Emissions of Euro 3-5 Passenger Cars Measured Over Different Driving Cycles

C. A. Alves, A. I. Calvo, D. J. Lopes, T. Nunes, A. Charron, M. Goriaux, P. Tassel, and P. Perret

***Abstract*—**The reduction in vehicle exhaust emissions achieved in the last two decades is offset by the growth in traffic, as well as by changes in the composition of emitted pollutants. The present investigation illustrates the emissions of in-use gasoline and diesel passenger cars using the official European driving cycle and the ARTEMIS real-world driving cycle. It was observed that some of the vehicles do not comply with the corresponding regulations. Significant differences in emissions were observed between driving cycles. Not all pollutants showed a tendency to decrease from Euro 3 to Euro 5.

***Keywords*—**Chassis dynamometer, driving cycles, emission factors, exhaust emissions, light-duty vehicles.

I. Introduction

EMISSION testing in the laboratory constitutes an essential part of the European type approval process for light-duty vehicles, yielding reproducible and comparable data and providing clear design criteria for vehicles that have to meet the terms of applicable emission limits. Although emission limits have become increasingly strict in the past years, road transport remains the most significant source of urban air pollution in Europe with respect to NO_x, CO, hydrocarbons (HC) and particulate matter (PM). Some studies have been performed to determine the driving cycles for light-duty vehicles as part of enhancing traffic management systems, determining fuel consumption patterns and reduce transport impacts on health [1]-[4]. However, comprehensive studies reporting emissions of light-duty diesel and gasoline vehicles representative of the Southern European fleet under typical driving cycles are still scarce. This work aimed at assessing the composition and emission characteristics of the in-use vehicle fleet in Portugal.

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II. Methodologies

A. Description of the Chassis Dynamometer and Driving Cycles

The exhaust emission tests were carried out using a chassis dynamometer belonging to the French Institute of Science and Technology for Transport, Spatial Planning, Development and Networks (French: *Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux* or IFSTTAR). The chassis dynamometer platform consists of a large roller placed underneath the vehicle's tyres. When a chassis dynamometer test is run, the vehicle to be tested is driven onto the dynamometer platform according to a defined driving cycle. The dynamometer platform simulates road resistance. During a test, the chassis dynamometer gives an accurate reading of the engine's power, speed, torque, exhaust temperature, etc. The exhausts of tested vehicles are diluted with filtered ambient air through a Constant Volume Sampler (CVS) composed of two dilution tunnels, one dedicated to diesel vehicles and the other one to petrol vehicles. Measurements and samplings are made from the dilution tunnel. The sampling units and the chassis dynamometer are servo-controlled in order to relate the measurements to the activity of the vehicle so that the emission factors may be computed.

Sampling of vehicle exhausts were performed using two real-world driving cycles determined within the European ARTEMIS project. The ARTEMIS Road (ArtRoad) and ARTEMIS Urban (ArtUrb) cycles are representative of real driving behaviour on roads and in an urban environment, respectively [5], [6]. In addition, the regulated MVEG driving cycle (Motor Vehicle Emissions Group, also called NEDC: New European Driving Cycle) was only performed for the measurements of regulated gases (CO, CO_2, NO, NO_2, and total hydrocarbons) in order to relate the vehicle to a Euro emission class, and to possibly exclude high emission vehicles.

B. Sampling and Measurements

Measurements of PM exhaust emissions were performed using two new sampling lines operating at flow rates up to 50L/min. PM samples were refrigerated immediately after the chassis dynamometer experiments.

Conditions of sampling - including dilutions and the repetition of driving cycles - were defined for each vehicle (depending on its emission levels, which were checked using the NEDC cycle). Each sampling of particulate matter was repeated once using different sampling flow rates and/or dilutions in order to obtain different conditions of analyses. A minimum of one blank per day was performed. Blanks correspond to the sampling of dilution air in the same conditions as the exhaust samples (including sampling time, transfer in the CVS, etc.). The following driving cycles were tested:

– urban driving cycle with cold start,
– urban driving cycle with hot start,
– road driving cycle (always hot start).

