1 for the specific emissions of NO_X, CO, HC and PM during the 8-mode-test (referred to PTO-work). By comparing 100 % diesel ("DIESEL") with 100 % rapeseed oil operation ("100 %") the NO_X emissions are 22 % higher for rapeseed oil. The other three researched emission components were decreasing, CO for 17 % and HC and PM for approx. 40 %. In operation mode "AUTO" the fuel-management used for mode 1 to 7 rapeseed oil and for mode 8 (idle) diesel fuel. A further reduction of CO by 17 % and PM by 9 % was observed. This indicates that the emission of CO and PM were in mode 8 better with diesel fuel than with rapeseed oil.

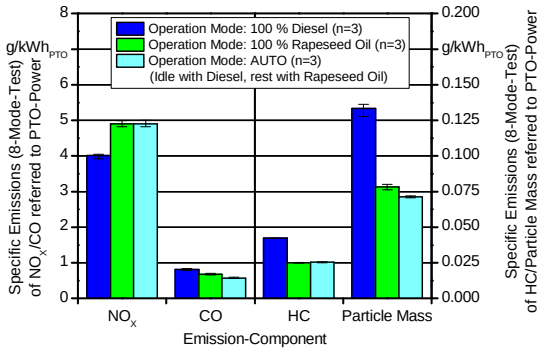

Figure 3: Specific emissions of NO_X, CO, HC and PM of tractor 1 with different operation modes during the 8-mode-test based on ISO 8178

Figure 4 and Figure 5 show the emission concentration of the tractor for the eight modes in particular. Generally the NO_X emissions were higher for high load modes and especially in these modes higher during rapeseed oil operation. From mode 1 to 7 the CO emissions were similar or lower by using rapeseed oil as

a fuel. As expected, in mode 8 (idle) the emission behaviour changed and the highest CO emissions were measured with rapeseed oil. This indicates that the combustion process for rapeseed oil at idle mode was worse than for the other modes. The HC emissions were for rapeseed oil always much lower, except of idle mode, where both fuels were on the same level. The PM emissions were in mode 8 lower with diesel fuel and in mode 4 (low torque mode) on the same level for both fuels. For the other six modes the PM emissions were much lower with rapeseed oil.

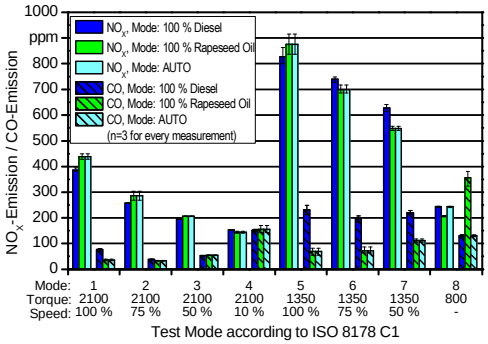

Figure 4: Emission concentrations of NO_X and CO of tractor 1 with different operation modes for the 8-mode-test points

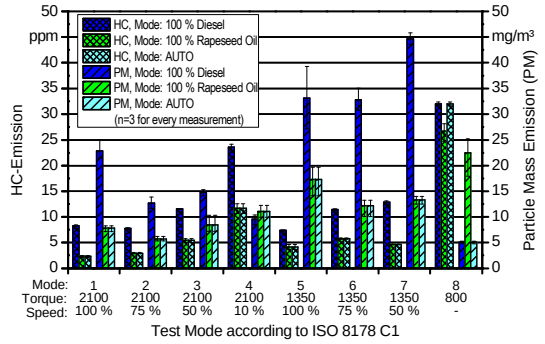

Figure 5: Emission concentrations of HC and PM of tractor 1 with different operation modes for the 8-mode-test points

The observed differences in the emission behaviour of tractors using the 8-mode-test with rapeseed oil and diesel fuel are consistent with former studies done by Rathbauer et al. (2008) [3] and Thuneke et al. (2009) [5]. As expected, the absolute level of NO_X emissions was much lower compared to exhaust gas stage II and I tractors.

