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Analysis of fuel consumption and pollutant emissions of regulated and alternative driving cycles based on real-world measurements

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ABSTRACT

Discrepancies between real-world use of vehicles and certification cycles are a known issue. This paper presents an analysis of vehicle fuel consumption and pollutant emissions of the European certification cycle (NEDC) and the proposed worldwide harmonized light vehicles test procedure (WLTP) Class 3 cycle using data collected on-road. Sixteen light duty vehicles equipped with different propulsion technologies (spark-ignition engine, compression-ignition engine, parallel hybrid and full hybrid) were monitored using a portable emission measurement system under real-world driving conditions. The on-road data obtained, combined with the Vehicle Specific Power (VSP) methodology, was used to recreate the dynamic conditions of the NEDC and WLTP Class 3 cycle. Individual vehicle certification values of fuel consumption, CO_2, HC and NO_x emissions were compared with test cycle estimates based on road measurements. The fuel consumption calculated from on-road data is, on average, 23.9% and 16.3% higher than certification values for the recreated NEDC and WLTP Class 3 cycle, respectively. Estimated HC emissions are lower in gasoline and hybrid vehicles than certification values. Diesel vehicles present higher estimated NO_x emissions compared to current certification values (322% and 326% higher for NO_x and 244% and 247% higher for HC + NO_x for NEDC and WLTP Class 3 cycle, respectively).

Introduction

In 1970, the Economic European Community started to define measures to reduce air pollution from positive-ignition vehicles. The regulation defined several types of tests to quantify the exhaust gas emission and the methods and specifications to perform them (European Economic Community, 1970). In order to harmonize legislation against air pollution due to motor vehicles, the foundations were laid to introduce the EURO emission standards in 1991 (European Economic Community, 1991), which became effective with EURO 1 in July 1992.

The current standard driving cycle where each vehicle is tested in predefined conditions – New European Driving Cycle (NEDC) – was introduced in 1998 and consists of four urban transient cycles – ECE-15 – and one extra-urban speed profile – EUDC – performing a total of approximately 11 km (Dieselnet, 2013a). This speed cycle is performed on a chassis dynamometer following a strict procedure of gear changes and tolerances of speed and acceleration. Prior to the test there is preconditioning of the vehicle, in an ambient between 20 and 30 °C for at least 6 h to assure that cooling water and engine

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oil are within the range of 20–30 °C. While the vehicle is operated, tailpipe emissions are collected using constant-volume sampling (CVS) in one or more bags. The collected exhaust emissions are analyzed following strict procedures (European Community, 1998). Using this cycle, CO, HC, NO_x and particulate matter emitted per kilometer (g/km) are calculated and compared with EURO standards.

Information about certification fuel consumption and regulated pollutants for each vehicle is public and is used to define vehicle eco-labeling for consumer choice purposes (European Community, 1999). However, some studies have reported consistent differences between real-world fuel use and emissions and homologation values. While performing the NEDC, a typical gasoline vehicle spends 90% of the time below 2500 rpm and 85% below 10 kW of power required at the wheels (Farnlund and Engstrom, 2002). Consequently, only a small part of the engine/vehicle available working range is effectively tested. Thus, NEDC is recognized as a low load cycle, where only a narrow range of operation is effectively tested (Kageson, 1998).

Several works have been presented comparing NEDC with real-world driving cycles that are representative for a given city, country, etc. A study performed by Tzirakis et al. (2006) comparing a typical driving cycle in Athens (ADC) shows an increase in fuel consumption between 56% and 79% compared with NEDC. The same trend of fuel consumption was observed for CO_2. Regarding pollutant emission, NO_x in grams per kilometer can go up to 300% comparing ADC with NEDC. For CO, an increase of up to 132% was observed in NEDC for the vehicles studied. Hydrocarbons did not present a significant variation (Tzirakis et al., 2006).

A study carried on three vehicles (one EURO 2, one EURO 3 and one EURO 4) reached a similar conclusion by comparing chassis dynamometer measurements of ECE and EUDC driving cycles and a Belgium MOL drive cycle (Pelkmans and Debal, 2006). When performing the MOL driving cycle, EURO 3 and EURO 4 vehicles presented an increase in fuel consumption and CO_2 between 15% and 25%. Considerably different results are also present for CO and NO_x.