In the absence of available data, it was considered that the proportion of vehicles with cold start in urban areas may be as high as vehicles with hot start.

The measurement of regulated pollutants was simultaneously done by means of a series of common analysers (nondispersive infrared for CO and CO_2, chemiluminescence for NO_x and flame ionisation detection for total hydrocarbons). The regulated particle mass was also measured. The 8 most frequent vehicle types in the Portuguese fleet, according to vehicle motorisation, European emission class and engine capacity, were selected for the chassis dynamometer tests (Table I).

III. Results and Discussion

Emissions tested over the MVEG (NEDC) chassis dynamometer procedure permitted to test whether the vehicles fulfil the EU emission standards or not. This step is necessary to identify vehicles that emit abnormal levels compared to vehicles of the same category. Comparisons with EU emission standards showed that vehicles 1, 3, 4, 5, and 6 fulfil the EU emission standards (Fig. 1). Vehicles 2 and 7 presented slightly higher CO emissions than the Euro 3 and Euro 4 standards for diesel powered models, probably due to catalyst ageing. However, the difference is weak and it can be considered that the diesel cars are representative of ageing vehicles of their categories. Vehicle #8 no longer fulfils the EU emission standards because of PM and NO_x emissions that are higher than the Euro 4 standard for diesel cars.

TABLE I
Vehicles Selected for the Tests

Vehicle number	Motorisation	European emission class	Engine capacity
1	petrol	Euro 3	<1.4 L
2	diesel	Euro 3	1.4-<2 L
3	diesel	Euro 4	1.6 L
4	petrol	Euro 4	1.0 L
5	diesel	Euro 5	1.7 L
6	petrol	Euro 5	1.2 L
7	diesel	Euro 4	2.0 L
8	diesel	Euro 4	1.3 L

In general, the effect of cold start driving conditions on exhaust emissions was rather significant, especially in diesel vehicles (Figs. 2 and 3). Cold start emissions are of particular interest because these generally occur in urban areas and might substantially exceed average on-road emissions levels. The temporary ineffectiveness of motor vehicle emission controls at startup causes emission rates to be much higher for a short period after starting than during fully warmed, or stabilised, vehicle operation. Strict stoichiometric control of the air-fuel ratio results in lower levels of CO and HC production relative to fuel-rich operation, and lower levels of NO_x production relative to fuel-lean combustion. Stoichiometric air fuel mixtures are also required for the treatment of exhaust gases by three-way catalytic converters, which simultaneously oxidise HC and CO to carbon dioxide (CO_2) and reduce NO to N_2. New vehicles, equipped with these and other emission controls, typically emit less than 5% of the pollutants emitted by pre-control vehicles [7]. One drawback of contemporary vehicle emission control systems is that they are ineffective for a short period after a vehicle is started. At startup, the fuel-air mixture is purposely enriched to help ignition and improve cold engine operation. This enrichment leads to enhanced formation of pollutants during combustion, and limits the oxidation of these exhaust constituents in the catalytic converter. Cold-start emissions of individual vehicles span over a relative large value range. More detailed insights into cold-start emission patterns require a more careful analysis and additional testing NO_2 emissions of gasoline vehicles are negligible in comparison to the emissions of diesel vehicles, while the share of NO_2 in the total NO_x emissions is substantially higher for diesel than for gasoline vehicles (data not shown). Contrary to what has been reported for on-road emissions of light-duty vehicles with portable emission measurement systems [8], in the present study total HC emissions do not show a general increase from Euro 3 to Euro 4 gasoline vehicles both in absolute terms and as percentage of Euro 3-4 emission limits. An overall downward in CO emissions from gasoline vehicles was registered: Euro 3 - 1.001 g/km, Euro 4- 0.426 g/km and Euro 5 - 0.051 g/km. Unlike other pollutants, results suggest that there is not any clear tendency to the decline in the on-road NO_x emissions of Euro 3 towards Euro 5 gasoline vehicles (Fig. 4). NO_x emissions of diesel and gasoline vehicles are generally higher during NEDC testing than they are on the real-world driving cycle ARTEMIS. Also, the NEDC tests have generally higher HC and CO emissions than the ArtUrb (hot start) and ArtRoad cycles. This can be explained by the NEDC cold start effects. The results do not allow identifying a trend towards lower CO emissions from Euro 3 to Euro 5 diesel vehicles, while it seems there is a decrease for gasoline cars.

