THE MEASUREMENT OF EXHAUST EMISSIONS FROM THE ENGINES FITTED IN AGRICULTURAL TRACTORS UNDER REAL OPERATING CONDITIONS

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Abstract: The exhaust emissions tests from non-road vehicles including machines used in agriculture are currently performed on engine dynamometers in NRSC and NRTC tests. Such tests do not entirely reflect the real machine operating conditions. Real operating conditions are characterized by variable loads and variable engine speeds and to a large extent they depend on other factors that occur under operation (variable weather conditions). In light of the growing emission requirements in relation to transport it seems justified to determine the real emissions under real operating conditions. This testing method is one of the main trends in the development of the emission testing methodology worldwide. The tests performed under real operating conditions should be used for the optimization of future powertrains used in both road and non-road vehicles. The results of such tests should also be included in the works on the improvement of the emissions legislation. The paper presents the results of the emission tests from the engines fitted in agricultural tractors (plowing). For the measurement of the emissions a portable exhaust emissions analyzer SEMTECH DS. by SENSORS was used. Based on the obtained results an analysis was developed of selected engine parameters. The performed analysis is a comparison of two tractors performing similar field work. In the final part of the paper the authors present the possibilities and trends in further works related to the emissions measurements under real operating conditions from vehicles used in agriculture.

Introduction

The necessity to reduce exhaust emissions and fuel consumption in transport has recently led to the development of new testing methods. In order to be able to develop new environment friendly designs the engineers must have full information on the relations between the exhaust emissions and the engine operating parameters including vehicle on-road parameters. At the same time methods are developed aiming at improving the accuracy of the exhaust emissions measurements. Observing the development trends of the exhaust emission measurement methodology we can see more frequent instances of vehicle testing under vehicle real operating conditions [2]. The results of the road tests provide important information on the influence of the engine operating parameters and parameters of the whole vehicle on the exhaust emissions. Also, in the case of the non-road vehicles the use of this method seems reasonable.

Testing method and experimental equipment

The tests were performed on two farm tractors A and B. The basic technical data have been shown in tables 1 and 2. The engine fitted in tractor A is a modern second generation common rail diesel turbocharged unit. The maximum injection pressure in this unit is 1600 bar. The engine is bio fuel B100 compatible. In order to reduce the exhaust emissions exhaust gas recirculation and an oxidizing catalyst were applied. Tractor B was fitted with a direct injection diesel engine. In comparison with tractor A it is an older generation unit. This engine is not fitted with EGR and an oxidizing catalyst. During the tests the tractors were fueled with standard diesel oil. The view of the tractors has been presented in figure 1.

Table 1: Basic technical data tractor A

number of cylinders/ displacement	6 cyl., straight 7,145 dm^3
maximum power output	198 kW/ at 2350 rpm
maximum torque	1052 Nm/ at 1600 rpm
cooling	forced circulation/ coolant
injection	Common rail, max. injection presure 1600 bar
number of valves	24

Table 2: Basic technical data tractor B

engine	6 cyl., straight/6,842 dm^3
bore and stroke	110mm x 120mm
maximum power output	111 kW/ at 2200 rpm
maximum torque	520 Nm/ at 1450 rpm
cooling	forced circulation/ coolant
compression ratio	17
minimum unit fuel consumption	245 g/kWh
number of valves	12

In order to measure the concentration of the exhaust emissions a portable exhaust emission analyzer SEMTECH DS by SENSORS was used [4]. The analyzer measured the concentration of the exhaust components with a simultaneous measurement of the exhaust mass flow. The exhaust gas introduced into the analyzer by means of a probe maintaining the temperature of 191oC was then filtered out of particulate matter (CI engine) and directed to the flame-ionizing detector (FID) where the HC concentration was measured. Then the exhaust gases were cooled down to the temperature of 4oC and the measurement of the concentration of NOx (NDUV analyzer), CO, CO2 (NDIR analyzer) and O2 followed in the listed order. It was possible to add the data sent directly from the vehicle diagnostic system to the central unit of the analyzer and make use of the GPS signal (tab. 3, fig 2). In the tests the measurements of the emissions were used and also, for the purpose of comparison, signals from an on-board diagnostic system were recorded such as engine speed, load, vehicle speed and temperature of intake air. Some of these signals served to specify the time density maps presenting the share of the operating time of a vehicle under real operating conditions. The GPS signal was used in further visualization of the obtained data (fig. 3).

