COMPARISON OF INTERNATIONAL VEHICLE TESTING CYCLES USING SIMULATION

LEVENTE KOCSIS[1], CĂLIN DAN ICLODEAN[2], FERENC GASPAR[1], NICOLAE VLAD BURNETE[1]

Abstract. Over the last decades, one of the major risks faced by mankind has been the anthropogenic contribution to environmental pollution and degradation in general. This has posed a substantial burden on both human health and economy, so targets were set to minimize pollution. To guarantee that these targets are achieved by all vehicle manufacturers, testing procedures have been developed all over the world based on the data gathered from the driving patterns in that region. This paper compares driving cycles from three different regions: WLTC and NEDC (Europe), FTP (USA) and JC08 (Japan) with the aid of simulation. The aim was to evaluate the pollution performances in a controlled testing environment such that clear differences can be highlighted. After modelling these cycles using the AVL Cruise software, a Euro 6 vehicle was chosen to run on all four cycles, thus ensuring the same initial test conditions. By doing so, the authors were able to define the most demanding cycle for the vehicle in terms of fuel consumption and pollution level per unit distance.

Key words: FTP, WLTC, NEDC, JC08, test cycle, pollution.

1. INTRODUCTION

Combustion of fossil fuels implies a significant production of pollutant emissions, which are proven to contribute to the general degradation of air, water and soil. Transportation accounts for a high share of these emissions, so targets have been set to minimize pollution. To implement these targets, one key issue is to establish the exact procedures under which vehicles should be tested. Different procedures and different driving cycles were developed around the world to assess this issue and today, one of the key challenges for the legislation worldwide is to ensure that emissions from vehicles measured during the certification procedure are in line with real world driving emissions [1].

Depending on the entity which imposes the cycle, there can be legislative or non-legislative driving cycles. Legislative exhaust emissions specifications are imposed by governments for car emission certification, such as the FTP-75 used in the USA, the NEDC used in Europe or the JC08 used in Japan. Non-legislative driving cycles, such as the Hong Kong driving cycle [2], the Tehran driving cycle

[1] Technical University of Cluj-Napoca, Romania
[2] ESTACA Ecole d'Ingénieurs, Paris, France

Ro. J. Techn. Sci. – Appl. Mechanics, Vol. 63, N° 1, P. 25–35, Bucharest, 2018

[3], the Athens driving cycle [4] or the Macau driving cycle [5] are used in research for energy conservation and pollution evaluation or to obtain a better understanding of driving characteristics.

There are two different approaches when developing a driving cycle. For the first method, various driving modes of constant acceleration, deceleration and speed are composed, which is referred to as “modal” or “polygonal” driving cycle, such as NEDC and ECE driving cycles [3]. For the second method, a driving cycle is derived from actual driving data and is referred to as a “real world cycle”, such as FTP-75 and WLTC [6]. The real-world cycles have more dynamics, reflecting faster acceleration rates and deceleration patterns experienced during driving conditions. The increased dynamics of driving in real world conditions leads to higher emissions compared to those from the modal test cycles [3].

2. MATERIAL AND METHODS

Simulations were conducted in the AVL Cruise software, which is a comprehensive tool for postprocessing of information that emerges during the simulation. This application provides information concerning the accumulated pollutant emissions, giving clear and valid information for the simulated vehicle model. Different driving cycle models (NEDC, WLTC, FTP and JC08) were loaded and run in AVL Cruise to evaluate the pollutant emissions characteristics of the simulation model.

2.1. Driving Cycles

The NEDC (New European Driving Cycle, used for emission testing and certification in Europe – Fig. 1) was designed to assess the emission levels of passenger car engines as well as their fuel economy and has often been criticized for being too smooth and underloaded compared to typical vehicle operation, as it covers only a small area of the engine operating range [7]. According to [8], there is a discrepancy between the NEDC driving cycle laboratory emission levels and the on-road testing measurements. This difference can be due to several external factors, including the NEDC low dynamics and narrow temperature range, a higher vehicle load during on-road testing, shifting time, starting conditions and the difference between the vehicle’s theoretical and real speed.

