

Real Time Emissive Behaviour of a Bi-Fuel Euro 4 SI Car in Naples Urban Area

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ABSTRACT

An experimental campaign was carried out to evaluate the influence of CNG and gasoline on the exhaust emissions and fuel consumption of a bi-fuel passenger car over on-road tests performed in the city of Naples. The chosen route is very traffic congested during the daytime of experimental measurements. An on-board analyzer was used to measure CO, CO₂, NO_x tailpipe concentrations and the exhaust flow rate. Throughout a carbon balance on the exhaust pollutants, the fuel consumption was estimated. The exact spatial position was acquired by a GPS which allowed to calculate vehicle speed and the traffic condition was monitored by a video camera. Whole trip realized by the vehicle was subdivided in succession of kinematic sequences and the vehicle emissions and fuel consumption were analyzed and presented as value on each kinematic sequence. Moreover, throughout a multivariate statistical analysis of sequences, the driving cycles characterizing the use of vehicle were identified.

Finally, comparison between regulated emissions of CNG and gasoline configurations was performed qualitatively by the analysis of speed and emission profiles belonging to the same cluster of cycles. Frequency distribution of mean values of CO₂, CO, NO_x emissions, and fuel consumptions, respectively with CNG and gasoline fuel type are presented. They are very well differentiated, both in the range of values than in the mode of frequency distribution. Particularly CO₂ emissions relative to gasoline fuel show a range of higher values respect on CNG fuel. Related to CO emissions, values obtained with CNG fuel also result much low. Concerning NO emissions, the richer combustion occurring when CNG is fuelled, due to different ECU tuning respect to gasoline, discourages the production of NO_x.

Moreover it was realized a statistical distribution analysis evaluating emission and fuel consumption mean values in each cluster. This analysis allows to compare emission and fuel consumption distribution between two different fuel types in the same traffic condition. To better underline difference due to fuel type, some statistical moments such as mean, standard deviation and range of regulated emissions are presented, cluster by cluster, to better evaluate the dispersion for each subgroup. The reducing effect computed in pair on each subgroup is clearly evident and repeatable.

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INTRODUCTION

The measurements of emission factors conducted under real-world driving conditions are becoming more and more important in the recent years. This approach can provide precious information about the real emissive behavior of in-use vehicles, necessary for making the prediction on air quality more reliable. On road test, in fact, takes into account the influence of a lot of actual variables such as traffic, vehicle maintenance, driving style, road gradient and weather conditions [1,2]. In this context, it was consolidated the use

of PEMS (Portable Emission Measurement Systems) which allow to measure exhaust pollutant emissions directly during on-board tests [3,4]. This measurement of tailpipe emissions for on-road and in-use vehicles is an approach that enables collection of data at any time and location, thereby resulting in a more representative emissions data over the use of chassis dynamometer.

In particular, the use of PEMS should avoid the extraction of the engines from machines, allowing the check of functionality of the emissions control technologies and an implicit protection against defeat strategies [5,6].

A recent study has showed that under motorway driving conditions PEMS measurements are quite different from off-cycle emission factors. Moreover, NO_x emissions of Euro 5 diesel vehicles resulted much higher than emission standards [7,8,9]. A further advantage of PEMS tests derives from fuel consumption and CO₂ data strictly related to energy savings in transport. In [10], the real increment of fuel consumption due to heavy traffic flow was assessed. In addition PEMS measurement campaigns in Europe covered only a small number of vehicles; insufficient for the derivation of technology-specific Emission Factors (EFs), best used for validating existing EFs or making relative comparisons [11].

Until now, European and US legislation recognized PEMS as a cost effective solution to perform in-use emissions testing of large combustion engines from heavy-duty vehicles or non-road applications. The application of PEMS to Light Duty Vehicles (LDVs) remains outside the regulatory field but in Europe in-use emissions regulations are being developed because there is an increasing need to bring on-road off-cycle emissions in line with those measured at type approval.

In this context this paper tries to give a contribution to the evaluation and comparison of the fuel consumption and emissions during road tests performed in the real world. Particularly the differences in emissions of a bi-fuel passenger car powered by gasoline and CNG (compressed natural gas) on representative of urban traffic road conditions are investigated.

The increasing interest in the use of alternative fuels for conventional vehicles introduces one additional dimension to the issue of fuel consumption and emissions [12]. In particular, the use of CNG helps to reduce the average CO₂ emissions of the automotive fleet and this helps to the automotive industry to achieve the statutory CO₂ emission requirements introduced in 2012 [13]. Furthermore using natural gas as automotive fuel other environmentally harmful pollutants can be significantly reduced [14].

So it becomes crucial to utilize a methodology that allows the comparison of vehicular emissions under comparable on-road conditions.

In this work emissions and fuel consumption are measured on board of a small-size passenger car during real use on a urban route of the city of Naples by PEM equipment. Kinematic characteristics are acquired by GPS system and also by other parameters coming from the engine control unit via the OBD system. Exhaust emissions and fuel consumption are correlated with kinematic data by using statistical multivariate methods. A particular concern is given to the characterization of the kinematics of the vehicle, from real-world driving cycles. A precise mapping of the emissions in relation to the path realized requires a thorough analysis of trips made by the vehicle on the chosen path, and the realization of multivariate statistical analysis of the velocity profiles in order to define the sequences kinematics and subsequently driving cycles. These analysis must not be

based only on the average speed, as asserted on [15,16]. Also kinematic sequences and driving cycles are precisely located by the association with GPS coordinates. Finally in the general approach presented here the calculation of regulated emissions and fuel consumption average values are made on these sequences and cycles. In the final phase of driving behavior analysis, cycles are characterized and grouped by multivariate statistical analysis to obtain clusters that may be associated with the level of traffic and the characteristics of the path. This comprehensive approach was developed to correlate kinematic operating conditions and emission values in real use, on the basis of methods previously developed in [16,17,18].