Figure 1: The tractors with the measurement equipment

Table 3: Characteristics of the portable exhaust analyzer SEMTECH DS

Parameter	Measurement method	Accuracy
1. Emissions		
CO	NDIR, range 0–8%	±3%
HC	FID, range 0–10.000 ppm	±2%
NOx = (NO + NO2)	NDUV, range 0–2500 ppm	±3%
CO2	NDIR, range 0–20%	±3%
O2	Electrochemical, range 0–25%	±1%
2. Data storage capacity	Over 10 hours at 1 Hz data acquisition rate	
3. Vehicle interface capacity	SAE J1850 (PWM), SAE J1979 (VPW) ISO 14230 (KWP-2000) ISO 15765 (CAN), ISO 11898 (CAN) SAE J1587, SAE J1939 (CAN)	

The tests of the tractor emissions included the tractor drive to the field on which the plowing was done, measurements during the field work (plowing) and the drive back from the field. The drives in which the measurements were done have been shown in figure 3. In this figure we can see thick overlain lines showing the tractor drives while working.

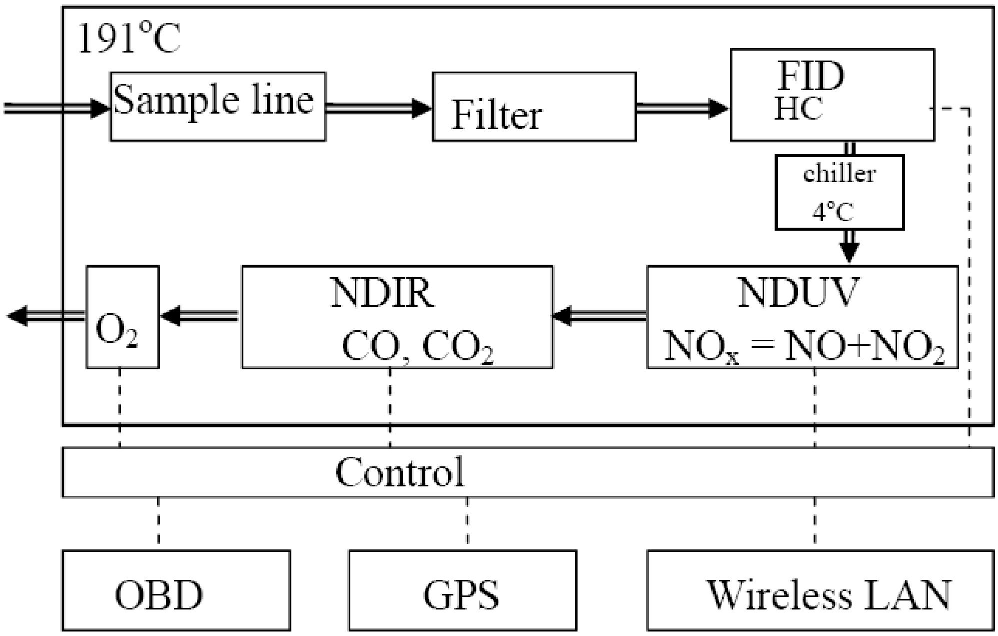

Figure 2: A diagram of a portable analyzer SEMTECH DS; exhaust gas flow channels (===) and electrical connections circled (– – –)

Figure 3: Tractor drive map during the tests (tractor A operation – left, B – right)