The World-wide Harmonized Light Duty Test Procedure (WLTP – Fig. 2) is designed to check the emissions compliance of Light Duty Vehicles (LDVs) around the world and the European Commission is planning to introduce the WLTP in the European Type Approval process starting with 1 September 2017. WLTP has greatly reduced the flexibilities that are in the NEDC procedure and has eliminated many loopholes. The WLTC driving cycle for a Class 3 vehicle is divided into four different parts for Low, Medium, High, and Extra High speed [9].

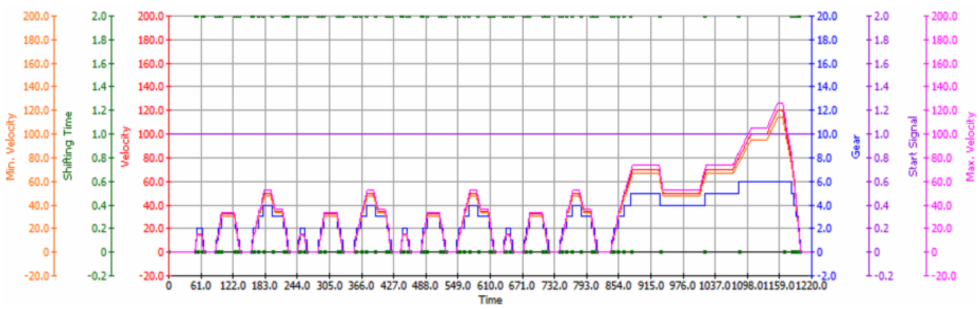


Fig. 1 – NEDC Driving Cycle implemented in AVL Cruise.

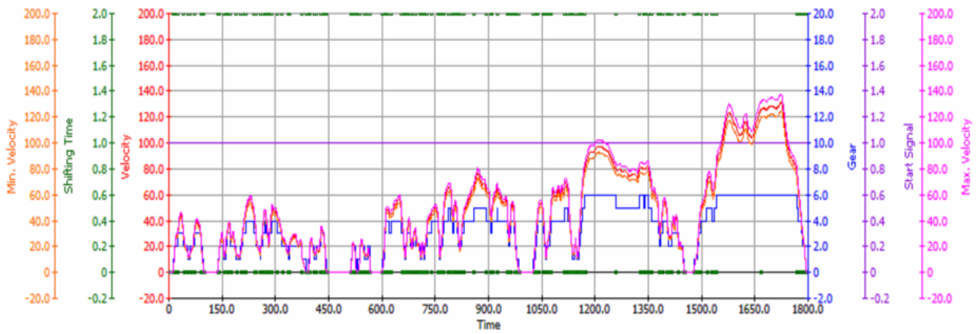


Fig. 2 – WLTC Driving Cycle implemented in AVL Cruise.

The FTP75 (Federal Test Procedure – Fig. 3) is used for emission certification and fuel economy testing of light-duty vehicles in the United States. It consists of 5 segments: cold start transient phase-ambient temperature 20–30 °C, 505 s; stabilized phase, 864 s; Hot soak – min 540 s, max 660 s; hot start transient phase, 505 s and for hybrid vehicles: repeated stabilized phase, 864 s. Emissions from phases 1, 2, 4 and 5 are collected and analyzed separately.

The weighting factors to calculate the total emissions from the absolute bag results are calculated whether the car is hybrid or not. After weighting, all absolute emissions are added up and divided by the total driven distance to achieve the final distance-based emission result for the whole cycle [10].

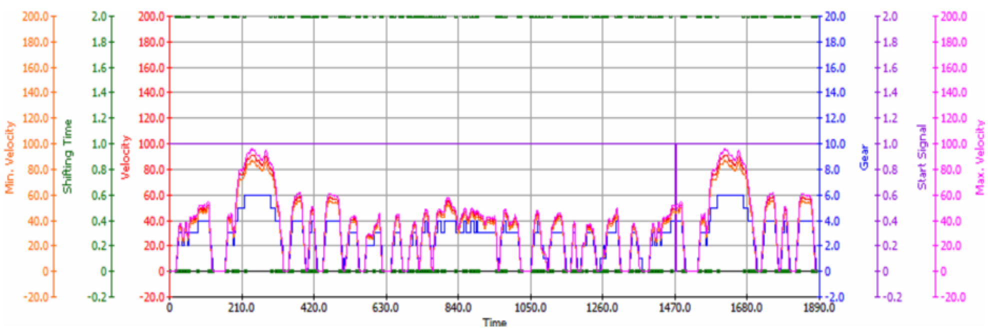


Fig. 3 – FTP-75 Driving Cycle implemented in AVL Cruise.

