REDUCTION OF GREENHOUSE GAS EMISSIONS IN BIOMASS PRODUCTION BY USING PLANT OIL FUEL IN TRACTORS

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ABSTRACT: Modern plant oil compatible tractors with emission control systems show high technical maturity. Limited exhaust gas components, as there are nitrogen oxides, carbon monoxide, hydrocarbons and particle matter, determined at a tractor test stand and under real driving conditions are at a very low level and similar to diesel operation. However, with rapeseed oil fuel from decentral production a greenhouse gas (GHG) reduction of up to nearly 90 % compared to diesel can be achieved. Additionally, a bunch of ecological benefits are associated. Hence, plant oil fuelled tractors could play an important role within decarbonisation strategies of the agricultural sector.
Keywords: rapeseed oil, liquid biofuel, agriculture, alternative fuel vehicles, greenhouse gases (GHG), emissions

1 INTRODUCTION

The use of fossil diesel fuel in tractors considerably contributes to greenhouse gas (GHG) emissions when producing food or biomass feedstock. Since there are many barriers regarding the electrification of propulsion systems for heavy load non-road applications, regionally produced plant oil fuels may be an alternative for the agricultural sector. Rapeseed oil fuel can significantly reduce GHG emissions in comparison to diesel and thus, lowering the carbon footprint of agricultural products. Rapeseed oil quality is of crucial importance for a reliable operation of compatible diesel engines. Quality parameters for rapeseed oil, which is used as fuel, are defined in DIN 51605 [1]. Apart from rapeseed oil also other vegetable oils, such as sunflower oil or soybean oil can be used as fuel. For these plant oils the German fuel standard DIN 51623 [2] has been developed.

The usage of rapeseed oil fuel in vehicles requires the technical adaption of engine periphery (especially the fuel system), that is either realized directly by the manufacturer or by a conversion workshop. Moreover, adjustment of the engine software is another appropriate measure to obtain compatibility with pure plant oil fuels.

2 PURPOSE

It is the purpose of this work to show the state of the art of pure rapeseed oil compatible tractors with regard to technical performance and exhaust gas emissions. Apart from practice experiences, emission measurements should be conducted at the tractor test stand and during real operation. Based upon experimental studies the GHG reduction potential should be calculated.

3 APPROACH

The investigations are carried out on 19 plant oil compatible tractors, 18 of them are being operated at test farms of the Bavarian State Research Center for Agriculture. The tested tractors are listed in **Table I**. Most tractors are fully adapted to pure rapeseed oil (single-tank system) without using a secondary fuel system for cold starts or idle/low load operation. Four tractors, however, are equipped with a two-tank solution and featuring a fuel management system, which provides fuel from either, the plant oil or diesel tank depending on the operation mode.

Table I: Data of monitored tractors

Tractor type	Year of manu-facture	Exhaust stage	Engine/ injection	Engine power in kW	Ope-ration hours
Fendt 724 Vario S4 (2T)	2014	IV	6 cyl. CR[1]	174	1200
John Deere 6210R	2012	IV	6 cyl. CR[1]	154	2200
John Deere 6100RC	2014	IIIB	4 cyl. CR[1]	74	800
John Deere 6115R	2014	IIIB	4 cyl. CR[1]	85	700
John Deere 6125R	2013	IIIB	4 cyl. CR[1]	92	2300
John Deere 6210R	2012	IIIB	6 cyl. CR[1]	154	2800
Fendt 718 Vario (2T)	2012	IIIB	6 cyl. CR[1]	92	1400
John Deere 5080R	2013	IIIA	4 cyl. CR[1]	59	900
John Deere 6630	2012	IIIA	6 cyl. CR[1]	96	2700
John Deere 7830	2010	IIIA	6 cyl. CR[1]	173	2500
Deutz-Fahr M 650 Agrotron	2010	IIIA	6 cyl. CR[1]	136	2500
John Deere 6630	2010	IIIA	6 cyl. CR[1]	96	2800
Fendt 820 Vario greentec (2T)	2009	IIIA	6 cyl. CR[1]	152	6000
Fendt 820 Vario greentec (2T)	2009	IIIA	6 cyl. CR[1]	152	5200
John Deere 6930	2008	IIIA	6 cyl. CR[1]	134	4200
John Deere 6930	2008	IIIA	6 cyl. CR[1]	134	4500
Deutz-Fahr 1160 Agrotron TTV	2005	II	6 cyl. PLN[2]	119	6000
Fendt 412 Vario	2003	I	4 cyl. PLN[2]	94	7500

