Exhaust Gas Emission Behaviour of Rapeseed Oil Fuelled Tractors

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Abstract
Pure plant oils, used as fuel in compatible tractors reduce greenhouse gas emissions of the agricultural sector and thus, lower CO_2-footprints of agricultural products. Furthermore plant oils can contribute to increase security of supply of long-term moderately priced fuels. Since 2008 leading manufacturers offer rapeseed oil compatible tractors. To enlarge raw material base, the usage of other pure plant oils than rapeseed oil is considered. However, the operating and emission behaviour of tractors, fuelled with different plant oils is widely unknown. Thus, it was the purpose of a research project, financed by the Bavarian State Ministry of Food, Agriculture and Forestry to investigate vegetable oil compatible exhaust gas stage IIIA tractors in regard to exhaust gas emissions with diesel fuel, rapeseed oil, sunflower oil and soybean oil.
Both tractors showed significant less hydrocarbon and particle mass emissions during rapeseed oil in comparison to diesel fuel operation. For one tractor with rapeseed oil fuel also lower CO- and equal NO_X- concentrations were ascertained, whereas for the other tractor CO and NO_X were at an higher level. Sunflower oil and soybean oil showed a similar emission behaviour like rapeseed oil and from this point of view they seem a promising option to enlarge the basis for biofuels. However, further research on the long-time behaviour of sunflower oil, soybean oil and further plant oils in tractors is necessary and a fuel quality standard has to be set up like it was done for rapeseed oil.

Introduction

In the last decade, the usage of rapeseed oil as a fuel in tractors gained more and more importance in some European countries, especially in Germany and Austria. Besides environmental benefits, a reduction of fuel costs could be achieved due to tax incentives for biofuels in agricultural machinery. Hassel et al. (2005) [2], Rathbauer et al. (2008) [5] and Thuneke et al. (2009) [6] showed, that vegetable oil compatible tractors can be operated reliably with rapeseed oil fuel (RSO). Exhaust gas emissions strongly depend on the operating mode of the engine. It can be recognized, that usually during high-load operation carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM) are equal or lower for many vegetable oil compatible diesel engines fuelled with RSO, than for diesel fuelled engines. In contrast, nitrogen oxides (NO_X) are often higher. During low-load or idle operation however, higher CO, HC and PM emissions are often detected, whereas the NO_X-emissions are equal or lower with RSO compared to diesel fuel. Since 2008 series produced vegetable oil compatible tractors of two manufacturers are on the market. A third company presently evaluates a further vegetable oil compatible tractor within the “2nd VegOil” demonstration project [4].
In Germany the predominant vegetable oil used in tractors is rapeseed oil (RSO). The RSO quality is of crucial importance for a reliable operation of vegetable oil compatible diesel engines. Quality parameters for RSO, which is used as fuel, are defined in DIN 51605 [4]. In September 2010 the standard DIN 51605 replaced the former pre-standard DIN V 51605. The current available series produced vegetable oil compatible tractors feature manufacture approvals solely for RSO complying DIN 51605. Especially for other countries also other vegetable oils, such as sunflower oil (SFO) or soybean oil (SBO) may be of interest to be used as a fuel.
Thus, it is the aim of a present research project to investigate the exhaust gas emissions of stage IIIA tractors fuelled with rapeseed, sunflower and soybean oil in order to evaluate the feasibility of using these plant oils as fuel.

Approach

Objects of investigation are two vegetable oil compatible tractors. The technical data of the tested tractors are listed in Table 2. One tractor (T1) is entirely adapted to rapeseed oil fuel without using a secondary fuel system for cold starts or idle operation. The second tractor (T2) is equipped with a two-tank solution featuring a fuel management system, which provides fuel from either the plant oil or diesel tank, depending on the operation mode. During measurement the fuel management system was deactivated. This means that during each test cycle, solely one test fuel was used. If the fuel management system was activated, diesel would be used during the idle test mode. Both tractors fulfill exhaust gas stage IIIA and are equipped with an external cooled exhaust gas recirculation.

Table 2: Technical data of the tested tractors

Tractor code	T1	T2
Number of cylinders	6	6
Engine displacement in dm³	6.79	6.06
Rated engine power in kW (with diesel)	114 (with PM[1)] 132)	140
Rated speed in min^{-1}	2100	2100
Exhaust gas stage	IIIA	IIIA
Year of manufacture	2008	2009
Operating hours in h	ca. 625	ca. 350

[1)] PM: Power Management, not activated during measurement

As reference fuel specified diesel test fuel (CEC RF-06-03) was used. Tested plant oil fuels are:

- Two batches of cold-pressed rapeseed oil (RSO1 and RSO2) complying with the national German standard DIN 51605 for rapeseed oil fuel,
- refined and winterized sunflower oil (SFO) and
- refined soybean oil (SBO).