The JC08 (Fig. 4) was introduced in 2005 into Japanese emission regulation and fuel economy determination. The JC08 test was fully phased-in by October 2011. Measurement is made twice, with a cold start being weighted by 25% and a hot start being weighted by 75% [10].

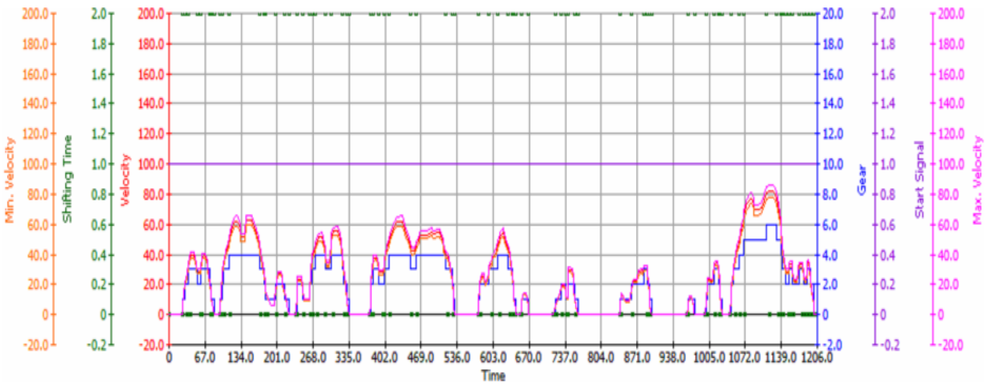


Fig. 4 – JC08 Driving Cycle.

The main characteristics (according to Fig. 1 through 4) of the test cycles were summed up in Table 1.

Table 1

Characteristics of the analyzed driving cycles

Characteristics	MU	NEDC	WLTC	FTP	JC08
Distance	[km]	10.93	23.266	17.770	8.171
Total time	[s]	1180	1800	1877	1204
Idle (standing) time	[s]	267	242	358	357
Average speed (including stops)	[km/h]	33.35	51.76	34.1	24.4
Average driving speed (excluding stops)	[km/h]	43.10	56.25	42.4	34.8
Maximum speed	[km/h]	120	131.3	91.25	81.6
Maximum acceleration	[m/s^2]	1.042	1.58	1.48	1.53

2.2. Vehicle model

The vehicle model used for simulation (Fig. 5) includes all the elements which are related to propulsion performance: Vehicle (1), IC Engine (2), Torque Converter (3), Gear Box (4), Final Drive (5), Vehicle Rear Right (6), Vehicle Front Right (7), Vehicle Rear Left (8), Vehicle Front Left (9), Rear Disk Brake (10), Front Disk Brake (11), Rear Disk Brake (12), Front Disk Brake (13), Differential (14), Cockpit (15), GB Control (16), GB Program (17), Catalyst (18), and Monitor (19) [11].

Table 2

IC Engine component input data

Name	MU	Value
Engine Displacement	[cm³	1460
Engine Working Temperature	[°C	90
Number of Cylinders / Strokes	[-	4/4
Idle Speed	[min^{-1}]	700
Maximum Speed	[min^{-1}]	6000
Inertia Moment	[kg·m²]	0.200
Response Time	[s]	0.050
Heating Value for Gasoline	[kJ/kg]	44200
Fuel Density	[kg/m^3]	737
Idle Consumption	[l/h]	0.700

