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Measurement of emissions of a tractor – round robin test of ART, FJ-BLT and TFZ

Regulations for emission measurements on an engine test rig are existing for type-approval of tractor engines, but a uniform procedure for emission measurements with the engine installed on the tractor is not available. In order to determinate the reproducibility of results of different research institutes, Agroscope Reckenholz-Tänikon (ART), Francisco Josephinum Biomass-Logistics-Technology (FJ-BLT) and Technologie- und Förderzentrum (TFZ) performed measurements on one tractor. The results show, that for fuel consumption as well as for nitrogen oxide and carbon monoxide emissions a good reproducibility is given. Higher relative variations between the measurements could be observed only for the hydrocarbon-emissions during rapeseed oil operation due to a generally low absolute emission level.

Keywords
Emission characteristics, tractors, rapeseed oil fuel, diesel fuel, round robin test

Abstract
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The requirements and the test procedure for determining the emissions behaviour within the framework of type approval of tractor engines are defined in the directives 2000/25/EC [1] and 97/68/EC [2] and relevant subsequent directives as applicable. A precise description of the test procedure is given in ISO 8178-1 [3]. In these the engine-related emissions are recorded on an engine test rig with the engine removed from the tractor. More recently studies to determine the actual emissions behaviour of the overall „tractor" system (with engine in situ and power taken off at the power take-off shaft) are coming to be increasingly important [4; 5; 6; 7]. In most cases the test sequence is based on the C1 cycle (8-mode cycle) in accordance with ISO 8178-4 [8]; it can also be used for determining gaseous emissions components for purposes of type approval. The reproducibility of measurements of this nature in relation to a number of test agencies using the C1 cycle has up to now been questionable because there is no uniform specification in existence for the procedure. The aim of the tests described in the following was, therefore, to compare the procedures and results of emissions measurements on a tractor undertaken by the research institutes ART, FJ-BLT and TFZ and to obtain knowledge which might be used for improving and standardizing emissions measurements on in situ tractor engines.

Procedure

The comparative measurements were carried out on a non-series prototype John Deere 6930 Premium „Greenpower" tractor capable of running on diesel or on rapeseed oil fuel. The tractor was transported to the individual research agencies one after the other. The studies were carried out in accordance with the C1 test cycle ISO 8178-4 (8-mode cycle). The fuels used were reference diesel quality CEC RF-06-03 (DK) and a standard batch of rapeseed oil fuel with 0.1 % additive (John Deere Biodiesel Protect 100) (RK) was made available by the tractor manufacturer which met the requirements of DIN V 51605 with the exception of the acid number.

The research institutes were equipped with a range of different measuring devices which are listed in **Table 1** along with the most important measured variables. When it came to calculating the mass flow of the emissions components the mass flow of exhaust gas was unanimously adopted. The mass flow of exhaust gas was determined by measuring the intake air mass and fuel consumption; at FJ-BLT and TFZ the mass flow of exhaust gas was calculated with the help of a carbon balance based on the exhaust gas concentrations measured and the fuel consumption. Measurements of the gaseous emissions compon-

ents carbon monoxide (CO), nitrogen oxide (NO_x) and hydrocarbons (HC) were taken at each test laboratory for each fuel. The fuel consumption was recorded at the same time.
In order to enable the effect of the test modes to be determined at the same time the results were evaluated for each of the 8 test modes individually. Arithmetical mean values (MW) were derived from the 2 or 3 (as applicable) individual measurements carried out by each measuring institute for each type of fuel and these were compared with the grand mean (GMW) of the results from all 3 measuring institutes. The variation in the results based on the average value for each of the 8 test modes was described by means of the relative standard deviation from the mean value (variation coefficient). The arithmetical mean of the variation coefficient of all 8 test modes was designated as the average variation coefficient (dVarK). Correspondingly, the maximum variation coefficient (maxVarK) indicated the greatest relative standard variation of all 8 test modes.

The results were classified by comparing them with the results of a round robin test to ISO 8178 conducted by Stein and Herden (1998) [9]. In this the statement of reproducibility between the test agencies referred to the variation coefficients, determined on the basis of the weighted overall cycle values from 28 measuring institutes with 3 engines of different power output from 18 to 190 kW. The single variation coefficient (VarK) was around 5 % for NO_x, around 13 % for CO, for HC it was around 17 % and for the particle mass emissions, approx. 9 %.

Results and Discussion

Figure 1 shows the tractor's fuel consumption of diesel (grey columns) and rapeseed oil fuel (orange columns) for each test mode. The mean values ascertained by the 3 measuring institutes and shown as crosses were practically tantamount to one another in that they were above the grand mean, something that indicates excellent correspondence of the results. This is also made clear by the low average variation coefficients (dVarK) of 1.4 % when operating with diesel fuel (DK) and 1.0 % when operating on rapeseed oil fuel (RK). The greatest variations in the results between the individual institutes were recorded in test mode 4 in which variation coefficients of 2.6 (DK) / 2.3 % (RK) were determined.

