COMPARISON OF CVS AND PEMS MEASURING DEVICES USED FOR STATING CO_2 EXHAUST EMISSIONS OF LIGHT-DUTY VEHICLES DURING WLTP TESTING PROCEDURE

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Abstract. In 2014, the United Nations Economic Commission for Europe (UNECE) released the Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP). The European Commission focused on introducing a new trial test procedure into the European legislation with the aim to replace the existing test for stating exhaust emissions, the so-called New European Driving Cycle (NEDC). The official data measured in laboratories show lower average fuel consumption and emission production of carbon dioxide (CO_2) of European car fleet than it is in real driving conditions. Experts and the public declare that the officially stated CO_2 values do not reflect the reality. This article presents results from two measuring devices from constant volume sampler (CVS) and from portable emissions measurement system (PEMS) used for stating the concentration of CO_2 emissions. The experiment was conducted according to the Worldwide Harmonized Light-Duty Vehicles Test Procedure. The results show that there are not statistically significant differences between the CVS and PEMS devices, which are usually used for emission measuring in real driving emissions (RDE). Results of this paper provide information from the measurement, which was carried out according to WLTC with PEMS and CVS equipment. The experiment reflects the actual legislation requirements for emissions measurements. The results are useful tools for comparation technologies used for emissions measurements in laboratories (CVS) and on road emissions (PEMS).

Keywords: WLTP, PEMS, CVS, CO_2, emissions, exhaust gas.

Introduction

Traffic represents a big share of global emissions of greenhouse gases and toxic pollutants. Emissions of vehicles contribute significantly to the production of CO, CO_2, HC, or NOx. Due to the continuous growth of the demand for travelling, the fuel consumption and greenhouse gas emissions (GHG) increase [1]. The transport sector is the only area in the European Union (EU), in which the emissions of CO_2 grow by 19 % in comparison of the year 2013 with the year 1990 [2]. According to the European Commission [2] in the area of road transport, the amount of vehicles and transport performance will still be growing. Even now, transport is responsible for the production of more than 20 % of CO_2, 71 % of which is represented by the road transport itself [3]. Generally, the transport activities will increase in the following 40 years, according to the predictions, but the total amount of CO_2 emissions produced will be lower, thanks to the lowered fuel consumption of vehicles and increasing number of electromobiles. Based on the current trends, the level of CO_2 emissions should remain stable, so its volume in the year 2030 and 2050 should be approximately 35 % higher than in the year 1990. However, this fact is not in accordance with the policy stated in the White Paper on Transport, which also mentions lowering the greenhouse gas emissions until the year 2050 by 60 % in comparison with their level in the year 1990 [4]. The study [6] predicts that the amount of CO_2 emissions will probably continue to grow in connection with the improving quality of human life and economic growth of population.

Due to these problems caused by traffic, the EU prepared a measure for car manufacturers, who should help lower the environmental impact on air. One of the measures is the necessity to keep the maximum average car fleet production of CO_2 corresponding with 130 $g \cdot km^{-1}$ since the year 2015. At the end of 2020, a stricter limit will become valid, which is 95 $g \cdot km^{-1}$ CO_2 [3]. These limits may be adjusted to 78 $g \cdot km^{-1}$ in the year 2025, respectively 48 $g \cdot km^{-1}$ in the year 2030 [6]. The aim of these limits is stimulation of investments of the car manufacturing industry into new technologies and therefore into lowering CO_2 emissions [7].

Nowadays, vehicles, which were tested using the currently valid New European Driving Cycle (NEDC), are still being sold. However, some studies [8] showed that the fuel consumption and the related pollutant emission production could be significantly higher in the real driving conditions in comparison with the values measured during the testing on dynamometer in the testing laboratories [9]. One of the reasons of this discrepancy is NEDC, which is still used. The current testing cycle was

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frequently criticized for being too smooth, non-dynamic and did not reflect the typical vehicle operation [10; 11]. In many countries, the demand raised for development of a new driving cycle and new testing procedure, which would be more representative for the driving conditions and emissions in the real world. In 2009, the United Nations Economic Commission for Europe (UNECE) started a new project using the Working Party on Pollution and Energy (GRPE) with the goal of creating the Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC), respectively the Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP). WLTP was adopted by the World Forum for Regulation Harmonization as the Global Technical Regulation 15 in March 2014. The new testing procedure WLTP, which defines the global standard for defining pollutant emissions and CO_2 emissions, aims to minimize the discrepancies between the fuel consumption measured in the real world with the conditions during the testing of the vehicle type approval. The manufacturers were also given the responsibility to conduct emission measuring in real operation using the PEMS tool. The RDE test, however, does not replace the laboratory test, it complements it.