By looking at the single modes, for all researched emission components similar changes between rapeseed oil and diesel operation of the tractor were found like for exhaust gas stage II and I tractors, researched by Thuneke et al. (2009) [5].

3.2 Emissions with rapeseed oil and sunflower oil

Figure 6 shows the emission results for tractor 2 over the 8-mode-test by operating the engine on the 100 % vegetable oil mode with rapeseed oil and sunflower oil. For all researched emission components no differences of the specific cycle results between rapeseed oil and sunflower oil could be observed.

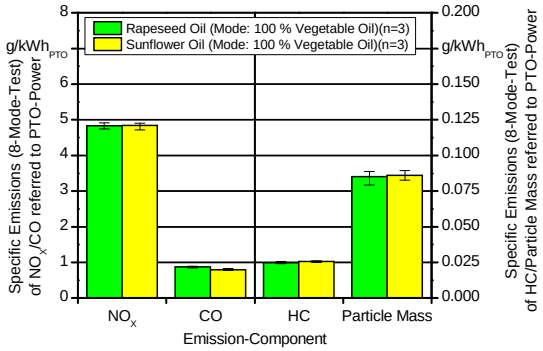

Figure 6: Specific emissions of NO_X, CO, HC and PM of tractor 2 in operation mode "100 %" with rapeseed oil and sunflower oil during the 8-mode-test based on ISO 8178

Figure 7 and Figure 8 show the emission concentrations for every single test mode. As well as for the cycle results within the single modes no significant differences between rapeseed oil and sunflower oil could be recognized. No differences could be also seen in PTO power, torque and specific fuel consumption for both vegetable oils.

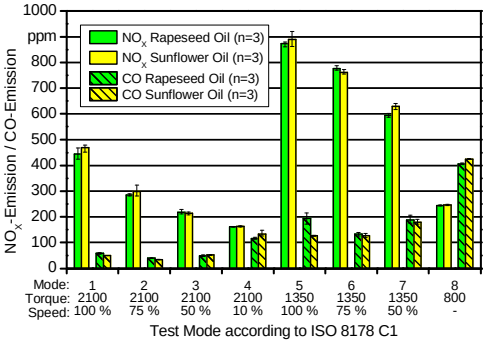

Figure 7: Emission concentrations of NO_X and CO of tractor 2 in operation mode "100 %" with rapeseed oil and sunflower oil for the 8-mode-test points

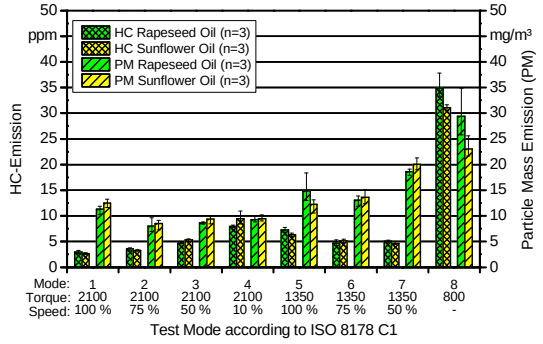

Figure 8: Emission concentrations of HC and PM of tractor 2 in operation mode "100 %" with rapeseed oil and sunflower oil for the 8-mode-test points

4 CONCLUSIONS

The CO, HC and PM emissions were lower with rapeseed oil than with diesel fuel, whereas the NO_X emissions were higher. The lowest CO and PM emissions were reached, when the fuel-management system was enabled and the idle mode was operated with diesel instead of rapeseed oil. As expected, especially the NO_X emissions were on a much lower level like exhaust gas stage II or I tractors.

Sunflower oil showed the same emission behaviour like rapeseed oil and from this point of view seems promising for being used as a fuel in vegetable oil compatible engines. Further research on the long-time behaviour of sunflower oil in tractors must be done and a fuel quality standard has to be set up like for rapeseed oil.

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