Test results and analysis

The concentration of CO during engine operation grows significantly when the engine revolutions increase. Higher CO concentration occurs mainly during the tractor drives and tractor and equipment preparation for work. During the plow the concentration of CO drops and stays on a more or less constant level except points on the map where a sudden rise in the engine load occurs resulting from the work specificity. A reduction of the CO concentration when plowing results from an increase in the engine load, hence the increase in the exhaust gas temperature, which again increases the oxicat efficiency. A significant difference in the CO concentrations is seen when the tractor enters and leaves the field - this results from the fact that the engine (also the catalytic converter) has a higher temperature. In figures 4 and 5 the changes in the CO concentration and engine speed during tractor operation in the field have been presented. The increase in the engine speed to approximately 1700 rpm shown in this figure corresponds to the increase in the engine load (tractor begins to plow). Also in this figure we can see the relation between the CO concentration and the engine load – operation without a load increases the CO concentration in the exhaust gas, which should be construed as a reduction in the oxicat efficiency.

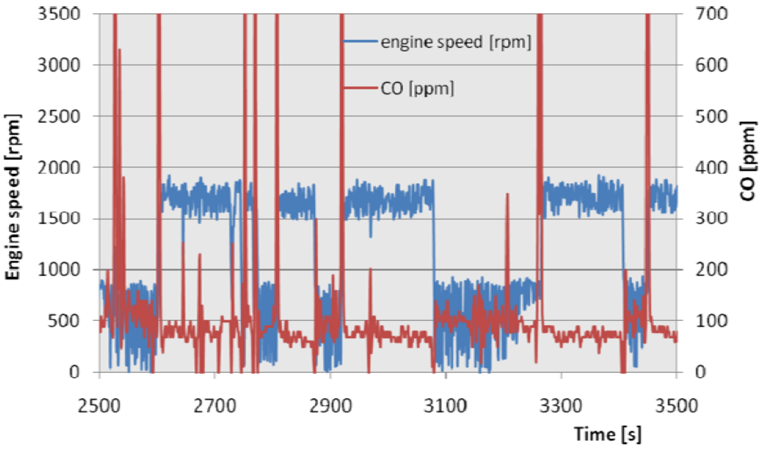

Figure 4: CO concentration and engine speed during the tests on tractor A

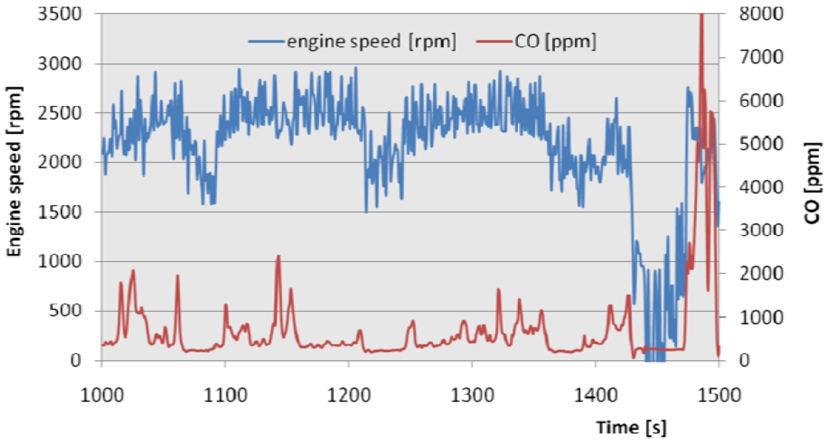

Figure 5: CO concentration and engine speed during the tests on tractor B

The concentration of HC in the exhaust gas shows similar dependencies as the concentration of CO described above (fig. 6 and 7). We can see a clear relation between the increase in the engine speed, the engine load and the concentration of HC. In the case of HC no significant increases in the concentration were recorded, as was in the case of CO.