The paper presents the results of testing of two independent measuring devices (PEMS and constant volume sampler (CVS)) of CO_2 emissions produced by passenger cars, PEMS is used for the measurement of CO_2 emissions in real operation, the CVS system under laboratory conditions, the experiment was carried out for both measuring devices in a test laboratory and the aim was to compare the emission results obtained by these measuring devices under identical conditions on the WLTC driving cycle. The purpose of the research is to provide results from measurements in same ambient conditions for both technologies used during testing of vehicles.

Materials and methods

This study compared two measuring devices, which analyzed the exhausts of 12 selected vehicles. According to the European Union's regulation 2017/1151 on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (EURO 5 and EURO 6), it is necessary to keep many responsibilities and procedures. One of these requirements is the regular validation of the PEMS system. This part describes the requirements, based on which the PEMS system functionality is validated.

It is recommended to validate the mounted PEMS system once at each vehicle combination with the PEMS system either before the emission testing in real driving conditions or after finishing the testing. The validity test is conducted on vehicle dynamometer according to the conditions of the type approval according to the appendix 4 requirement and the UNECE regulation No. 83 or another suitable method of measuring. It is recommended to conduct the validity testing using the WLTC which is described in appendix 1 in the global technical regulation No. 15 of UNECE. It is also recommended to lead away the flow of the exhaust gas, which will be drained by the PEMS back to the CVS (constant volume sampler) during the validity testing.

The total produced emissions for a specific distance ($g \cdot km^{-1}$) measured using the laboratory equipment are calculated according to appendix 4a of the UNECE regulation No. 83, series of amendments 07. The emissions measured by the PEMS system are calculated according to the point 9 of amendment 4, the testing (km), which is subtracted from the vehicle dynamometer. For the validation of the PEMS results, these values must be in the permissible deviations. If any of the permissible deviations is not kept, a correction is made and the PEMS validation is repeated. Permissible deviation for CO2 ($g \cdot km^{-1}$) is ±10 $g \cdot km^{-1}$ or 10 % of the laboratory referential value.

The experiment for the PEMS validation on a chassis dynamometer was conducted according to the valid legislation and during the WLTC. Contrary to the old testing cycle NEDC, WLTC is significant mainly for its more dynamic characteristics and longer distance reached. The length of the testing period and the distance reached of WLTC and NEDC differ significantly. Another significant difference is the higher value of NOx and CO_2 emissions. This fact is given by the longer period of driving, higher average speed and a lower idle time. [12].

The idle time was an important part of the testing according to NEDS, too. The car manufacturers reacted on this parameter by introducing the START-STOP system. The purely beneficial influence of this technology has not been fully proven until this day. Although the CO_2 emissions decreased both in the laboratory conditions and in the real driving conditions, the introduction of the START-STOP system is still questionable [13].

The following Figure 1 and Figure 2 clearly show the main difference between the old NEDC cycle and the new WLTC cycle. The testing parameters are also clearly organized in Table 1.

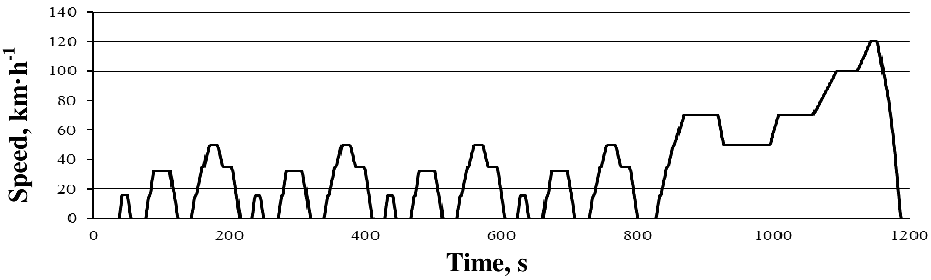

Fig. 1. **Speed profile NEDC**

The NEDC cycle includes four urban driving cycles (UDC). These parts are characteristic for their low vehicle speed, low engine load and low exhaust temperature. The UDC parts are followed by one extra-urban driving cycle (EUDC), which contributes to a more aggressive style of driving and reaches a higher vehicle speed.

