REAL DRIVING EMISSIONS OF VEGETABLE OIL FUELLED TRACTORS

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ABSTRACT: Conventional engine test-cycles usually do not represent real driving emissions. Due to their relevance for human health and their effect on climate change, determination of real driving emissions by portable emission measurement systems (PEMS) becomes increasingly important. The purpose of this work is to measure real world gaseous and particulate emission components of diesel and vegetable oil fuel operated mobile agricultural machinery with PEMS. Variation and comparison of machine work types as well as operating conditions will show the range of fluctuation and are basis for optimisation processes. Additionally, this work will support the development of propulsion systems that are more efficient and have lower impacts on air quality and climate change. First results show that real driving emissions of tractors fulfill related proposed limits easily. The results however, have to be verified within ongoing measurements.
Keywords: biofuels, vegetable oil, agriculture, emissions

1 INTRODUCTION

Despite the introduction of uniform EU-wide exhaust emission legislation in the 1990s and despite continuous tightening of the emission thresholds, adequate improvement of air quality has not been observed. Conventional test cycles usually do not represent real driving emissions (RDE) of limited pollutants since real driving conditions cannot be fully reproduced on the test stand and testbed conditions are typically idealized. Additionally, vehicles can be optimised for the operating profile, which is performed within the test cycles. Various studies prove differences between test stand and real world emissions and thus, indicate the need for action [5, 6]. Measurement of real driving emissions (RDE) will become more and more important for evaluating the impact of vehicles and machines powered by combustion engines and hence RDE are further incorporated in legislation. In order to verify fulfillment of real driving emission requirements, measurement takes place by using portable emission measurement systems, so-called PEMS.

2 BACKGROUND

For trucks the testing of the so-called in-service-conformity (ISC) is mandatory since the entry into force of exhaust stage EURO 6 in the year 2013. Here emissions of vehicles that are already in operation are monitored regularly over their life-time under real driving conditions by using a PEMS. The legal provisions for trucks are basically defined in EU-directives 582/2011 and 64/2012.

The statutory basis for real driving emissions (RDE) of passenger cars is EU-Directive 715/2007. Presently method and testing protocol forms are developed. Beginning in 2017 fulfillment of exhaust gas limits under real-driving conditions will be tested for new vehicles during type approval and additionally over the life-time.

For non-road mobile machinery (NRMM) a similar procedure as for trucks (see above) is suggested. Due to the great variety of non-road applications and their specific operation conditions the method has to be adapted. To support the introduction of PEMS as tool to control in-service-conformity from non-road mobile machinery in terms of exhaust gas emissions the so-called NRMM PEMS Pilot Programme was launched (Bonnel et al. (2013) [1]). Implementation in legislation is expected in 2019.

For data evaluation methods from heavy duty commercial vehicles serve as base for NRMM. When applying the so-called European "Moving Averaging Window Method (MAW-method)" certification limits at type approval serve as reference values. By using the MAW-method the average emissions of consecutive opening measuring segments (windows) during a longer operation period of the test vehicle are monitored. The widths of the test windows correspond to the total work or CO_2-emissions of the test stand cycle. For modern tractors the reference test cycle is usually the non-road transient cycle (NRTC). For every new data point a new window is being started and stays open until the same total work or CO_2 value is reached as during the reference test cycle.

The total amount of pollutants emitted during MAW is related to the legal emission limit of the test cycle. This ratio is defined as conformity factor (CF). As reference the 90th percentile is being used. This means that 90 % of all calculated conformity factors must be below a defined threshold (e.g. CF = 1.5 according to RDE regulation for trucks).

During result evaluation windows are excluded, when average engine load is below 20 % of nominal engine load (20 % power threshold). To eliminate long idle periods, additionally working and non-working events are defined. If cold start emissions are not considered, measurement starts, when a minimum engine cooling water temperature is reached (e.g. 70 °C).

At least 50 % of valid windows are mandatory for a entire valid measurement.

Detailed description of the measuring method is given in Bonnel et al. (2013) [1]. Despite the lack of legislative basis for non-road mobile machinery, several studies about real driving emissions are conducted with various test equipment [2, 3, 4] and different data evaluation methods. Thus, coherent comparison of results is hardly possible.

3 PURPOSE

Purpose of this work is to set up a portable emission measurement system (PEMS) for gaseous emission components, particulate mass and number in order to measure real driving emissions (RDE) of mobile agricultural machinery. Furthermore, RDE measurements should be conducted with non-road mobile machinery, including variation and comparison of type of conducted machine work as well as operating conditions. Finally, measurements should be carried out with diesel and rapeseed oil fuel.

4 APROACH

The portable emission measurement system has been installed in a purpose built safety box. Fig. 1 shows the set-up of the PEMS Semtech Ecostar from the company *Sensors, Inc.*, Michigan, USA. The analysers for measurement of gaseous components of combustion engines comply with the guidelines of directive UN-ECE.R-49 and Commission Regulation (EU) No. 582/ 2011 as well as US EPA 40CFR part 1065.

Figure 1: Set-up of portable emission measurement system PEMS Semtech Ecostar in purpose built box

Following parameters are recorded with PEMS Semtech Ecostar from *Sensors, Inc.*:

- Exhaust gas mass flow (Pitot pipe)
- NO and NO_2 - NDUV
- CO and CO_2 - NDIR
- THC and methane - FID
- Particle mass or number -
  - ○ Proportional dilution
  - ○ Pegasor® PPS-M Sensor
  - ○ Gravimetric analysis
- Operation data (CAN bus)
- Position (GPS)
- Ambient conditions

The purpose built box with analysers, sensors and an external independent power supply is mounted in front of a tractor and simultaneously serves as front weight.