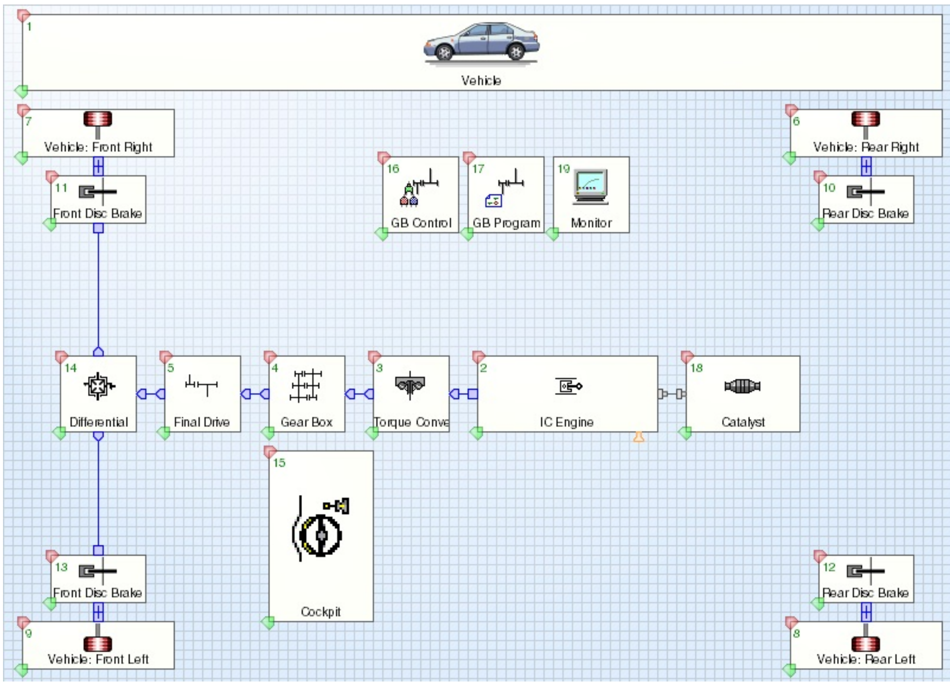


Fig. 5 – Virtual vehicle model in AVL Cruise.

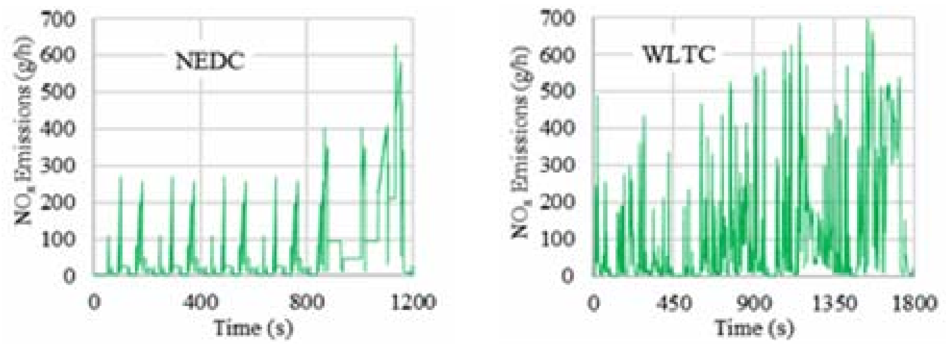
The Vehicle (1) component contains general data of the vehicle, such as nominal dimensions and weights. The IC Engine (2) component contains a model of an internal combustion engine (Table 2). The characteristic curves for full load, fuel consumption, and others are defined according to the Euro 6 pollution standards. The Torque Converter (3) employs the force represented by a moving fluid to transmit engine torque. The component Gearbox (4) contains a model of a gearbox with different gear steps. The Final Drive element (5) is a gear step with fixed ratio. The Differential (14) performing the division of one drive torque into two power take-off torques will be done by considering the transmission and the moments of inertia. The Wheels component (6, 7, 8, 9) takes many influencing variables into account and their effect on the rolling state. The Brake component (10, 11, 12, 13) is described by brake data and dimensions. The Cockpit (15) links the driver and the vehicle, connections being made only via the Data Bus connection. The GB Control (16) defines an automatic gearbox and allows the gear shifting process to be defined automatically without any influence from the driver. The GB Program (17) is used for automatic gearboxes in combination with the gearbox control for a more complicated gear shifting process than the gearbox control alone, as the load signal of the engine is considered. The Catalyst (18) or exhaust systems consider the effects of the catalytic converter and soot filler on the raw emissions of the engine [11].