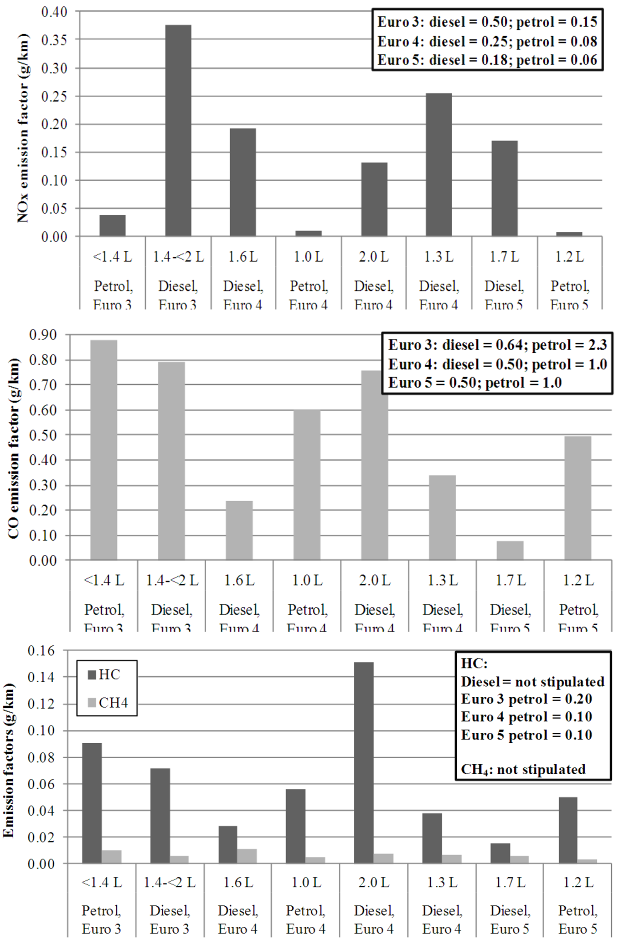

Fig. 1 Average emission factors obtained with the New European Driving Cycle and comparison with the European emission standards for passenger cars

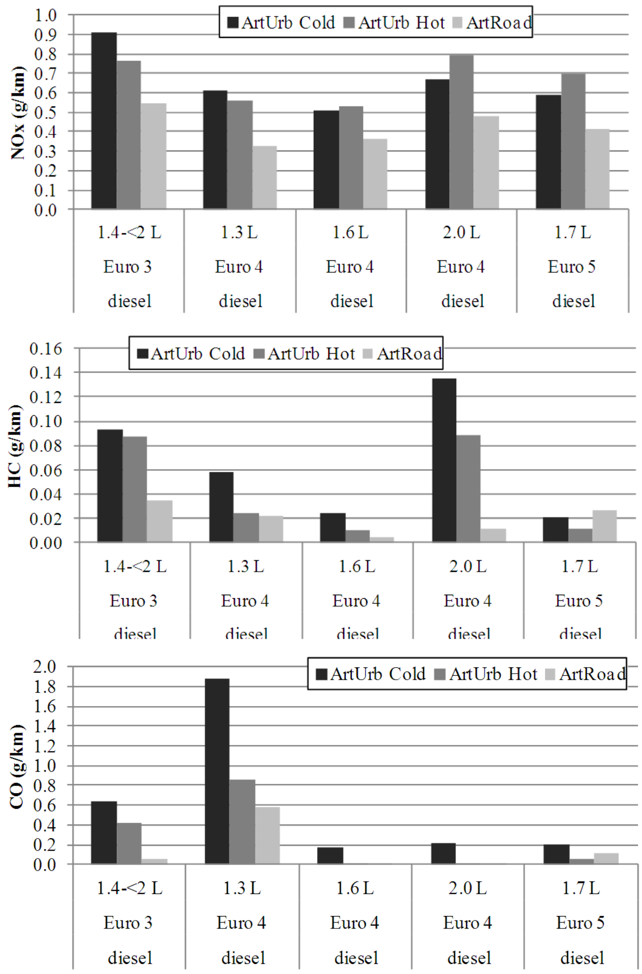

Fig. 2 Average exhaust emissions on the ARTEMIS Road and Urban driving cycles for diesel vehicles