The test vehicle a Fendt 724 Vario SCR meets latest exhaust stage IV and is equipped with SCR catalyst and particle filter. The rated power of the engine is 176 kW. The tractor was retro-fitted by the BayWa AG to make it compatible for the use of pure vegetable oil fuel according to DIN 51623 or rapeseed oil fuel according to DIN 51605. Solely diesel operation is also still possible.

So far, measurement took place mainly with rapeseed oil fuel during several ploughing events as well as during cultivating and transport. Fig. 2 shows the tractor Fendt Vario 724 SCR ploughing with mounted PEMS box during RDE measurement at a test farm near Mainkofen, Germany.

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

5 RESULTS

The tractor route for the example of a ploughing event is traced back by recorded GPS data and shown in OpenStreetMap of Fig. 3.

Figure 3: Tractor route (ploughing), recorded by GPS data during PEMS measurement

First emission measurements could be conducted successfully during various types of tractor use, as there are ploughing, cultivating and transport.

The average RDE of CO, NO_x, THC and PM are lower than the decisive emission benchmarks of the engine certification test cycle. This becomes obvious due to the fact that the majority of conformity factors is below 1. Typically 90 % of conformity factors are less than the threshold of 1.5 according to legislation for trucks. Mostly CO-, THC- and PM-emissions are close to detection limit. Only NO_x-emissions vary wider, depending on SCR activity especially during cold start events, as result of the exhaust temperature.

Fig. 4 shows the cumulative percentage of conformity factors for carbon monoxide (CO), nitrogen oxides (NO_x) and total hydrocarbons (THC) of the tractor Fendt 724 Vario SCR during ploughing, operated with rapeseed oil fuel. The data were recorded with PEMS and include cold start. Within the entire trip duration of 2 hours 21 minutes and 32 seconds 8324 measuring segments were valid. The average ambient air temperature was 13.7 °C.

At the 90th percentile conformity factor for carbon monoxide (CO) is 0.01 for nitrogen oxides (NO_x) 1.29 and for total hydrocarbons (THC) 0.11.

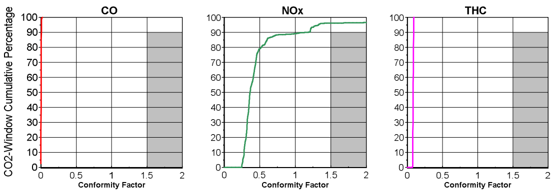

Figure 4: Cumulative percentage of conformity factors for carbon monoxide (CO), nitrogen oxides (NO_x) and total hydrocarbons (THC) of a tractor Fendt 724 Vario SCR during ploughing, operated with rapeseed oil fuel

6 CONCLUSIONS

First results on one tractor show that recorded real driving emission values easily meet thresholds derived from truck legislation. Conformity factors that describe the ratio of actual emissions, measured with PEMS, to test cycle values, measured at the test stand are largely lower than 1.0. 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. Latter are characterized by more transient operation profiles. During the ongoing project results have to be validated.

The results of the work can help to determine real world emissions of biofuel compatible agricultural mobile machinery, to derive work specific emission factors and 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.

7 OUTLOOK

The research will be continued by repetitive measurements of different types of tractor work for data validation (e.g. transport, see Fig. 5). Additionally, further vehicles will be tested with biofuels and conventional diesel for comparison.

Figure 5: PEMS measurement during street transport with vegetable oil compatible Fendt 724 SCR (Stage IV)

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9 REFERENCES

[1] P. Bonnel, A. Perujo, A. Provenza, M. Villafuerte (2013): Non Road Engines Conformity Testing Based on PEMS. Lessons Learned from the European Pilot Program. European Commission (EC) (Hrsg.). Joint Research Centre, Institute for Energy and Transport (IET). JRC Scientific and Policy Reports, Nr. EUR 26438 EN, pag. 45.

[2] J. Merkisz, P. Lijewski, P. Fuc, P. Weymann (2013): Exhaust emission tests from non-road vehicles conducted with the use of PeMs analyzers. Eksploatacja i niezawodnosc – Maintenance and reliability, Jg. 15, Nr. 4, pag. 364–368.

[3] C. Gietzelt, H.W. Knuth, H. Heinle (2012): Mobile "in-use" Emissionsmessung bei realen Agraranwendungen. Ein Beitrag zu EU-PEMS Pilotprojekt für mobile Maschinen (NRMM). In: AVL Deutschland GmbH (Hrsg.): Abgas- und Partikel-Emissionen. 7. Internationales Forum. Ludwigsburg, 6.-7. März. Mainz-Kastel: AVL Deutschland GmbH, pag. 70–80.

[4] FREY, H.; RASDORF, W.; KIM, K.; PANG, S.-H.; LEWIS, P. (2008): Comparison of Real-World Emissions of B20 Biodiesel Versus Petroleum Diesel for Selected Nonroad Vehicles and Engine Tiers. Transportation Research Record: Journal of the Transportation Research Board, Jg. 2058, pag. 33–42.

[5] P.A. Brooks, United States Environmental Protection Agency (EPA) (2015): Re: Notice of Violation. Certified Mail an Empfänger: D. Geanacopoulos, S. Johnson, Volkswagen Group of America, Inc., Volkswagen AG and AUDI AG. Washington, D. C., 18. September 2015, pag. 6.

[6] V. Franco, F. Posada Sánchez, J. German, P. Mock (2014): Real-world exhaust emissions from modern diesel cars. A meta-analysis of PEMS emission data from EU (Euro 6) and US (Tier 2 Bin 5/ULEV II) diesel passenger cars. Part 1: Aggregated results. International Council on Clean Transportation Europe (ICCT) (Hrsg.). Beijing, Berlin, Brussels, San Francisco, Washington, D. C. ICCT White Paper, Nr. October 2014, pag. 53.

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