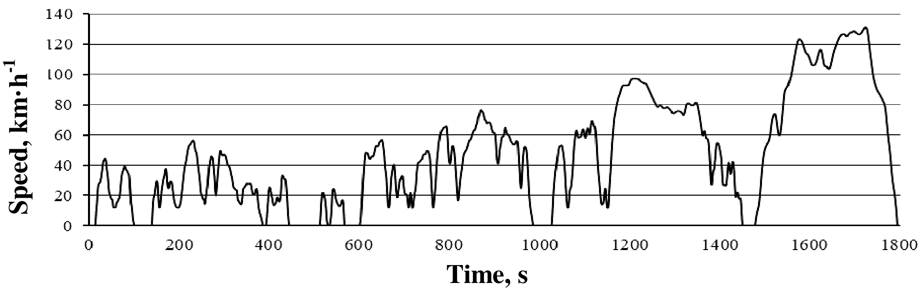

Fig. 2. **Speed profile WLTC class 3**

The complete cycle consists of a phase with low speed (Low), a phase with medium speed (Medium), a phase with high speed (High), and a phase with extra high speed (Extra High). WLTC lasts 1800 (s), has a more dynamic speed profile and a higher kilometer performance than NEDC.

Table 1

Summary of parameters for NEDC and WLTC

Testing parameter	NEDC	WLTC
Length of period, s	1180	1800
Reached distance, km	11.03	23.27
Average speed, km·h^{-1}	33.6	46.5
Maximum speed, km·h^{-1}	120	131.3
Idle time, %	23.7	12.6
Stable driving, %	40.3	3.7
Acceleration share, %	20.9	43.8
Deceleration share, %	15.1	39.9
Average acceleration, m·s^{-2}	0.59	0.41
Average deceleration, m·s^{-2}	-0.82	-0.45

During the duration of the period at WLTC, the vehicle accelerates or decelerates 84 % of the time, only 13 % of the time is spent by idling and 4 % by stable driving. During testing according to NEDC the vehicles about 40 % are characterised by stable driving, 24 % by idling, and the remaining 36 %, accelerate or decelerate.

Test vehicles

Altogether, the experiment included 12 vehicles with a different level of equipment and with various technical parameters. The selected vehicles were tested in the period between May 2017 and January 2018, the aim was to cover a representative part of newly sold automobiles on the European market. All vehicles were of category M1 and they were equipped with an engine fulfilling the emission standard EURO 6. Five vehicles were equipped with a petrol engine, while the other seven vehicles were equipped with a diesel engine. Each vehicle was equipped with some of the technologies for adjusting emission, specifically the vehicles with the petrol engines were equipped with a three-way catalyst (TWC) and two vehicles had an OPF filter, additionally. All diesel vehicles had a DPF filter and for four vehicles had an additional installed system of a selective catalyst reduction (SCR).

All vehicles were tested in the conditions of cold start according to the legislation procedures for type approval, including the pre-conditioning of vehicles. In order to ensure the representativeness of the measured data, vehicles defined by four parameters were selected. Among these parameters were the fuel type, the engine capacity, the type of transmission, and the engine power. The authors' study was based on the same technical parameters [14]. The thesis considers the part of the selected car fleet, in which the vehicles fulfilling the specified parameters are included. Table 2 shows the selected vehicles and their parameters. It is noticeable that the measurement was carried out for vehicles with petrol and diesel engines. Vehicles had different engine cylinder capacity, engine power and transmission type. It is necessary to state that all selected vehicles presented in the following table were equipped with the START-STOP system, which was, however, deactivated during the testing.

Table 2

Summary of parameters for NEDC and WLTC

Vehicle	Test weight, kg	Fuel	Technology for lowering emissions	Transmission	Engine capacity, cm^3	Power, kW	Year of production
1	2030	petrol	TWC	automat	1984	132	2017
2	1657	petrol	TWC	automat	1498	110	2017
3	1589	petrol	TWC, OPF	manual	1984	140	2017
4	1636	petrol	TWC, OPF	manual	1984	180	2017
5	1763	petrol	TWC	manual	1798	132	2017
6	1467	diesel	DPF, SCR	manual	1968	81	2017
7	2014	diesel	DPF, SCR	automat	1968	110	2018
8	1743	diesel	DPF, SCR	automat	1598	85	2017
9	1361	diesel	DPF	manual	1598	85	2016
10	1354	diesel	DPF	manual	1968	110	2016
11	1590	diesel	DPF	manual	1598	85	2017
12	2041	diesel	DPF, SCR	automat	2967	200	2017

Test equipment CVS

Exhaust emissions were led to CVS equipment with a constant capacity (CVS i60, AVL, Germany) using a critical Venturi jet for flow regulation (flow CVS: 3-30 $m^3 \cdot min^{-1}$). Gas emissions were analyzed from a set of Tedlar bags. The bags were filled with a diluted exhaust gas from a CVS (Automatic Bag Sampler, CGM electronics) and the concentrations of emissions were measured using an integrated measuring system (AMA i60, AVL). CO_2 emissions from all vehicles were measured by a non-dispersive infrared signal (NDIR for CO/CO_2).

