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Real Driving Emissions from Vehicle Fuelled by Petrol and Liquefied Petroleum Gas (LPG)

Ante Vučetić, Vjekoslav Sraga, Boris Bućan, Krunoslav Ormuž,
Goran Šagi, Petar Ilinčić, Zoran Lulić

*University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture,
Laboratory for IC Engines and Motor Vehicles, Ivana Lučića 5, 10000 Zagreb*
Zagreb, Croatia

Abstract

In recent years, in addition to laboratory tests to determine emissions from road motor vehicles, tests in real driving conditions RDE (Real Driving Emissions) with the use of portable measuring equipment PEMS (Portable Emissions Measurement System) have been conducted. The paper presents the results of the emission research conducted on a vehicle Dacia Duster 1.0 TCe 100 ECO-G fuelled by petrol Eurosuper 95 and liquefied petroleum gas (LPG). The aim of the research was to determine the emissions of harmful substances and carbon dioxide, i.e. fuel consumption, in accordance with the prescribed RDE procedure and their comparison for the two types of motor vehicle fuel. Results clearly showed that the method used can differentiate between fuel types. The results correspond to the RDE emissions public data, which secures that the methodology used is in accordance with the procedure for measuring emissions in real driving conditions.

Keywords

Emissions of harmful substances from motor vehicles, Real driving emissions, RDE, Portable Emissions Measurement System, PEMS, Liquefied Petroleum Gas, LPG

1. Introduction

Due to the constant increase in the number of motor vehicles and their impact on global warming, the limit of the permissible values of pollutants from internal combustion (IC) engines are constantly decreasing. Consequently, the use of alternative fuels and renewable energy sources is especially encouraged.

Using alternative fuels and renewable energy sources helps reduce greenhouse gas emissions and human dependence on fossil fuels [1]. The largest share of greenhouse gases is carbon dioxide (CO_2), the main by-product of most human activities and the burning of fossil fuels [2]. As an incentive for the use of renewable sources, the European Union (EU) adopted Directive 2009/28/EC in 2009, with the goal that by the year 2020, 20% of total energy consumption and 10% of energy consumption in traffic should come from renewable energy sources [3]. As the goals were not achieved, a new Directive (EU) 2018/2001 (RED II) [4] was adopted, which established a common framework for the promotion of energy from renewable sources in the EU and set a binding target of 32% for the total share of energy from of renewable sources until 2030.

Over the years, the limit values for emissions of harmful substances have decreased significantly [5, 6]. Since the introduction of the first limit value, the so-called Euro 1 to the currently valid Euro 6d-Temp limit value of certain emissions of harmful substances has been reduced by more than 95% [7].

Modern IC engines are tested in accordance with the type approval procedures before being put on the market, and the tests are conducted in a laboratory. As all individual engines of the same series are expected to be identical, only one or a few engines of each series are tested. Tests have shown that most of the total emissions come from relatively short episodes of high emissions, such as the cold start phase of the engine.

With the development and reduction of the overall dimensions of the measuring equipment, emission tests began to be carried out outside the laboratory in the actual operating conditions of engines and vehicles. The results of these tests showed that emissions in real working conditions are often significantly higher than in laboratory

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conditions. For this reason, emissions are measured in accordance with the RDE (Real Driving Emissions) test procedure and are mandatory today, i.e. measurements of emissions of harmful substances in real conditions of vehicle use are carried out. One of the most important features of measuring emissions in real conditions is a relatively fast change in driving conditions that correspond to the actual use of the vehicle (sudden and significant changes in load, acceleration, and engine speed).

It should be noted that the measurement of emissions in real conditions, the RDE procedure, is not a substitute for emission measurements carried out in laboratories but a mandatory supplement to laboratory tests. The RDE procedure is used to confirm that the vehicle's emissions of harmful substances do not exceed legally permitted limit values in real driving conditions. During RDE testing, the vehicle goes through various driving conditions and external road conditions, such as changes in altitude, temperature, additional load, driving uphill and downhill, highways and similar conditions.

The results determined by measurement in real conditions (RDE procedure) have lower repeatability than those determined in laboratory conditions and are considered good if they are within certain limits. Due to previously determined significantly higher emissions in real working conditions, the measured results are compared with the limit values for laboratory conditions increased by the Conformity factor (CF).