NO_x-Emissions

The NO_x emissions that were determined at the 3 measuring institutes are illustrated on a test mode-specific basis in **figure 2**. Here it is evident that FJ-BLT, with DK in 7 and with RK in 6 out of 8 test modes, arrived at higher NO_x values than ART and TFZ. One reason for this could be that, when the measurements were conducted at FJ-BLT, the engine hood was closed (contrary to what was the case at the other two measuring institutes). The higher temperatures in the engine compartment which are to be noted in test modes 1, 2, 5 and 6 in the upper load range in particular, usually lead to increased thermal NO_x formation. This explanation is confirmed by studies carried out at ART which indicate that, as intake air and engine oil temperature increase, the NO_x emissions rise considerably.
The VarK of the weighted NO_x cycle value is around 9 % for both DK and RK and therefore around 4 % higher than the values determined on the engine test rig in [9]. A comparison between diesel and rapeseed oil fuels as regards the mass flow of NO_x shows hardly any significant differences. However, it should be noted that, with rapeseed oil fuel, a lower output is achieved at the power take-off shaft.

Table 1

Measurement equipment used for the emission measurements by the three institutes

Messgröße/ ***Measured variable***	ART	FJ-BLT	TFZ
Drehmoment und Drehzahl/ *Torque and speed*	Wassergekühlte Wirbelstrombremse Schenk W 700/ *Water-cooled eddy current brake Schenk W 700*	Wassergekühlte Wirbelstrombremse Schenk W 780/ *Water-cooled eddy current brake Schenk W 780*	Luftgekühlte Wirbelstrombremse Eggers PT 301/ *Air-cooled eddy current brake Eggers PT 301*
Kraftstoffverbrauch/ *Fuel consumption*	Kraftstoffwaage AVL 733S/ *Fuel balance AVL 733S*	DK: Pierburg PLU 401, RK: Endress&Hauser Promass 83 M/ *Diesel: Pierburg PLU 401, Rapeseed oil: Endress&Hauser Promass 83 M*	Waage Pesa WT BR 210/B3/ *Balance Pesa WT BR 210/B3*
Kohlenstoffmonoxid CO/ *Carbon monoxide CO*	Pierburg AMA 2000 (NDIR-Analysator)/ *Pierburg AMA 2000 (NDIR-analyzer)*	Horiba Mexa 7170D (NDIR-Analysator)/ *Horiba Mexa 7170D (NDIR-analyzer)*	Rosemount Binos 1001 (NDIR-Analysator)/ *Rosemount Binos 1001 (NDIR-analyzer)*
Kohlenwasserstoffe HC/ *Hydrocarbons HC*	Pierburg AMA 2000 (HFID-Analysator)/ *Pierburg AMA 2000 (HFID-analyzer)*	Horiba Mexa 7170D (FID-Analysator)/ *Horiba Mexa 7170D (FID-analyzer)*	Compur Multi-FID 100 (FID-Analysator)/ *Compur Multi-FID 100 (FID-analyzer)*
Stickstoffoxide NO_x/ *Nitrogen oxides* NO_x	Pierburg AMA 2000 (CLD-Analysator)/ *Pierburg AMA 2000 (CLD-analyzer)*	Horiba Mexa 7170D (CLD-Analysator)/ *Horiba Mexa 7170D (CLD-analyzer)*	Beckmann Industrial 951A (CLD-Analysator)/ *Beckmann Industrial 951A (CLD-analyzer)*

CO-Emissions

Figure 3 shows a good level of correspondence of the CO emissions between the measuring institutes. This is confirmed by reference to the average variation coefficients (dVarK) which amount to 8.4 % in the case of DK and to 6.9 % in the case of RK. By far the highest VarK determined for both fuels was in test mode 5. At 22.3 % (DK) and 12.9 % (RK) this indicates a comparatively high level, especially as the VarK is below 10 % for all 7 other (DK) / 6 (RK) test modes. On explanation for the higher VarK in test mode 5 could be that, on changing from test mode 4 (partial load 10 %) to 5 (full load 100 %), the 10 minute minimum period for a test mode specified in ISO 8178-1 was not always sufficient given stationary operating conditions with a constant level of emissions on a tractor-mounted engine. Dwell times of consistently longer duration in this test mode could possibly increase the reproducibility of the results.

The variation coefficients (VarK) of the weighted cycle values were 5.9 % for DK and 3.1 % for RK. This means that they are more than 50 % lower than the VarK used for the comparison which was determined in the round-robin test in [9].

In the comparison of the CO emissions between DK and RK the values that emerged for RK were around 7 % more favourable. Nevertheless, the only advantages as far as RK was concerned were noted in the test modes with a minimum load of 50 %. In light load and no-load operation (test modes 4 and 8) the CO emissions in diesel operation were below the level for operation on rapeseed oil.