To investigate the pollutant emissions, the simulation model was run on each one of the described and implemented driving cycle.

3. RESULTS

To define the most demanding cycle for the vehicle in terms of pollution level per unit distance, NO_x, CO, HC and CO_2 emissions were taken into consideration.

The NO_x emissions for the four different driving cycles are plotted in Figure 6. It is obvious that real world cycles, such as the WLTC and FTP-75 exhibit a higher level of nitrous oxide emission due to the higher engine load, which is a result of running under operating conditions that require more fuel to be burnt. NEDC and JC08 are modal driving cycles and therefore operate to a greater extent with constant speed and load, so that not only that the mean values are lower, but extreme high spikes are fewer as well. As expected, high values of emissions appear at high velocities, while lower values belong to lower engine speed and load. The engine produces high level of NO_x owing to the increased combustion temperature. The main formation mechanism of the NO_x spike during accelerating conditions can be explained with the magnitude of EGR rate patterns as well as the lag between increased fueling and amount of air at steep load change conditions.



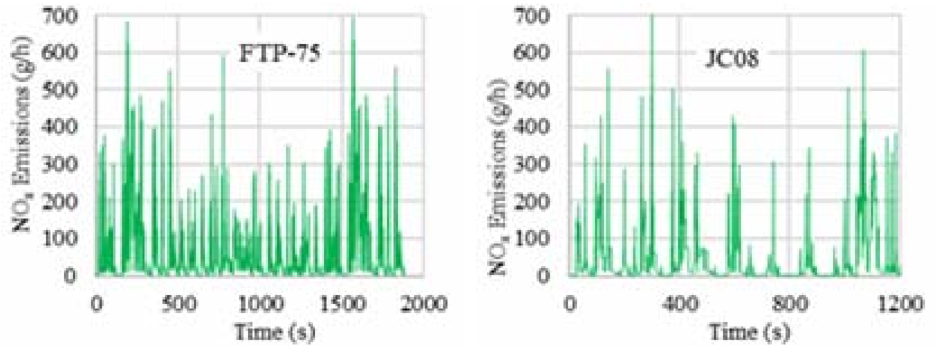


Fig. 6 – NO_x emissions for the analyzed test cycles.