Driving conditions can have a significant impact on the overall result. For the measurement according to the RDE procedure, the boundary conditions for assessing the validity of driving are defined. The threshold value determines whether the vehicle's driving was excessively aggressive, appropriate or excessively passive. At each drive and in each individual part of the drive, the limit value must not be exceeded for the drive to be considered valid. Alternative fuels are and will be part of green and sustainable mobility. Real world tests are key to define the directions of future developments to further increase sustainability levels. The goal of the presented research was to determine the emissions of harmful substances and carbon dioxide, and fuel consumption, in accordance with the prescribed RDE procedure and compare for the two types of motor vehicle fuel: petrol and LPG.

2. Measuring equipment and measurement methods

The AVL M.O.V.E portable emission measurement equipment (Portable Emissions Measurement System - PEMS) is installed on the vehicle to measure emissions of pollutants and carbon dioxide and fuel consumption in real driving conditions. This system makes the continuous monitoring of individual pollutants from the vehicle's IC engine possible.

The PEMS is mounted on the vehicle's towbar or in the luggage compartment and connected to the engine exhaust pipe outlet. The PEMS device is small enough in size and mass that it can be installed on the vehicle and does not significantly impact the vehicle's dynamics.

The PEMS is a complex portable emission measuring system consisting of several different and interconnected measuring devices. All measuring devices of the PEMS system are connected to a central computer that controls the measurement and also acquires and stores measurement data.

The main elements of the PEMS are:

- gas analysers for determining the concentration of individual components in exhaust gases,
- particle counter that measures the number of solid particles in exhaust gases,
- exhaust gas mass flow meter,
- global positioning system (GPS) that determines vehicles speed and location while driving,
- meteorological station that measures the ambient temperature, pressure and humidity,
- interface to On Board Diagnostics - OBD system to acquire vehicle data from the CAN bus.

Table 1. Technical specifications of the PEMS

Analyzer	NO/NO_2 and $CO/CO_2/N_2O$	THC/CH_4	Particle counter
Measuring method	Non-Dispersive Ultra Violet – NDUV Non-Dispersive Infrared – NDIR	Flame Ionisation Detector – FID	Advanced diffusion charger
Measuring range	NO: 0 do 5000 ppm	THC: 0 do 30000 ppmC1	from ~1500 to ~2,5 x 107 #/cm^3
	NO_2: 0 do 2500 ppm		
	CO: 0 do 5% vol.		

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	CO_2: 0 do 20% vol.	CH_4: 0 do 10000 ppmC1	
	N_2O: 0 do 2000 ppm		
Zero drift/8h	NO/NO_2: 2 ppm	± 5 ppm C1/8h	
	CO: 20 ppm		
	CO_2: 0,1% vol.		
	N_2O: 20 ppm		
Accuracy		0,3% FS	

Gas concentration measurement in the exhaust is based on methods that monitor a certain physical property of a gas or reaction with working gases. Gas concentrations are calculated by comparing the signal generated by analysing the exhaust gas sample and the signal from the calibration gases at a given concentration.

3. Test vehicle

In this research, a Dacia Duster 1.0 TCe 100 ECO-G was used as a test vehicle. The main feature of the test vehicle is that it uses liquefied petroleum gas (LPG) or petrol as a fuel.

Figure 1. Test vehicle Dacia Duster 1.0 TCe 100 ECO-G

Vehicle technical specifications are displayed in table 2.

Table 2. Technical specifications of the test vehicle

Manufacturer	Dacia
Model	Duster
Emission level	6D6
Variant	DHE2
Vehicle category	M1
Engine type	SI 4 stroke
Number of cylinders	3
Engine displacement, cm3	999
Maximum power, kW	74 at 5000 rpm
Type	Bi-fuel
Fuel	Petrol – LPG

4. Design of experiment

The method of vehicle utilisation significantly affects the total harmful emissions, and due to that, an appropriate design of experiment (DoE) was conducted. The main influencing variables are the fuel type (LPG or petrol), the cold or warm start of the IC engine and driving style. Other conditions, such as route, weather, etc. were kept as it was possible constantly. The experimental plan of the conducted emission tests is shown in table 3.