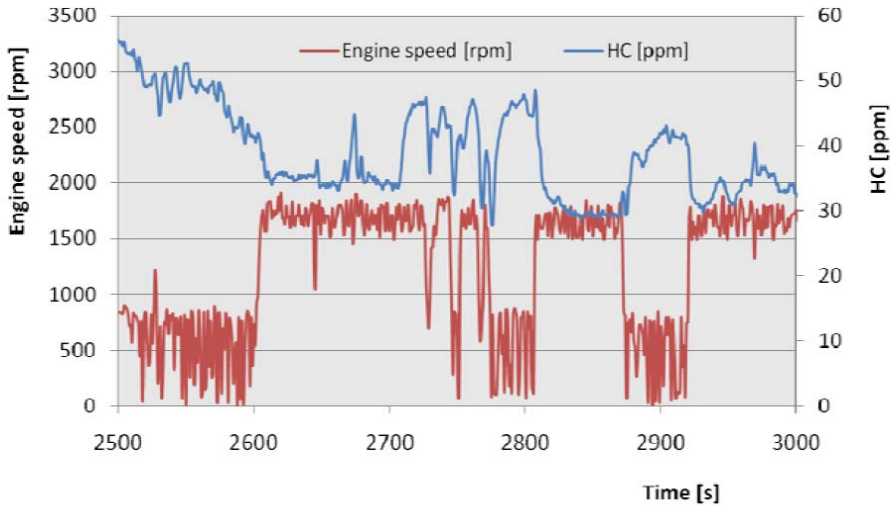

Figure 6: HC concentration and engine speed during the tests on tractor A

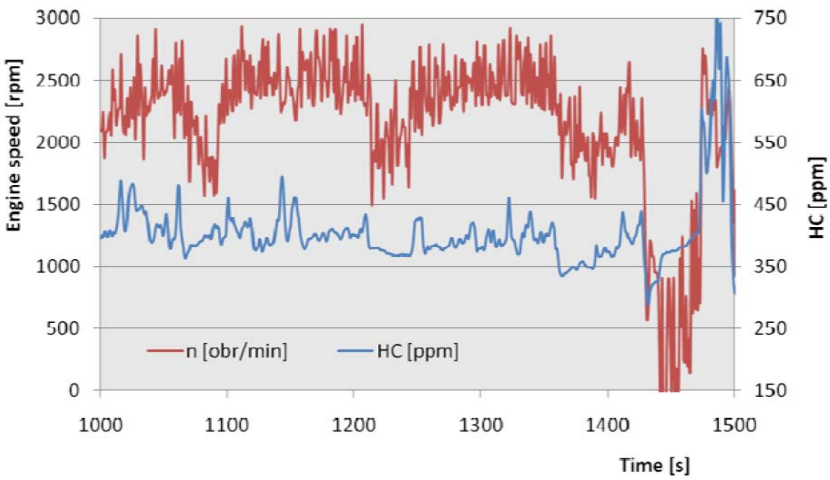

Figure 7: HC concentration and engine speed during the tests on tractor B

The concentration of NOx grows as the engine speed and load increase (fig. 8 and 9). This dependence is clearly visible in figure 8, showing the concentration of NOx during tractor preparation and plowing. From the visualization of NOx concentration shown in the figure (as overlain on the tractor trajectory) we can see that when plowing the concentration is many times higher than when the tractor drove to the field. The changes in the concentration of CO2 and NOx shown in figures 8 and 9 prove that increasing the engine load and speed when plowing results in a higher NOx concentration.

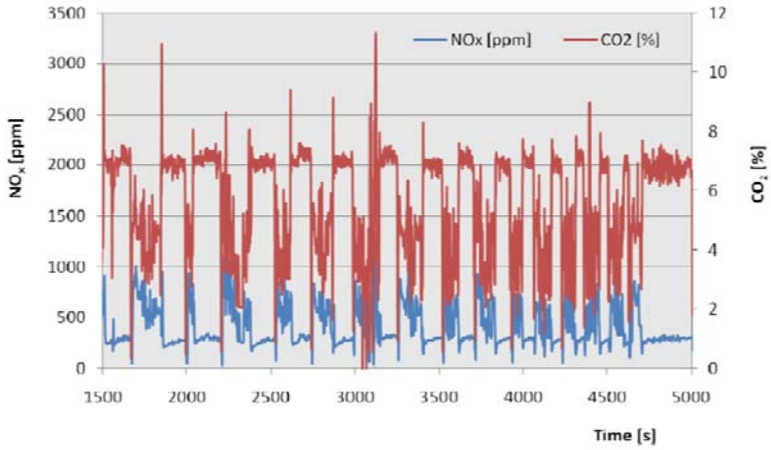

Figure 8: The concentration of NOx and CO2 when operating in the field (tractor A)