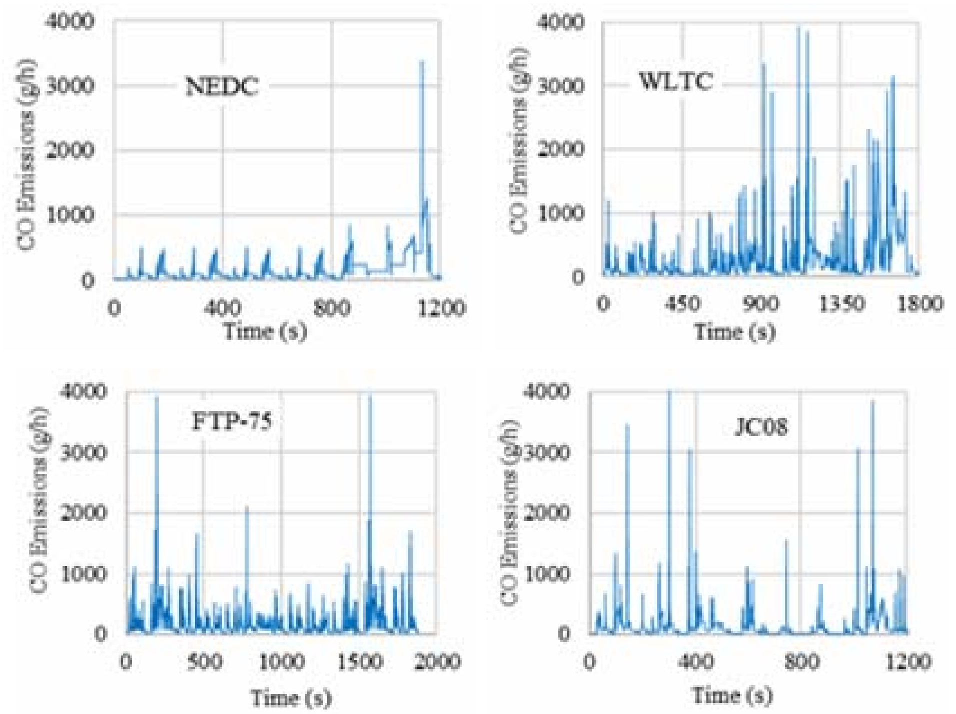


Fig. 7 – CO emissions for the analyzed test cycles.

The CO emissions for the four different driving cycles are plotted in Figure 7. Regarding the CO emissions, the simulations show higher levels of pollution for the FTP and WLTC driving cycles again.

Carbon monoxide results from the incomplete combustion where the oxidation process does not occur completely. This concentration is largely dependent on air/fuel mixture and it is highest where the excess-air factor (λ) is less than 1.0 that is classified as rich mixture. It can be caused especially at engine start and during instantaneous acceleration of the engine where the rich mixtures are required. In the rich mixtures, due to air deficiency and reactant concentration, incomplete combustion occurs and therefore carbon is not completely oxidized into CO_2, thus resulting a high CO concentration. Although CO is produced during operation with rich mixtures, a small portion of CO is also emitted under lean conditions because of chemical kinetic effects [12].

The HC emissions for the four different driving cycles are plotted in Fig. 8. Hydrocarbon emissions are composed of unburned fuels because of the relatively low temperature of the combustion chamber walls.

The major source of light-load hydrocarbon emissions is lean air-fuel mixing. In lean mixtures, flame speeds may be too low for combustion to be completed during the power stroke, or combustion may not at all occur and, as a result, these conditions cause high hydrocarbon emissions. HC emissions in the exhaust gas also depend on irregular operating conditions.

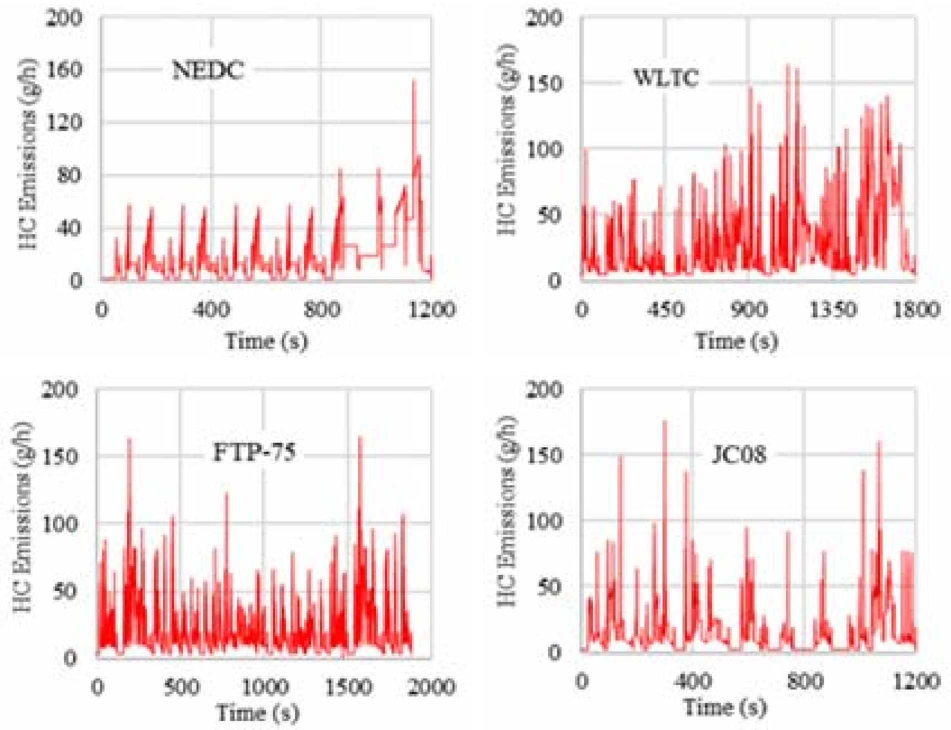


Fig. 8 – HC emissions for the analyzed test cycles.