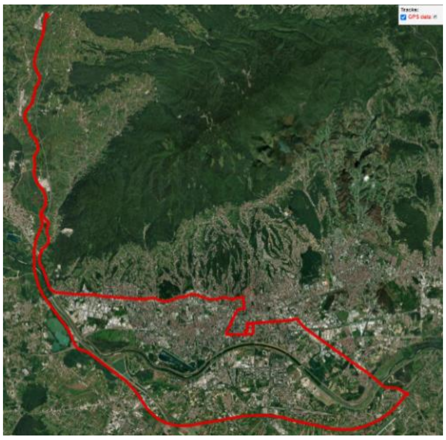
Table 3. Design of experiment

https://doi.org/10.55343/CogSust.38

RDE Test Number	Engine fuel	Engine start
Test no. 1	Petrol	Cold start
Test no. 2	Petrol	Cold start
Test no. 3	Petrol	Worm start
Test no. 4	Petrol	Worm start
Test no. 5	LPG	Cold start
Test no. 6	LPG	Cold start
Test no. 7	LPG	Worm start
Test no. 8	LPG	Worm start

5. Vehicle emissions measurement in real driving conditions

A test drive of three parts was conducted on a public road in accordance with the RDE procedure. The first part is urban, the second part is rural, and the third part is motorway. The geographical features of the test route and the characteristic values of individual parts of the test drive are shown in Figure 2.



Total time		Between 90 and 120 min
Driving conditions		
Distance	Urban	> 16 km
	Rural	> 16 km
	Motorway	> 16 km
Driving share	Urban	29% - 44% of the total trip
	Rural	23% - 43% of the total trip
	Motorway	23% - 43% of the total trip
Average speed	Urban	15 - 60 km/h
	Rural	60 - 90 km/h
	Motorway	> 90 km/h (> 100 km/h minimum 5 min)

Figure 2. RDE test route around the City of Zagreb, Croatia

Before every test drive, the device calibration procedure was carried out (see Figure 4). The calibration procedure was also carried out immediately after the end of the measurement in order to determine whether, during the test drive, there were any changes in the accuracy of the measurement results (shifting of the zero point and the measuring range).

Figure 3. Test vehicle with built-in measuring equipment

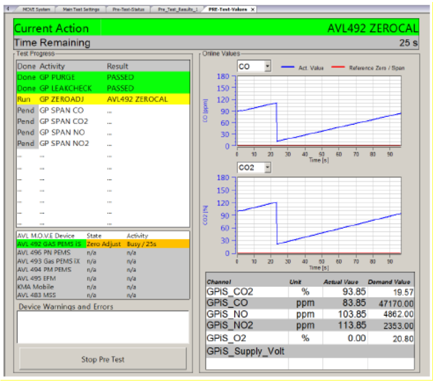


Figure 4 Program interface of the AVL M.O.V.E System Control during PEMS calibration

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During the test drive, the acquired data is continuously analysed, and it is checked whether the limit conditions of the RDE test procedure are met.

6. Results and discussion

After the test was carried out in accordance with the prescribed procedure, the results were processed in the AVL Concerto software package. The results are shown in Figures 5 to 9 in the same way in all diagrams. The green bars show the values measured when driving with LPG, and the blue colour shows the results when driving with petrol.

In all the diagrams, in addition to the measured results, the values taken from the publicly available certificate of conformity of the vehicle are plotted, whereby the value during testing according to the NEDC cycle (New European Driving Cycle) is marked in purple, the value measured during testing is marked in red according to the WLTP cycle (Worldwide Harmonized Light Vehicles Test Procedure), and the value of Euro 6 d in blue.

The mean value of fuel consumption in all cases of LPG drive is 8.4 l/100 km, and the standard deviation is 0.5 l/100 km. The results confirm the well-known fact that fuel consumption is slightly lower after a warm start. The LPG consumption measured by the PEMS device is near the limits measured by the NEDC or WLTP test procedure during the homologation tests.

