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MONITORING OF RAPESEED OIL FUELLED AGRICULTURAL MACHINERY

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Abstract

Pure plant oil fuels, used in compatible agricultural machinery contribute to sustainable food supply. Especially rapeseed oil fuel significantly reduces greenhouse gas emissions up to 91 % and thus, lowers the carbon footprint of agricultural products. However, despite this advantage plant oil fuels are barely used in practice, because of technical, economical and sustainability concerns of potential users. It is the purpose of this work, to show the reliability, downtimes and the emission behaviour of pure rapeseed oil compatible tractors in practice. As test fuel, cold-pressed rapeseed oil fuel, complying with the national German standard DIN 51605 was used. Emission testing on the tractor test stand is based on the standard procedure of EU guideline 2016/1628. Differing from type approvals, where engine test stands are used, here the measurement is done at the tractors with mounted engines. The power is measured at the power take-off (PTO) with a dynamometer. As testing cycle, the Non-Road-Steady-Cycle (NRSC) and an adapted Non-Road-Transient-Cycle (10sNRTC) are applied. For real driving emission (RDE) measurements, two state-of-the-art tractors are being used. By using a PEMS Semtech Ecostar, which was set up in a box for off-road use, the emission components CO, HC, NO_X are measured. Investigation of the monitored 20 tractors (exhaust stages I, II, IIIA, IIIB and IV) for more than 60.000 hours, showed no considerable failures or damages. Generally, the limited exhaust gas components (NO_X, CO, HC, PM) determined at a tractor test stand remained nearly at the same level over the operating time. Plant oil tractors with exhaust gas stage IV achieve the legal emission limits with rapeseed oil fuel during both, the NRSC and 10sNRTC. Results of RDE measurements also show that recorded emission values are within expected limiting values for both fuels. Conformity factors that relate actual emissions, measured with PEMS, to corresponding test cycle values, measured at the test stand are within approaching legitimacy.

Keywords: *greenhouse gas emissions, liquid biofuel, pollution, environmental protection*

1. Introduction

The use of fossil diesel fuel in tractors considerably contributes to greenhouse gas (GHG) emissions when producing food or biomass feedstock. For combating climate change sustainable low carbon energy carriers have to be introduced. 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 [1].

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 the German fuel standard DIN 51605 [2]. 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 [3] 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.

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 field monitoring, emission measurements should be conducted at the tractor test stand and during real operation.

2. Field test and exhaust gas emission measurement

The investigations are carried out on 20 plant oil compatible tractors with exhaust stages from I to IV at several test farms of the Bavarian State Research Centre for Agriculture. 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, feature a two-tank solution with included fuel management system, which provides fuel from either, the plant oil or diesel tank depending on the operation mode. The emission measurements are performed on the TFZ tractor test stand (Fig. 1) with diesel and rapeseed oil fuel based on the non-road mobile machinery (NRMM) legislation according to EU guideline 2016/1628.

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. The torque is controlled at the power take-off (PTO) with a dynamometer. Measurements are conducted 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) [4]. Furthermore, the real emission behaviour is measured in practice with a portable emission measurement system (PEMS), as shown in Fig. 2.

Fig. 1. Emission measurement based on legal test cycles with a John Deere 6215R (Stage IV) at the tractor test stand

Fig. 2. PEMS measurement during ploughing with a vegetable oil compatible tractor Fendt 724 SCR (Stage IV)

The real driving emissions (RDE) 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. The Fendt Vario 724 S4 was measured during ploughing on three field sections with a duration of 2.5 h, 3 h and 3.5 h. The RDE on the John Deere 6215R with single-tank system includes road transport journeys without additional trailer load on a test track of 116 km over 2.6 h in threefold repetition. Both tractors were operated solely with rapeseed oil fuel for the entire measuring period. The two-tank system (use of diesel fuel for cold start) of the Fendt Vario 724 S4 was deactivated.

The evaluation of real driving emissions is based on the method of the moving averaging window in line with the NRMM 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).

3. Results

Operation behaviour

20 plant oil operated tractors (exhaust stage I to IV) have proved full suitability in everyday use for more than 60,000 operating hours. Over 150 engine oil analyses demonstrate that these tractors show very low wear and require only little maintenance. Except for the older plant oil compatible tractors with pump-line-nozzle injection, which require engine oil exchange more frequently (every 250 operating hours), modern tractors with common rail injection feature maintenance intervals of 500 operating hours equal to diesel. On seven rapeseed oil tractors, catalytically coated soot particle filters could be operated with a total of over 11,500 operating hours of passive regeneration. Therefore, it is not necessary to "burn out" the filter periodically by injecting an additional fuel dose into the combustion chamber or the exhaust pipe, as it is mostly the case with diesel vehicles.