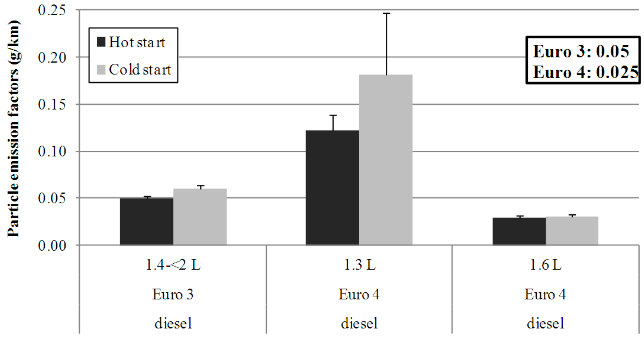

Fig. 3 Average particle emissions on the ARTEMIS Urban driving cycles for some of the diesel vehicles and comparison with European emission standards

Next to regulated pollutants, on-road CO_2 emissions are of particular interest to policy makers. To reduce greenhouse gas emissions from transport, the European Commission sets a target of 130g CO_2/km for new passenger cars of a reference mass of 1372kg [9]. For reasons of simplicity, we uniformly use here 130g CO_2/km as benchmark for all test vehicles, thereby disregarding the specific mass of vehicles. The CO_2 emissions of all vehicles tested under the ArtUrb cycles exceeded the EC target value. Excepting the Euro 5 diesel car, the limit was met when the engines were operated under the ArtRoad driving cycle (Fig. 5). The average CO_2 emissions of all vehicles tested on NEDC amount to 134±13g/km. Under this cycle, diesel vehicles emit on average 138±10g/km, whereas gasoline vehicles emit 126±17g/km CO_2. These deviations might increase if vehicles are driven at extremely high speeds, e.g., as it frequently occurs on the German Autobahn [8].

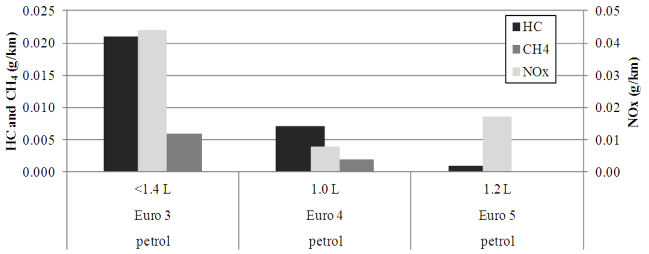

Fig. 4 Average emissions on the ARTEMIS Road driving cycle for petrol vehicles

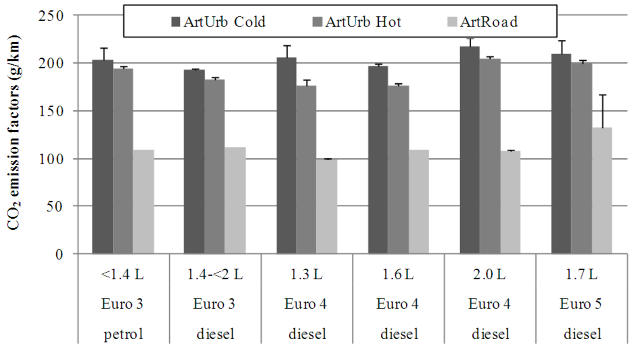

Fig. 5 Average CO_2 emissions for some of the vehicles, under different ARTEMIS driving cycles

The vehicles with DPF (diesel particulate filter) have significantly lower PM emissions comparing to the non-DPF vehicles. During regeneration the DPF vehicle has much higher PM emissions than the non-regeneration test. The modern diesel engines have extremely low particle emissions, almost at the level of the measurement error of the existing gravimetric method. Since coarse particles are eliminated by new engine technologies, fine particles, with very negative effects on human health, dominate in the emission of Euro 5 vehicles. Therefore, it is necessary not only to measure mass of emitted particles but also to investigate other important particle characteristics, such as size distribution, number, composition, and surface [10].