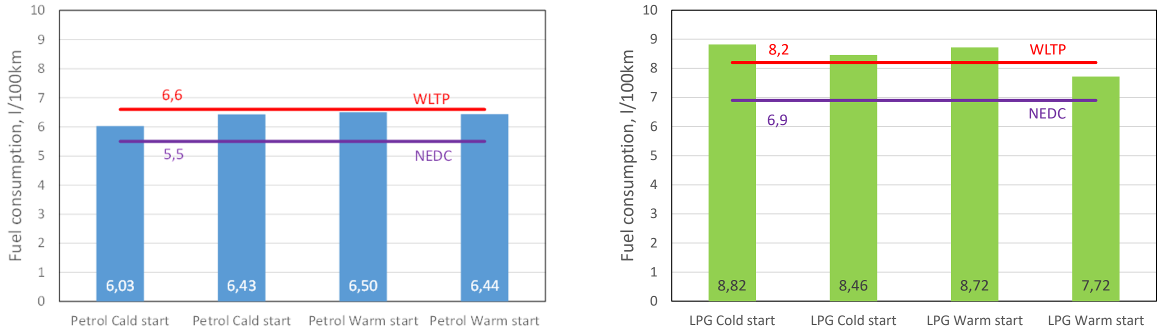

Figure 5. Vehicle fuel consumption when fueled with petrol (blue) and LPG (green)

The emission of CO_2 is directly related to fuel consumption. In Figure 6 the value trend for individual tests is the same as in Figure 5, that is, as in fuel consumption.

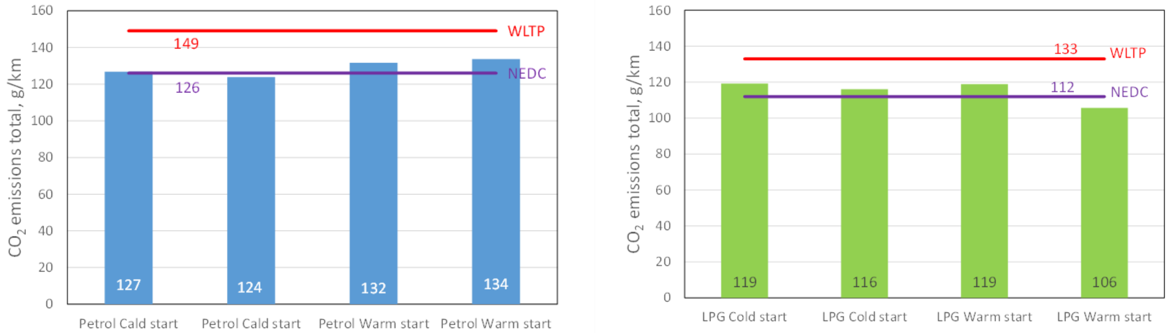

Figure 6. Vehicle CO_2 emission when fuelled with petrol (blue) and LPG (green)

The emission of carbon monoxide, CO, measured by the RDE procedure when running on petrol, is slightly lower than when running on LPG, see figure 7.

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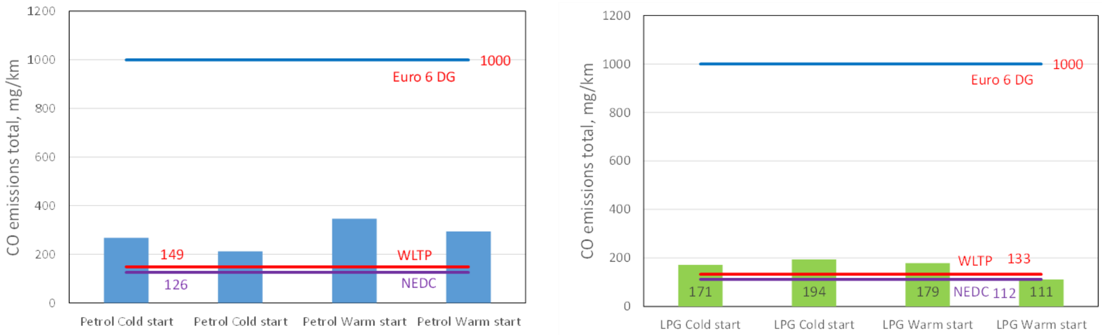

Figure 7. Vehicle CO emission when fuelled with petrol (blue) and LPG (green)

Emissions of NO_X are, in some cases, 50% lower when the vehicle is fuelled with LPG than in the case when it is fuelled with petrol. Furthermore, it is observed that during most of the conducted RDE tests, NO_X emissions are lower than in NEDC or WLTP test procedures (except the first test with petrol with a cold engine start).