Table 3 shows the properties of the tested plant oils. In comparison to diesel fuel, plant oils feature higher densities and lower heating values. Latter arise from different elemental composition with less carbon and hydrogen content and instead of that the presence of oxygen in the fuel with a content of some 10.9 %. Within the different tested plant oils the elemental composition and heating values are rather similar. Except for the oxidation stability of sunflower oil all tested plant oils meet the requirements of DIN 51605 (which actually only applies for rapeseed oil).

Table 3: Properties of tested rapeseed oil batches (RSO1, RSO2), sunflower oil (SFO) and soybean oil (SBO)

Property	Testing method	Unit	RSO1	RSO2	SFO	SBO
Density (15 °C)	DIN EN ISO 12185	kg/m³	920.0	920.2	922.7	922.1
Kin. Viscosity (40 °C)	DIN EN ISO 3104	mm²/s	34.5	34.5	32.7	32.9
Calorific value	DIN 51900-2	MJ/kg	37.1	37.1	37.1	37.1
Iodine value	DIN EN 14111	g Iodine/100g	111	111	125	121
Sulphur	DIN EN ISO 20884	mg/kg	3.4	<1	1.1	1.7
Acid value	DIN EN 14104	mgKOH/g	0.85	1.30	0.05	0.10
Oxidation stability (110°C)	DIN EN 14112	h	6.4	7.0	3.1	6.9
Phosphorous	DIN EN 14107	mg/kg	<0.5	8.2	<0.5	1.3
Mg+Ca content	DIN EN 14538	mg/kg	<0.5	16.3	<0.5	<0.5
Water content	DIN EN ISO 12937	mg/kg	580	442	62	66
Carbon	calculated	mass-%	77.5	77.5	77.5	77.5
Hydrogen	calculated	mass-%	11.6	11.6	11.5	11.6
Oxygen	calculated	mass-%	10.9	10.9	10.9	10.9

Emission testing is based on the standard procedure of ISO 8178-1 [3]. Differing from type approvals, where engine test stands are used, the measurements within this research project is done at the tractors (with mounted engines). The power is measured at the power take-off (PTO) with a dynamometer (Eggers PT 301 MES). As testing cycle the stationary 8-mode-test, which is also known as Non-Road-Steady-Cycle (NRSC) is applied. Within the NRSC the emission results of every single test stage are added up with consideration of specified weighting factors. The emission results over the whole test cycle are calculated in g/kWh_{PTO}. A detailed description of the exhaust gas test stand is given in Thuneke et al. (2009) [6]. Recorded exhaust gas emissions are nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM), which are limited by law and thus referred to as “limited components”. Besides the emission concentrations, the power at the rear power take-off (PTO), torque and fuel consumption are logged continuously.

Results and Discussion

Figure 3 gives an overview of the results of emission measurements of two tractors with different plant oil fuels. The height of the columns corresponds to the arithmetic average and the error bars to the range of variation of three repetitions for the concentrations of NO_X, CO, HC and PM during eight test modes in relation to diesel fuel operation (specific diesel emissions are stated as 1.0).

For tractor T1 NO_X-emissions with rapeseed oil, sunflower oil and soybean oil are approximately 20 % higher than with diesel. Higher NO_X-emissions for plant oil fuelled engines are due to fuel born oxygen and higher combustion temperatures, both factors that stimulate NO_X-formation. Tractor T2 however,

shows the same NO_X-emissions with the tested rapeseed and sunflower oil as with diesel fuel. This might indicate a NO_X-related engine optimisation for plant oil fuel operation.
A similar result by trend can be observed for CO. For tractor T1 some 30 % higher concentrations were measured for all tested plant oils compared to diesel. Tractor T2 instead has up to 40 % lower CO-emissions with rapeseed and sunflower oil than with diesel fuel. HC-emissions are for both tractors some 35 to 45 % lower with plant oils than with diesel. Finally particulate mass is for tractor T1 about 35 % and for tractor T2 about 50 % lower with the plant oils than with diesel.