(2T) = tractor is equipped with a fuel management system and a second fuel tank with diesel fuel for engine start
[1] CR = Common-rail injection
[2] PLN = Pump-line-nozzle

The emission measurements are performed on the TFZ tractor test stand (**Figure 1**) with diesel and rapeseed oil fuel based on the NRMM legislation. On the tractor test stand the limited exhaust gas emission components nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) are recorded by an AVL SESAM 4 gas analysis system (including FTIR, FID and PMD) and a partial flow dilution tunnel. Measurements are conducted in accordance with Directive 97/68/EC by application of a steady state test cycle (NRSC). Additionally transient test cycles, similar to the original NRTC for type approvals on engine test benches are applied (10sNRTC). However the results are not presented in this paper.

Figure 1: Plant oil compatible tractor at test stand of the Technology and Support Centre (TFZ)

The real driving emissions are detected with a Semtech Ecostar PEMS of the company Sensors Inc. (combining NDUV, NDIR, FID, particle matter measurement and exhaust gas mass flow meter), which is mounted in a dust and water proof housing on the front linkage of the tractor (**Figure 2**).

Figure 2: Set-up of portable emission measurement system PEMS Semtech Ecostar in purpose built box

The evaluation of real driving emissions is based on the method of the moving averaging window in line with the EU Regulations 582/2011 and 64/2012 for heavy duty vehicles (HDV legislation). Thereby monitored data of the test vehicle are divided into consecutive starting (every second) segments (windows). The length of each window corresponds to the equivalent work, performed during the reference test cycle. For all windows the conformity factor (CF) is generated. The CF is calculated as the ratio between the average emission value of each window (in g/kWh) and the legal emission limit of the test cycle for type approvals of NRMM. The legal emission limit values refer to the crankshaft work for measurements on the engine test bench. Since no performance data for determining the crankshaft referred work are available for rapeseed oil operation, the work performed during the test cycle is determined by the measured work at the PTO according to OECD Code 2. Due to mechanical losses and additional auxiliary components in the drive train, the cycle work referred to PTO is lower and therefore the specific emissions are about 20 % higher compared to the values based on the crankshaft work. This difference is not corrected in the following. That means the outlined CF comprise limit values referred to crankshaft work and measurement data referred to PTO work. Based on the HDV legislation the 90 % cumulative percentile of the conformity factors should not exceed the value of 1.5. In other words: 90 % of all valid averaging windows monitored during an operation period must not exceed 150 % of the legal emission limits (determined during the test cycle).

For assessing GHG emissions, regional and farm-specific data for rapeseed cultivation and decentralized rapeseed oil fuel production were collected. A total of 36 farms and three decentralized oil mills in six soil-climate-areas of Bavaria, Germany could be assessed. The calculation of GHG emissions is based on the “ExpRessBio methods” [3], according to the ISO standards 14040 [4] and 14044 [5]. The system boundary includes rapeseed cultivation, transport of rapeseed to the oil mill and processing, which are the same process groups as comprised in the requirements of RED. The functional units used are kg CO_2-eq kg^{-1} rapeseed and kg CO_2-eq MJ^{-1} rapeseed oil.

4 RESULTS

4.1 Operation behaviour

19 plant oil operated tractors (exhaust stage I to IV) have proved full suitability in everyday use for more than 50,000 operating hours. Altogether more than 500,000 l of fossil diesel was saved.

Apart from minor malfunction of fuel system components (leakages, blocked fuel filter, defect fuel feed pump) no failures or damages occurred, which can be attributed to the operation with plant oil fuel.