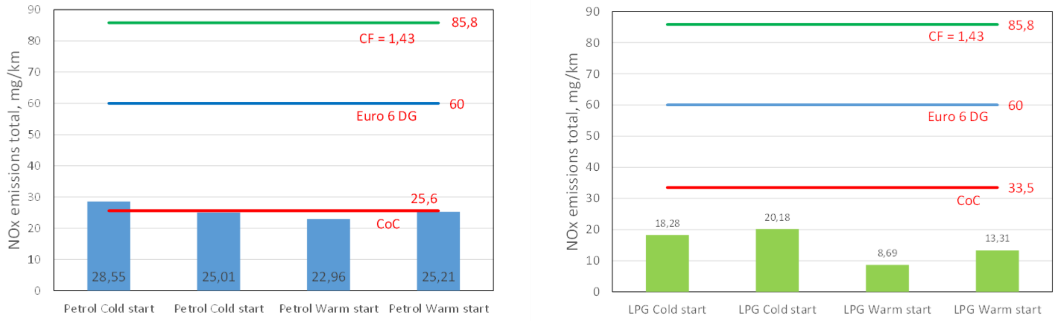

Figure 8. Vehicle NO_X emission when fuelled with petrol (blue) and LPG (green)

The measured emissions of the particles, more precisely, the number of the particles, is significantly higher when running on petrol. The significant difference in the number of particles can be explained by the fact that it is an internal combustion engine that, when powered by petrol, uses direct injection of petrol under high pressure into the engine cylinder to prepare the fuel mixture. In contrast, when powered by LPG, the mixture is prepared in the intake manifold.

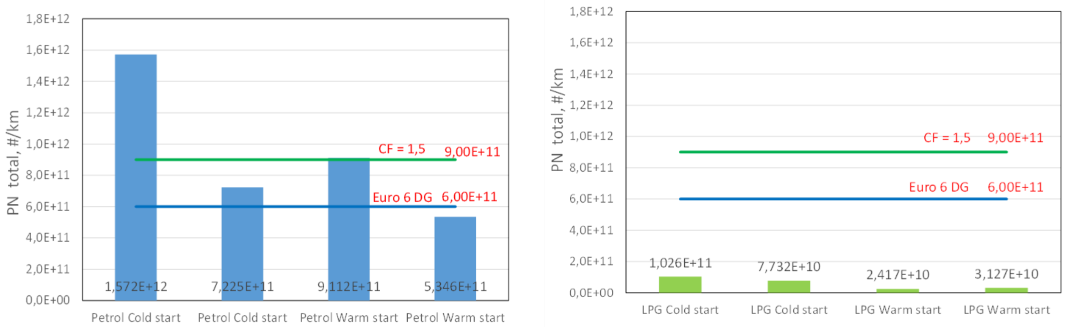

Figure 9. Vehicle particle number when fuelled with petrol (blue) and LPG (green)

Particle number in the first test with an engine fuelled by petrol on cold start is high due to the start of the regeneration process of the gasoline particulate filter (GDF), and this value is not taken into overall consideration.

7. Conclusion

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In accordance with the design of the experiment, eight measurements of the harmful emissions, carbon dioxide and fuel consumption in real driving conditions were carried out on the Dacia Duster 1.0 TCe 100 ECO-G using portable measuring equipment AVL M.O.V.E. The measurements were carried out in accordance with the prescribed procedure for measuring emissions in real driving conditions (RDE).

For the first time in the Republic of Croatia, the vehicle emissions fuelled by LPG were measured with the newly acquired measuring equipment for measuring vehicle emissions in real driving conditions and were compared with the emissions when the vehicle is fuelled by petrol.

The test vehicle, when running on petrol, uses a system that injects fuel directly into the engine cylinder, and as expected, higher particle emissions were measured than when running on gaseous fuel. Results showed that the used method can differentiate between different fuel types thus it is a valuable tool for future fuel developments.

The measured emissions correspond to the publicly published data on RDE emissions, which points to the conclusion that the measurements were carried out in accordance with the procedure for measuring emissions in real driving conditions.

Acknowledgement

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Nomenclature

CH_4	methane	NO	Nitric oxide
CO	Carbon monoxide	NO_2	Nitrogen dioxide
CO_2	Carbon dioxide	NO_X	Nitrogen oxides
HC	Hydrocarbon	PEMS	Portable emissions measurement system
IC	Internal combustion	PM	Particulate Matter
LPG	Liquefied Petroleum Gas	PN	Particle Number