The CO_2 emissions for the four different driving cycles are plotted in Figure 9. CO_2 emissions are related to the burnt fuel quantity, being the natural result of combustion.

The FTP-75 and the JC08 testing cycles show emissions over 160 g/km, while the more dynamic WLTC cycle achieve a value of 153 g/km of CO_2 emission.

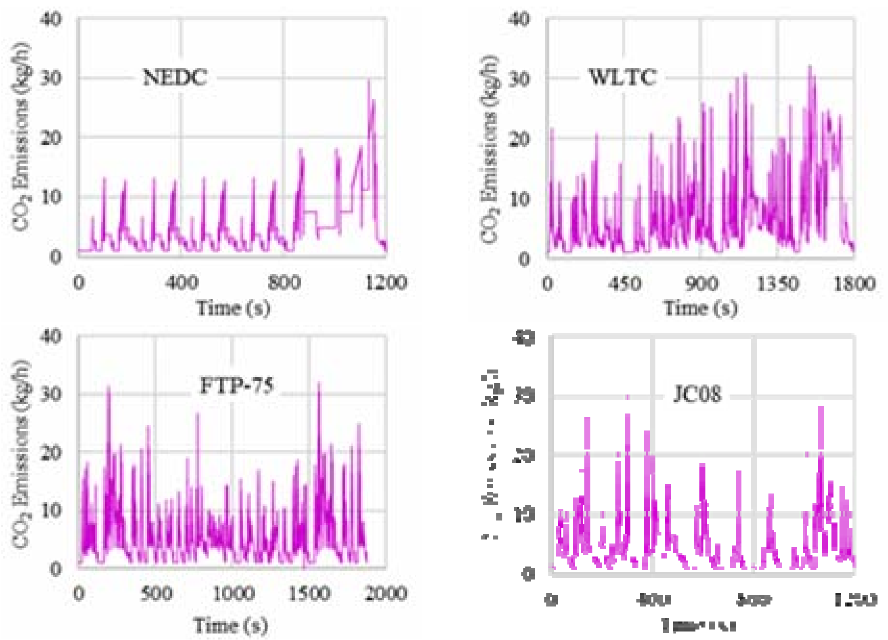


Fig. 9 – CO_2 emissions for the analyzed test cycles.

For the purpose of statistical data analyses, the mean values of different pollutant emissions are given in Table 3, per time unit and per distance unit.

Table 3

Comparison of the emission values for the four driving cycles

Cycle	Distance [km]	NO_x		CO		HC		CO_2	
		[g/h]	[g/km]	[g/h]	[g/km]	[g/h]	[g/km]	[kg/h]	[g/km]
NEDC	10.93	195	2.01	490	5.12	56	0.59	14.50	152
WLTC	23.27	228	2.45	568	6.01	57	0.61	14.10	153
FTP-75	17.77	146	2.25	383	5.91	42	0.68	10.67	164
JC08	8.17	148	1.96	452	5.75	48	0.66	12.55	171

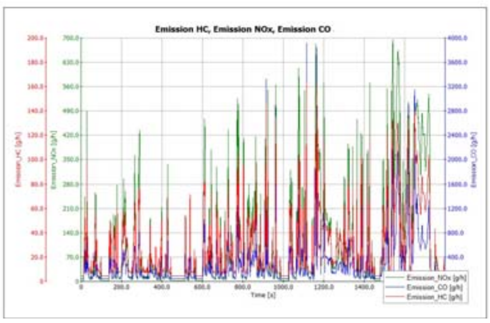


Fig. 10 – NO_x, CO and HC emissions for WLTC Driving Cycle in AVL Cruise.

Figure 10 shows the variation of NO_x, HC and CO pollutant emissions for the simulation model during the WLTC cycle. It can be observed that the pollutant components offer the same trendline of variation, depending on speed and load.