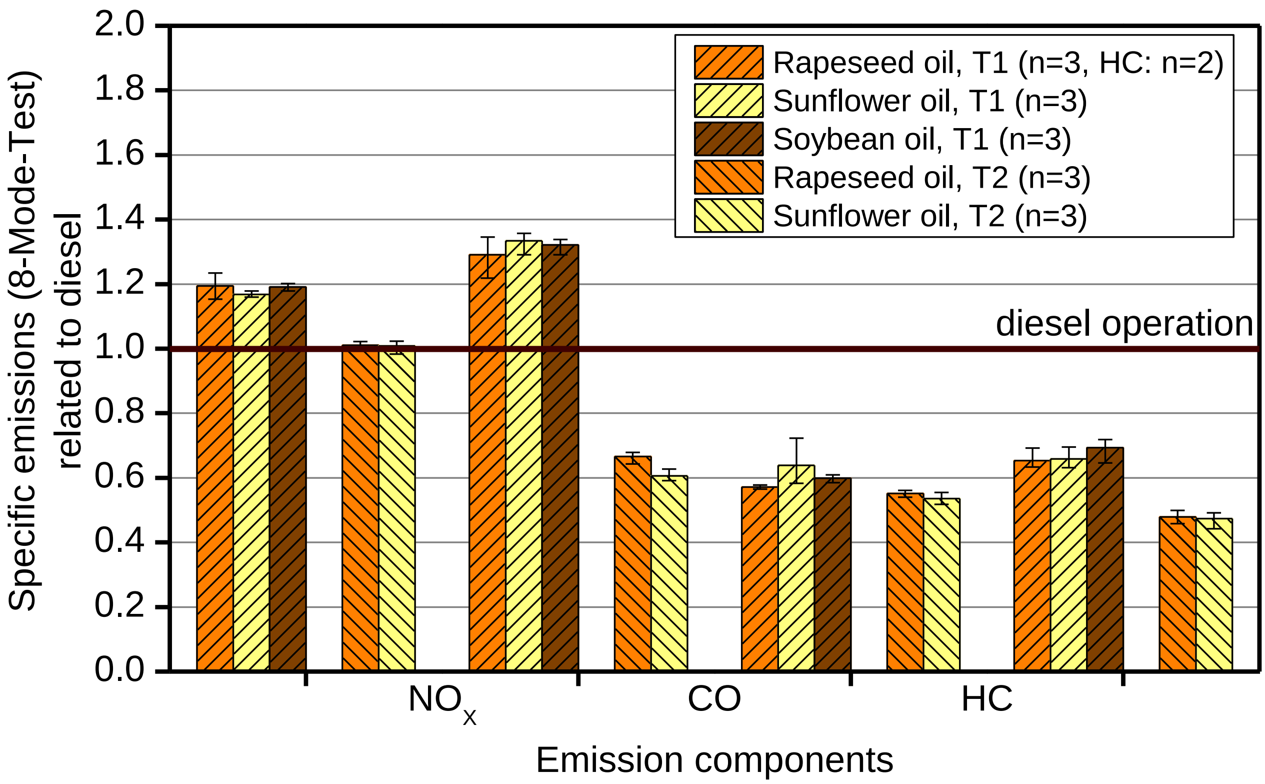

Figure 3: Specific emissions of NO_X, CO, HC and PM of tractor T1 and T2 with different plant oils in relation to diesel operation during the 8-mode-test (NRSC) according to ISO 8178

Overall differences in emission behaviour between the three tested plant oils are not significant for either tractor, when looking at the weighted eight test modes. In terms of the relative emissions between plant oils and diesel fuel the two tractors differ considerably. While tractor T1 is characterized by lower HC- and PM-emissions, but higher NO_X- and CO-emissions during plant oil fuel operation, tractor T2 shows equal NO_X-concentrations for plant oil and diesel fuel usage and distinctive lower CO-, HC- and PM-emissions, when fuelled with plant oils. However, the results, do not give any information about the differences of the absolute height of the emission components between the two tractors.
The observed differences in emission behaviour of tractors using the 8-mode-test with rapeseed oil and diesel fuel are consistent with former studies such as Rathbauer et al. (2008) [5] and Thuneke et al. (2009) [6]. For all ascertained emission components almost no differences in emission behaviour of the tested tractors by using rapeseed oil, sunflower oil or soybean oil could be observed.

Conclusions

Exhaust gas emissions of the tested new stage IIIA tractors are at a very low level, especially for CO, HC and particle mass. However, for both, diesel and vegetable oil fuelled tractors, further development is necessary to fulfill emission demands of exhaust gas stages IIIB and IV. Exhaust gas aftertreatment systems accompanied by fuels with low contents of ash forming elements are one part of the solution. Besides rapeseed oil also other plant oils from sunflower or soybean can be a promising alternative for being used as a fuel in vegetable oil compatible tractors. Further research on the long-time behaviour of prospective plant oils are required and therefore plant oil quality needs to be standardised.

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