A study carried by the European Commission Joint Research Center addressed the differences between certification tests and on-road emissions using portable emission measurement systems (PEMS) on 12 EURO 3 to EURO 5 vehicles (Weiss et al., 2011). In this study, on-road tests were carried on rural and motorway routes and generated CO_2 emissions over 21 ± 9% comparing with NEDC type approval. When performing NEDC under laboratory conditions, CO_2 was found to exceed 15 ± 10% regarding certification values. It was found that under on-road conditions emissions on typical rural and motorway routes NO_x emissions were over certification by a factor of 2–4. Under laboratory tests on chassis dynamometer, NO_x emissions were not compliant with applicable emission limits in diesel vehicles, but spark-ignition engines were found to be compliant. Hydrocarbon emissions were found to be lower under on-road conditions than while performing the certification cycle and always lower than certification limits.

The European Commission Joint Research Center published a study comparing type-approval certification data and real-world fuel consumption from several sources including particular studies from the ADAC organization in Germany, the Artemis project, automotive journals and vehicle owner's data, to establish correlations between these two indicators (Keller et al., 2011). This study also indicates that certification under-estimates fuel consumption by 10–15% on gasoline vehicles and 12–20% on diesel vehicles.

Most of the studies tend to compare real-world driving cycles and certification, but most of them in different routes, therefore under off-cycle conditions. The importance of the driving cycle in pollutant emission can be found, for instance, in the Artemis project (André, 2004; André and Rapone, 2009).

As an answer to the driving cycle issue, a study using data from remote sensing surveys was carried out in 2008 to simulate the New European Driving Cycle using the Vehicle Specific Power (VSP) methodology (Rhys-Tyler and Bell, 2012). Remote sensing data was used as an input to fill VSP modal bins with pollutant emission rates, divided in gasoline and diesel vehicles and engine displacement. The certification cycle was also classified by the time spent in each VSP bin. By combining the modal emission rates and the certification cycle VSP modal time distribution, it was found that for both gasoline and diesel vehicles and the ranges of engine displacement studied remote sensing provided higher emissions than certification. The highest discrepancies were found for NO_x in compression-ignition (CI) vehicles and CO on spark-ignition (SI) vehicles. For CI vehicles, NO_x emissions were found to be 50% over certification values for EURO 4 vehicles and 30% for EURO 3 (considering both engine displacements below and over 2 liters). For SI vehicles, remote sensing indicated a 34% increase of CO tailpipe emission over certification regarding EURO 4 vehicles for all ranges of engine displacement. EURO 3 vehicles presented an increase over certification of a factor of 2. Also on SI vehicles, hydrocarbon emissions collected via remote sensing were lower than certification values for EURO 4, but not for EURO 3 vehicles.

Recent efforts have been made to develop a driving cycle that could replace NEDC. The Worldwide harmonized Light-duty Test Procedures (WLTP) includes chassis dynamometer drive cycles that have been developed by United Nations Economic Commission for Europe to assess emissions and fuel consumption for light-duty vehicle (Dieselnet, 2013b; UNECE, 2008). The present article focuses on the WLTP Class 3 cycle proposal for vehicles with more than 34 kW/ton.

A working paper by the International Council on Clean Transportation (ICCT) (Mock et al., 2014) assessed how the introduction of the WLTP test procedures (particularly driving cycle, gearshift schedule and test mass) could have an impact on CO_2 emissions. This issue has economic and fiscal consequences as not only must vehicle manufacturers comply with CO_2 fleet emission targets, but also CO_2 emissions are used in the calculation of vehicle and road taxes. The paper concludes that in a direct comparison between NEDC and WLTP, the impacts of cold start are lower on WLTP (due to the longer duration), the higher speeds and loads on WLTP have the counter effect of engine efficiency typically increasing with load, the new gearshift schedule on WLTP can help reduce engine speed (hence friction effects) and the lower stop share on WLTP can