Regular analyses of the engine oil demonstrate the necessity of a more frequent engine oil exchange (every 250 operating hours) for the elder plant oil compatible tractors with pump-line-nozzle injection, due to the typical accumulation of plant oil fuel in the engine oil. Modern tractors with common rail injection however, feature maintenance intervals of 500 operating hours equal to diesel.

Inspections of several tractors confirm their good technical condition. Even though, some injection nozzles show deposits, whereas injection holes are clearly visible and injection spray quality seems not to be affected. Pistons and cylinders were mainly completely free of deposits.

4.2 Emission behaviour at test stand

Figure 3 gives an overview of the results of emission measurements of five tractors with the exhaust stages I, II, IIIA, IIIB and IV with rapeseed oil and diesel fuel. The height of the columns corresponds to the arithmetic average of three repetitions. There is a significant reduction of emission levels with proceeding exhaust stage for nearly all emission components. Considering the method-related higher values determined at the tractor test stand (by referring them to the work at the power take-off) in comparison to engine related values at engine test stands for type approvals, the relevant limiting values are met by all tractors with diesel and rapeseed oil fuel.

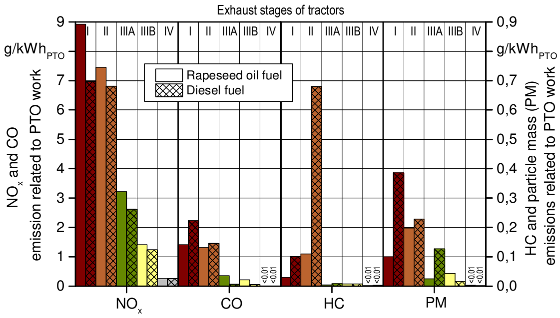

Figure 3: Specific emissions of NO_X, CO, HC and PM (particle mass) of five tractors (exhaust stages I, II, IIIA, IIIB, IV) with rapeseed oil and diesel fuel operation during the stationary 8-mode-test (NRSC) according to modified ISO 8178

Comparing rapeseed oil and diesel operation, little higher NO_X, but lower CO, HC and particle mass (PM) emissions were observed with rapeseed oil for the tractors with exhaust stages I, II and IIIA. Higher NO_X emissions for plant oil fuelled engines result from fuel-born oxygen and higher combustion temperatures, both factors that stimulate NO_X-formation. The tractor with exhaust stage IIIB that is equipped with an SCR exhaust after-treatment system for exhaust denitrification shows only marginally higher NO_X emissions during plant oil operation and generally very low concentrations of CO, HC and PM, which are close to the detection limit. Overall differences in emission behaviour between plant oils and diesel fuel decrease with proceeding exhaust stage and emission control measures. For the latest emission stage IV, no differences between the fuels can be noticed and apart from NOx all emission components range below the detection limit.

The observed 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. [6].

4.3 Emission behaviour under real driving conditions

During the measurements of real driving emissions of the Fendt 724 S4 (**Figure 4**) and the John Deere 6215 R with rapeseed oil fuel, ambient and operation conditions were always in compliance with guidelines and hence, all measurement windows were valid. Overall, there was a very low emission level during both, ploughing and street transport.

Figure 4: PEMS measurement during ploughing with a vegetable oil compatible tractor Fendt 724 SCR (Stage IV)

Figure 5 shows the NO_X emissions of the PEMS measurements for two tractors during ploughing and street transport, each work with three repetitions. CO, HC and PM emissions are not considered here, since they were very low.

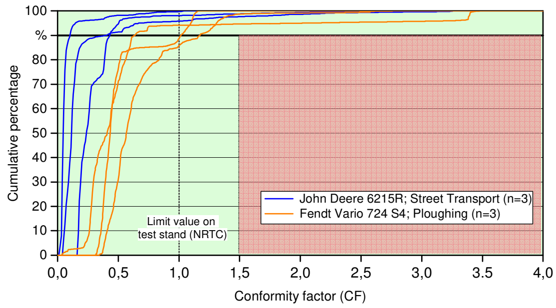

Figure 5: Cumulative percentage of conformity factors for nitrogen oxides (NO_x) of a Fendt 724 ploughing and a John Deere 6215 R during street transport, both operated with rapeseed oil fuel, each 3 repetitions

During all measurements at least 85 % of the windows show NO_X emissions less than the limit value fixed in current NRMM legislation (CF<1). One reason for the very low emission values is that actual tractor work is usually much less dynamic than the statutory test stand test cycle, which has to be applied for both, tractor engines as well as engines of construction machinery.