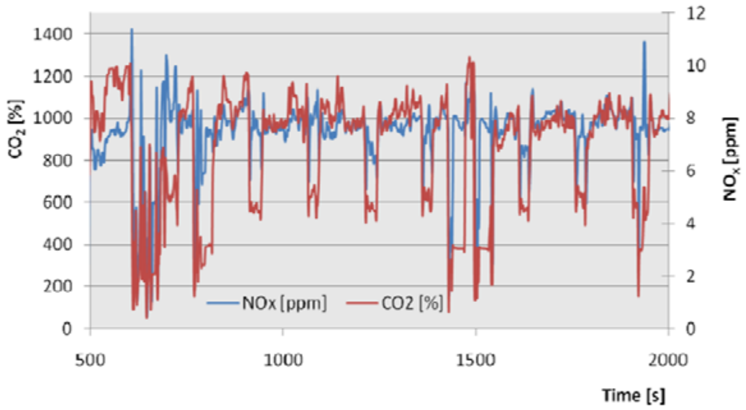

Figure 9: The concentration of NOx and CO2 when operating in the field (tractor B)

When comparing the exhaust emissions we need to take into consideration the work done by both tractors (A and B). Tractor A operated with a rotary five blade plow. The operating width of this plow is 2.4 m and the plow depth 0.35 m. Tractor B operated with a five blade plow of the operating width of 2 m and plow depth of 0.3 m. If we assume a comparable plowing speed we can state that tractor A did more work in a time unit (larger area of the plowed field). The concentrations of the tested exhaust components have been compared during a selected work portion (tractor in the plowing mode). This comparison has been shown in figures 10–12. These are representative of the whole measurements. From the comparison of the individual collective results we know that the concentration of all the exhaust components is higher for tractor B. The concentration of CO2 is higher by 30-40% and in the case of the other exhaust components these differences are much higher and reach several hundred per cent. The highest difference refers to the concentrations of HC and CO in the exhaust gas, which apparently results from the presence of an oxidation catalyst in the engine of tractor A. Hence, considering the work done by the tractor we can conclude that tractor A is characterized by more advantageous ecological properties as opposed to tractor B.