Test equipment PEMS

For testing of the exhaust emissions from the vehicles, PEMS consisting of gas analyzers SEMTECH-LDV® (Sensors Inc., USA) and a flowmeter of exhaust gases (EFM 4) were used. Using the PEMS system, the exhaust gas concentration was measured of carbon monoxide (CO) and carbon dioxide by a non-dispersive infrared signal. Sensors SEMTECH-LDV® were used for testing the immediate CO_2 emission concentration.

Test equipment chassis dynamometer

For experiment the AVL ROADSIM 48" MIM LIGHT TRUCK™ chassis dynamometer was used. This dynamometer was designed for testing passenger cars and light commercial vehicles in applications like emission analysis.

Fig. 3. **Light duty vehicle PEMS analyzer on vehicle during validation on chassis dyno**

Results and discussion

The results here presented show differences in the values of CO_2 between CVS and PEMS using the WLTC driving curve. All 12 vehicles were taken for at least 3 driving tests according to this WLTC curve.

The results of the measuring, which are presented in Figure 4, show that the gasoline vehicles have a smaller relative deviation results measured by CVS and PEMS than the diesel vehicles. Altogether, 36 comparative measurements were conducted. The relative values were always measured at the PEMS devices. The biggest deviation measured between the devices was 1.10 %, the lowest value was only 0.27 %. The differences in measurements are mostly dependent on the exhaust flow. The measurement of the exhaust flow of PEMS is exposed to bigger changes due to raw exhausts. The tolerance for CO_2 ($g \cdot km^{-1}$), which is ±10 $g \cdot km^{-1}$ or 10 % of the laboratory referential value, was kept by all monitored vehicles. During the observation of CVS and PEMS measuring devices, it is possible to declare that there was not found any significant statistic difference between both devices. But the absolute values for CO_2 were higher for PEMS for each measurement. A similar article [15] investigating deviation between PEMS and CVS states similar behaviour for all investigated instruments. Results of deviation for CO_2 were for PEMS indicated more CO2 than for the CVS. The reason is most probably the insufficient synchronization of the exhaust gas mass flow, concentration and density of the measured parameter.

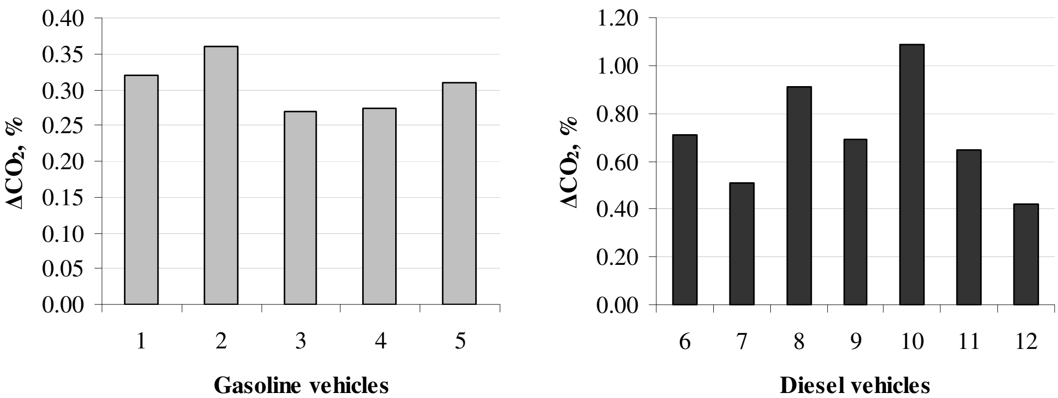

Fig. 4. **Relative deviation of emissions of CO_2 by using CVS and PEMS**

Conclusions

The aim of the present paper was to compare the results of the measurement of car CO_2 emissions obtained by the PEMS and CVS measuring systems in the laboratory conditions on the dynamometer. The test was conducted according to the WLTC driving cycle methodology on twelve cars; both petrol and diesel cars. Based on the obtained experimental results we can state:

1. All vehicles included in the experiment followed the condition of the legislation about the tolerance for CO_2, which is ±10 $g \cdot km^{-1}$ or 10 % of the laboratory referential value.
2. Altogether, 36 measurements of deviation were conducted for the values of CVS/PEMS, at petrol and diesel vehicles. The biggest deviation measured between the devices was 1.10 %, the lowest value was only 0.27 %.
3. The results of the automotive CO_2 emission concentration obtained by the PEMS measuring device were consistent with CVS measurement results throughout the experiment.

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