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. 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.

The rapeseed oil operation of all tractors replaced almost 570,000 l of diesel, which corresponds to a greenhouse gas saving of approx. 1,363 t CO_2 equivalent. At a workshop, the operators attested that they are very satisfied with the user-friendliness and reliability of the rapeseed oil fuelled tractors.

Emission behaviour at test stand

Measurements of tractors of exhaust emission levels IIIB and IV with the use of exhaust after-treatment systems show that emissions during rapeseed oil operation are at a very low level. As an example, this can be seen by the performance and emission measurements of the Fendt Vario 724 S4 and John Deere 6215R of the current emission level IV in Fig. 3. Both tractors are equipped with a DOC (Diesel Oxidation Catalyst), a DPF (Diesel Particle Filter) and a SCR (Selective Catalytic Reduction) system.

The emission values of both tractors during stationary (NRSC) and transient test cycles (10sNRTC), measured on the tractor test stand with rapeseed oil fuel, are in most cases significantly lower than the legal limit values for NO_X (0.4 g/kWh), CO (3.5 g/kWh), HC (0.19 g/kWh) and PM (0.025 g/kWh).

Real driving emissions (RDE)

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

During all measurements at least 90% of the windows show NO_X emissions less than the limit value, according to current NRMM legislation (CF < 1) performed on the engine test bench. 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. Especially at the start of measurement and during longer periods of low load operation, some higher NO_X emissions can be observed, since conversion efficiency of the SCR catalyst is poor. Further measurements need to be conducted for validation of results.