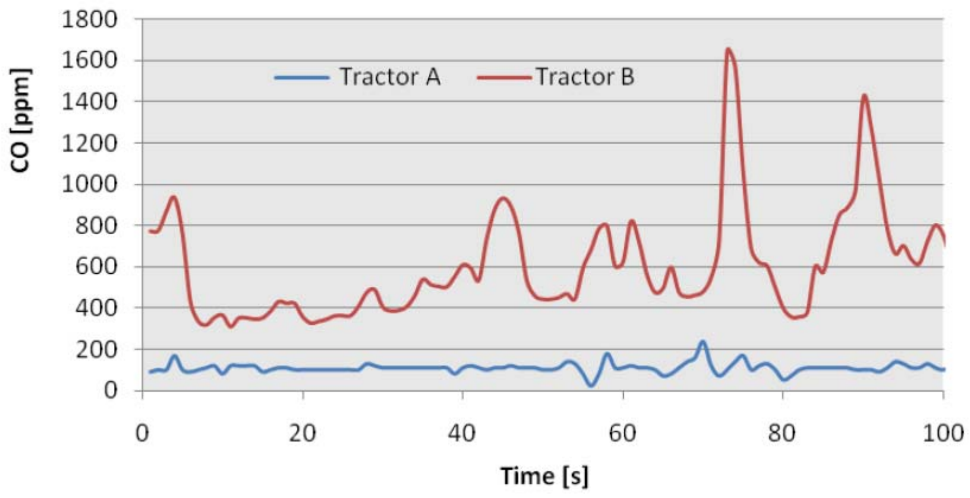

Fig. 10. CO concentrations from the tractor engines when plowing

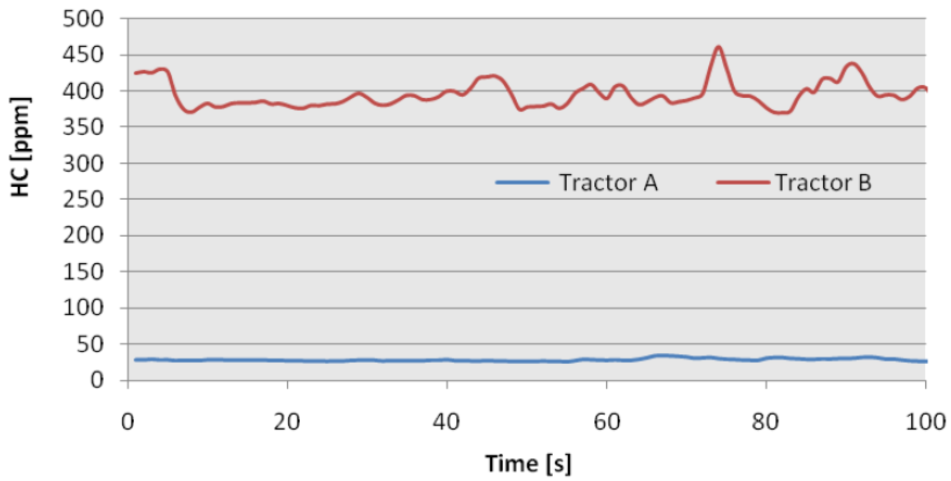

Figure 11: HC concentrations from the tractor engines when plowing

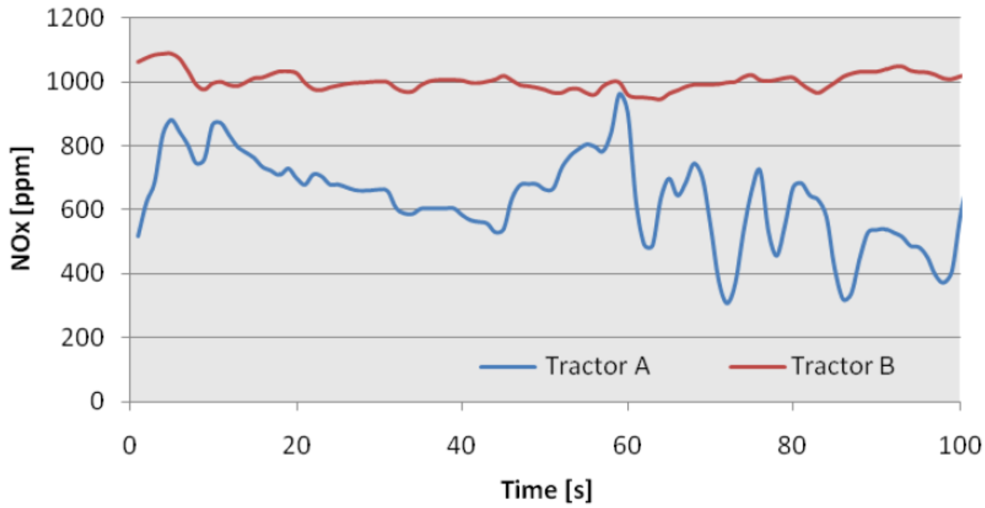

Figure 12: NOx concentrations from the tractor engines when plowing

Conclusions

The developed and here presented exhaust emissions testing methodology provides an opportunity to evaluate the ecological properties of farm tractors under different operating conditions, including operation with any selected agricultural equipment. Analyzing the work done by the tractor the authors state that tractor A is characterized by better ecological properties in comparison to tractor B (this relates to all the tested exhaust components in relation to the performed work - plowed area). Based on the performed tests, the authors also confirm lower fuel consumption by tractor A. The concentrations of CO and HC decrease when tractor A operates, which results from the application of an oxidizing catalyst. Proposals related to further trends in this research should focus on: the influence of the engine and tractor parameters (engine speed, gear ratio in the plowing mode etc.) on the exhaust emissions, the influence of the type and settings of the equipment (plow or other machinery) on the exhaust emissions and the influence of the type of soil and ambient conditions (temperature) on the exhaust emissions.

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