Comparing the two different types of tractors or tractor work respectively, a significant difference could be recognized. Further measurements need to be done for validation. Especially at the start of measurement and during longer low load operation, when the efficiency of the SCR catalyst is poor, some higher NO_X emissions can be observed.

4.4 Greenhouse gas (GHG) emissions

In **Figure 6** the GHG emissions for the complete product system of decentralized rapeseed oil fuel in Bavaria compared to the default values of the Directive 2009/28/EC (RED I) and the draft of its amendment (RED II) are shown. Thereby, the default values are calculated with allocation by calorific value and are related to industrial scale oil production (36 or 40 g CO_2-eq MJ^{-1} rapeseed oil [7][8]). The GHG emissions calculated with specific data and for decentralized rapeseed oil production in Bavaria, are slightly lower (approx. 33.3 g MJ^{-1} by calorific value allocation).

The lower GHG emissions of decentralized rapeseed oil fuel are due to the shorter transport distance on the one hand and due to the lower energy demand for decentralized oil production compared to industrial processing, on the other hand. The influencing key factors for GHG emissions are the N_2O-field emissions and the GHG emissions from the provision of mineral fertilizers. Hence, the biggest shares of GHG emissions from rapeseed cultivation derive from these two parameters.

In **Figure 6**, also the results of different methods for assessing co-products are shown: allocation by calorific value and substitution with credits for substituted soybean meal, respectively. By applying the substitution method without considering land use change due to the cultivation of soy in South America gross GHG emissions of rapeseed oil amount 33.1 g MJ^{-1}. Taking land use change into account gross GHG emissions of rapeseed oil decrease to 11.9 g MJ^{-1}.The comparison of GHG emissions of rapeseed oil fuel with the reference value for fossil diesel of RED II shows that the GHG reduction potential reaches up to 87.5 %. However, the substitution method including credits for co-products has not been accepted to be applied for quota counting according to RED I as well as the draft of RED II. For political analysis the substitution method is recommended.

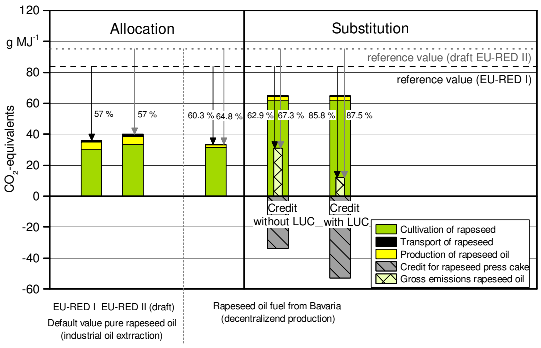

Figure 6: GHG emissions of rapeseed oil from decentralized oil production in Bavaria: Comparison of different methods for assessing co-products with default values specified by RED

5 CONCLUSIONS

Several years of research on various plant oil compatible tractors show prospective results in terms of engine performance, emission behaviour and overall technical reliability. With modern rapeseed oil fuelled tractors of emission stage IV it is possible to fulfill relevant emission limits during measurements on a tractor test stand (NRMM legislation) as well as reference RDE values during real tractor work based on the HDV legislative.

Regarding GHG emissions, producing decentralized rapeseed oil fuel and using it in agricultural machines lead to a reduction of GHG emissions up to nearly 90 %, when the substitution method is applied (credits for co-product press cake according to the feed value). Allocation by calorific value, which is used in the balancing approach of RED, characterizes the benefit of the co-product (rapeseed press cake) insufficiently.

The results of the work can help to support the development of propulsion systems that are compatible with sustainable biofuels. Thus, optimisation processes can be more effective for better air quality and less greenhouse gas emissions.

6 REFERENCES

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