IV. Conclusions

The analyses have revealed quite contrasting emission behaviours for diesel (rather sensitive to speed and stop parameters) and petrol-powered engines (rather sensitive to accelerations) and a certain resemblance between urban and rural driving for both categories of vehicles. The temporary ineffectiveness of motor vehicle emission controls at startup causes emission rates to be much higher, suggesting that the importance of cold-start emissions may be overstated in current emission inventories. The evolution of the vehicles appears to have had a positive impact on the CO and particle emissions, but an unclear impact on the NO_x and HC emissions, and a negative impact on the CO_2 emissions. These results are nevertheless only indicative, given the very small number of vehicles tested per category.

Acknowledgment

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References

[1] W. Saleh, R. Kumar, and A. Sharma, “Driving cycle for motorcycles in modern cities: Case studies of Edinburgh and Delhi”, *World J. Sci., Technol. Sust. Dev.*, vol. 7, pp. 263-274, 2010.

[2] C. C. Lee, Y. C. Wen, and J. J. Kang, “Motorcycle exhaust particles induce IL–8 production through NF–κ B activation in human airway epithelial cells”, *J. Toxicol. Environ. Health A*, vol. 68, no. 17-18, pp. 1537-1555, Sep. 2005.

[3] E. Tzirkasi, K. Pitsas, F. Zannikos, and S. Stournas, “Vehicle emission and driving cycle: Comparison of the Athens driving cycle (ADC) with ECE–15 and European driving Cycle”, *Global Nest J.*, vol. 8, no. 3, pp. 282–290, May 2006.

[4] W. T. Hung, H.Y. Tong, C.P. Lee, K. Ha, and L.Y. Pao, “Development of a practical driving cycle construction methodology: A case study in Hong Kong. Transportation Research”, *Transport. Res. D-Tr. E.*, vol. 12, no. 2, pp. 115–128, Mar. 2007.

[5] M. André, “The ARTEMIS European driving cycles for measuring car pollutant emissions”, *Sci. Total Environ.*, vol. 334–335, pp 73-84, Dec. 2004.

[6] M. André, R. Joumard, R. Vidon, P. Tassel, and P. Perret, “Real-world European driving cycles, for measuring pollutant emissions from high- and low-powered cars”, *Atmos. Environ.*, vol. 40, no. 31, pp. 5944-5953, Oct. 2006.

[7] B. C. Singer, T. W. Kirchstetter, R. A. Harley, G. R. Kendall, and J. M. Hesson, “A Fuel-Based Approach to Estimating Motor Vehicle Cold-Start Emissions”. *J. Air & Waste Manage. Assoc.*, vol 49, no. 2, pp. 125-135, Feb. 1999.

[8] M. Weiss, P. Bonnel, R. Hummel, U. Manfredi, R. Colombo, G. Lanappe, P. Le Lijour, and M. Sculati “Analyzing on-road emissions of light-duty vehicles with Portable Emission Measurement Systems (PEMS)”, *European Commission, Joint Research Centre, Institute for Energy*. EUR 24697 EN – 2011, 2011, Ispra.

[9] EC, “Regulation (EC) No. 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO_2 emissions from light-duty vehicles”, EC – European Commission. *Official Journal of the European Union* L 140, pp. 1-15, 2009.

[10] V. S. Petrovic, S. P. Jankovic, M. V. Tomic, M. M. Jovanovic, and D. M. Kneževic, “The possibilities for measurement and characterization of diesel engine fine particles – a review”. *Therm. Sci.*, vol. 15, no. 4, pp. 915-938, Aug. 2011.