4. CONCLUSIONS

The present paper compares driving cycles from three different regions: WLTC and NEDC (Europe), FTP (USA) and JC08 (Japan) with the aid of simulation. The authors concluded that the most demanding for the vehicle in terms of fuel consumption and pollution is the WLTC cycle.

There is clear evidence showing that the current test cycle (the NEDC) is not representative for assessing compliance to pollutant emission limits. Several studies have reported a significant and increasing gap between type-approval and real-life pollutant emissions level [9], clearly showing the learning process of OEMs in exploiting the flexibilities offered by the NEDC cycle. As a result, CO_2 emission targets set-up by EU Regulations are mainly achieved at type-approval but only marginally on the road, making the introduction of a new test cycle mandatory. The WLTC cycle defines a global harmonized standard for determining the levels of pollutants and CO_2 emissions, fuel or energy consumption and was developed using real world data from all over the globe. This cycle exhibits results that can actually be obtained in real world driving conditions, results that are very important in light of strengthening the truthfulness of the overall strategy given by the European Commission to reduce the carbon footprint of the road transportation sector, given the frail atmosphere surrounding the automotive industry.

Acknowledgements. The simulations presented in the paper were done using the software AVL Cruise supported by AVL List GmbH, Austria.

Received in February 2018

REFERENCES

1. MÄLKÖNEN, J., *Energy consumption of passenger vehicles on standard test cycles*, Master's Thesis, Aalto University, 2016.
2. TONG, H.Y., HUNG, W.T., CHEUNG, C.S., *Development of a driving cycle for Hong Kong*, Journal of Atmospheric Environment, **33**, pp. 2323–2335, 1999.
3. FOTOUHI, A., MONTAZERI-GH, M., *Tehran driving cycle development using the k-means clustering method*, Scientia Iranica, **20**, 2, pp 286–29, 2013.
4. TZIRAKIS, E., PITSAS, K., ZANNIKOS, F., STOURNAS, S., *Vehicle emissions and driving cycles: comparison of the Athens driving cycle (ADC) with ECE-15 and European Driving Cycle (EDC)*, Global Nest Journal, **8**, *3*, pp. 282–290, 2006.
5. WONG, P.K., CHEANG, K.M., *Development of a vehicle driving cycle for Macau*, www.umir.umac.mo/jspui/handle/123456789/14641, 2009.

6. TUTUIANU, M., MAROTTA, A., HENIZ, S., ERICSSON, E., *Development of a World-wide Worldwide harmonized Light duty driving Test Cycle (WLTC)*, Technical Report, UN/ECE/WP.29/GRPE/WLTP-IG, DHC subgroup, 2013.
7. SILEGHEM, L., BOSTEELS, D., MAYB, J., FAVRE, C., VERHELST, S., *Analysis of vehicle emission measurements on the new WLTC, the NEDC and the CADC*, Transportation Research, **32**, pp. 70–85, 2014.
8. DEGRAEUWE, B., WEISS, M., *Does the New European Driving Cycle (NEDC) really fail to capture the NO_x emissions of diesel cars in Europe?*, Environmental Pollution, **222**, pp. 234–241, 2017.
9. PAVLOVIC, J., MAROTTA, A., CIUFFO, B., *CO_2 emissions and energy demands of vehicles tested under the NEDC, and the new WLTP type approval test procedures*, Applied Energy, **177**, pp. 661–670, 2016.
10. KÜHLWEIN, J., GERMAN, J., BANDIVADEKAR, A., *Development of test cycle conversion factors among worldwide light-duty vehicle CO_2 emission standards*, www.theicct.org, accessed 01.07.2017.
11. VARGA, B.O., MARIAŞIU, F., MOLDOVANU, D., ICLODEAN, C., *Electric and Plug-In Hybrid Vehicles Advanced Simulation Methodologies*, Springer International Publishing Ed., 2015.
12. REŞITOĞLU, I., ALTINIŞIK, K., KESKIN, A., *The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems*, Clean Technologies and Environmental Policy, **17**, *1*, pp. 15–27, 2015.