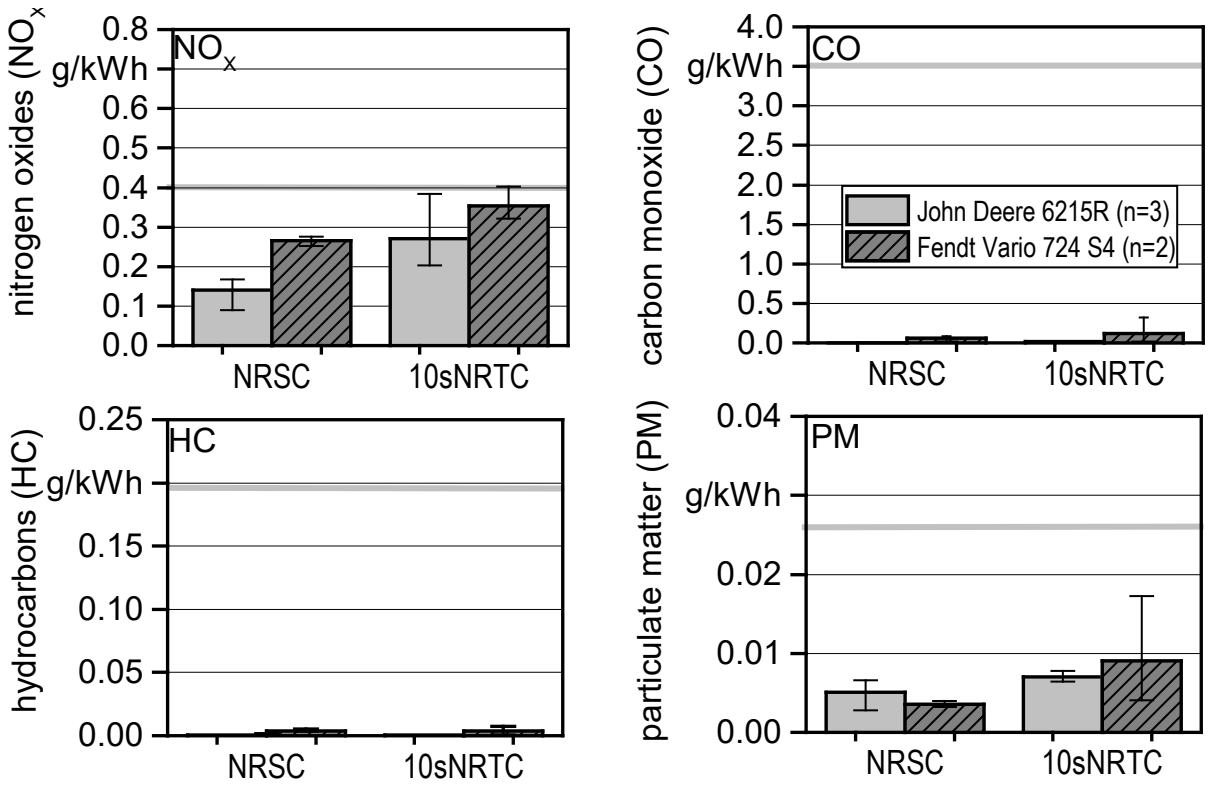

Fig. 3. Exhaust emissions of a Fendt Vario 724 S4 and a John Deere 6215R with rapeseed oil fuel on the tractor test stand

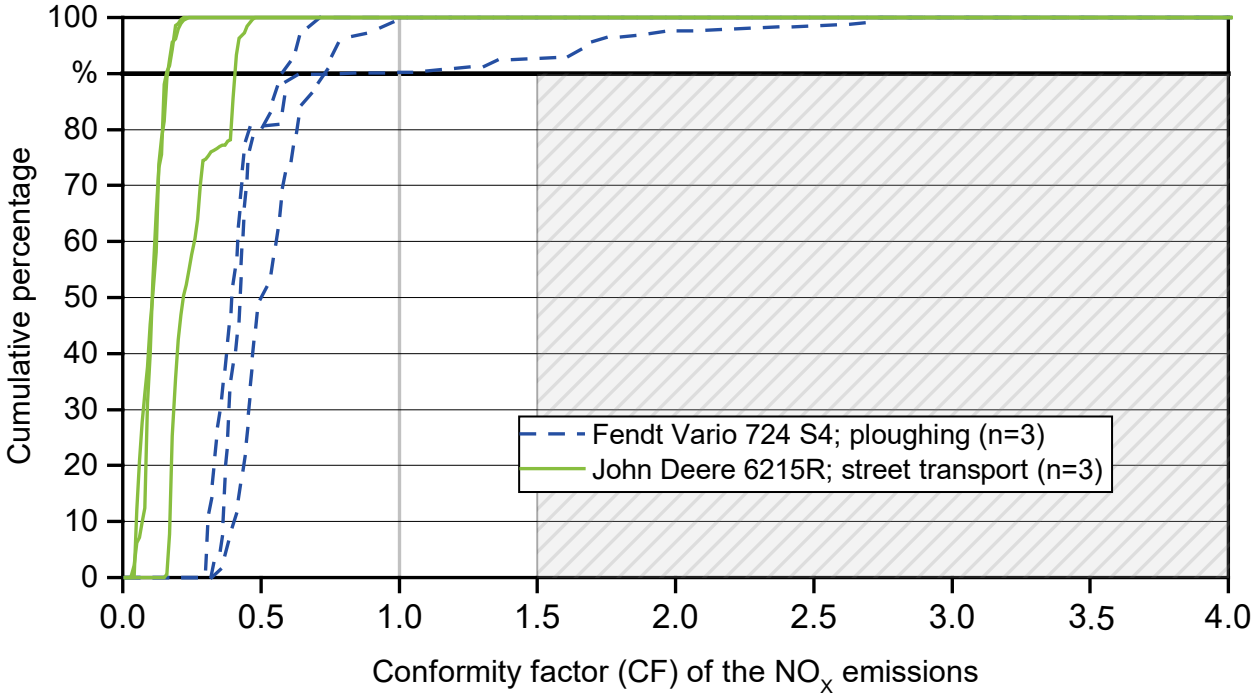

Fig. 4. Cumulative percentage of conformity factors for nitrogen oxides (NOx) of a Fendt 724 ploughing and a John Deere 6215R during street transport, both operated with rapeseed oil fuel, three repetitions each

3. Conclusion

Tractors suitable for rapeseed oil fuel, which range from exhaust emission stages I to IV have proven their suitability for practical use within comprehensive tests in Bavaria. Furthermore, exhaust emissions during rapeseed oil operation on the tractor test stand and during real operating conditions are generally at a very low level. Hence, rapeseed oil can play an important role as a sustainable alternative fuel in modern tractors to significantly reduce greenhouse gas emissions in agriculture and forestry.

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