HC-Emissions

The HC emissions are illustrated in **figure 4**. In accordance with expectations and as a result of the very low absolute emissions values as reported during operation on rapeseed oil fuels in particular, comparatively major relative fluctuations were noted between the individual measurements. The dVarK for DK amounted to 13.4 % and for RK it was 40 %. Likewise, the max VarK, at 23.5 % (DK) and 50.1 % (RK), was in many cases higher than for NO_x and CO. As regards the weighted HC cycle results carried out on the tractor test rig, the VarK amounted to 12.6 % for DK as against 35.3 % for RK. In [9] a VarK of 17 % was determined on the engine test rig for HC.

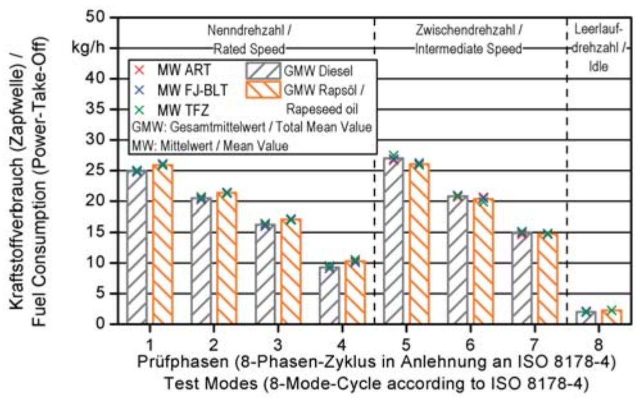
A comparison of the HC emissions for both fuels shows that, during operation on DK of 4-21 g/h, considerably higher values emerged than was the case with rapeseed oil fuel (1-9 g/h). This can also be seen from a large number of other studies.

Conclusions

The comparative measurements show that the results of the emissions measurements on the tractor demonstrate a good level of correspondence, despite the adoption of a different approach by each of the measuring institutions involved and differences in their measuring equipment. These results fluctuate within the range of values determined on the engine test rig. This applies in particular to specific fuel consumption as well as for NO_x and CO emissions. It was only the HC emissions related to RK that featured a more pronounced variation between the measurements, something which primarily had to do with the low absolute concentration values.

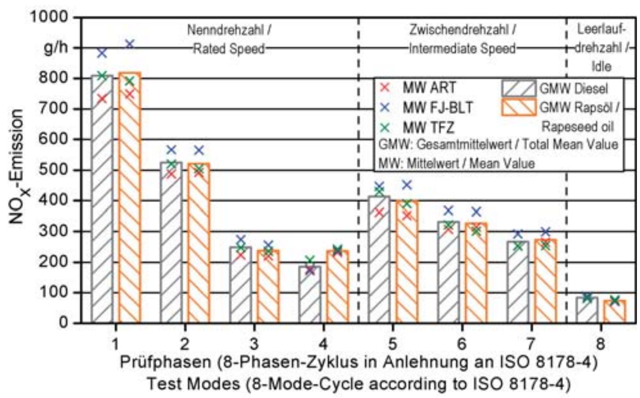
A further improvement in the reproducibility of the results between different measuring institutes could be achieved if the procedure as regards the emissions measurements were to be specified and standardized. This could, for example, take the form of specifications as regards the structure of the unit under test (open or closed hood), the sampling location or the exact amount of dwell time in the individual test modes.

Fig. 1



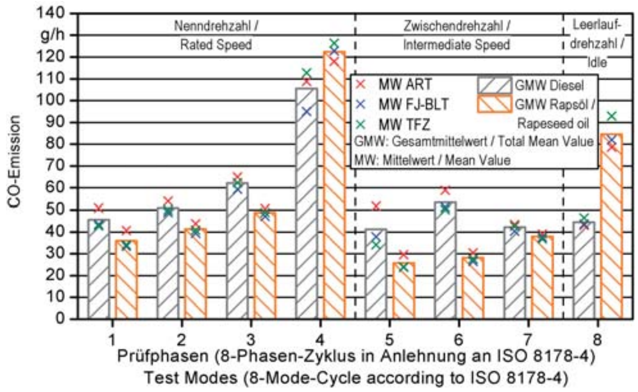
Fuel consumption of diesel and rapeseed oil during the test modes

Fig. 2



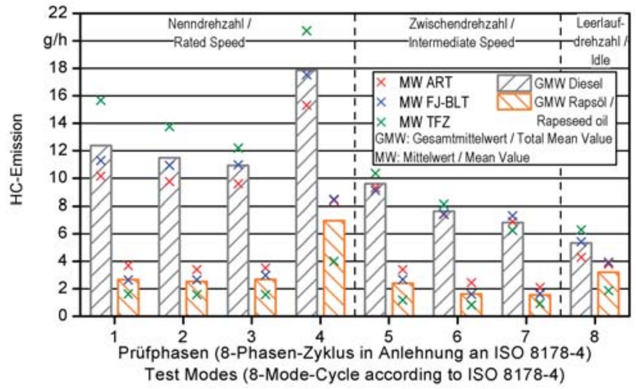
NO_x-emissions during the test modes

Fig. 3



CO-emissions during the test modes

Fig. 4



HC-emissions during the test modes

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