THE EXPERIMENTAL CAMPAIGN

A Natural Power Fiat Panda homologated EURO 4 (a bi-fuel car: compressed natural gas and gasoline powered) has been instrumented for on-road tests (Table 1). The main components of the monitoring system used in this work are:

- a Semtech gas analyzer produced by Sensor to measure at 1Hz CO, NO_x and CO₂ emissions. This analyzer uses NDIR cell (Non-Dispersive Infrared) for CO and CO₂ measurements, NDUV cell for NO/NO₂ and separate electrochemical sensor for oxygen. The analyzer is calibrated on a regular basis and zeroes itself on start-up using outside air.
- an EFM (Exhaust Flow Meter) by Sensor.
- an OBD interface and logging computer running proprietary software (EDS) to acquire engine operating parameters (speed, rpm, engine air flow...).
- a GPS receiver by Racelogic Ltd to acquire the spatial position.
- a video camera to record traffic situations.

Table 1. Vehicle characteristics

Vehicle model	Fiat Panda Natural Power	
Fuel	Gasoline	Methane (CNG)
N° of Cylinders	4	
Aspiration	Atmospheric	
Fuel Delivery	Multi point port injection	
Capacity [cm³]	1242	
Kerb Weight [kg]	1050	
Power [kW @ rpm]	44 @ 5000	38 @ 5000
Torque [Nm @ rpm]	102 @ 2500	88 @ 3000
Maximum Speed [km/h]	148	140
Transmission	Manual – 5 gears	
Odometer Reading [km]	~ 15.000	
Homologation Level	Euro 4	

The signals from all devices have been synchronized by using the same information obtained from different sources (i.e. speed from GPS and OBD).

The car has equipped with two engine electronic control units (ECU) applying different engine' strategies for gasoline and CNG. The main properties of two tested fuels are summarized in Table 2.

Table 2. Properties of gasoline and CNG

Fuel	Gasoline	Methane (CNG)
Physical state	<i>Liquid</i>	<i>Gaseous</i>
C/H ratio	~0.5	~0.25
Density at 15°C [kg/m³]	749	0.778
Research Octane Number	97	120+
Auto Ignition Temperature [°C]	257	540
Lower Heating Value / LHV [MJ/kg]	42.2	45.3

During the experimental campaign, instrumented car performed some missions in the city of Naples, along a traffic busy route. The chosen route is located in central Naples, having a characteristic predominantly flat and a length of about 22 km, as shown in Figure 1.



Figure 1. Experimental route: Outward (Istituto Motori-P.za Garibaldi) and return (P.za Garibaldi - Istituto Motori).

Initially some tests were carried out on the route (named "Route A") in the 10:00 to 15:00 time slot but the introduction of the Limited Traffic Zone (from 7 to 14.30) involved moving the time slot 14.30-18.30.

During the experimental phase thirteen trips were performed: nine with car fueled with gasoline and four fueled with CNG, some trips during morning and some during afternoon hours. Gasoline fueled trips are subdivided in five on outward and four on return journeys, while two CNG fueled trips are realized on outward and two on return part of "Route A"

The emission measurements acquired by PEMS and the kinematics and GPS data of each acquisition are filtered, synchronized and analyzed using statistical methods.

THE KINEMATIC APPROACH

Multivariate statistical analysis is used to perform correlations between vehicle kinematic operating conditions (kinematic sequences) and related measured emissions (mean/total value on a sequence). By these methodologies, the effectiveness of technological measures and/or different vehicle power fuels to improve emissions in real world use is also quantitatively evaluated.

Measured emissions are analyzed either by the instantaneous emissions profile, and/or by making the overall mean for a sequence/driving cycle. As vehicle operating conditions obviously vary continuously as a function of route and traffic, the overall average approach doesn't allow a precise quantitative evaluation because it doesn't take into account the vehicle operating conditions. These features could be considered analyzing and characterizing vehicle operating conditions, including also the instantaneous vehicle location.

The comparison of emissions by the two fuels is performed under equivalent operating conditions, defined by location, speed profile and traffic condition defined by driving cycle. In fact the speed profile varies continuously as a consequence of heavy or fluent traffic conditions and more or less aggressive driving style. So that it is obviously necessary to make the comparison of regulated emissions CO, NO_x, HC and fuel consumption based on homogeneous segments of speed profile, selecting the speed profile performed on roads with the same traffic characteristics.

The integrated statistical approach, developed to analyze the data from the continuous acquisition on-board system, is based on the analysis of parts of movements between two successive stops, hereinafter called a kinematic sequence. The sequence consists of an idling part and a running part. A series of successive sequences with homogeneous characteristics represents the same driving behaviour. So each speed profiles are subdivided into kinematic sequences. The kinematic pattern of each sequence is characterized by a number of parameters; the entire set of parameters is a multivariate observation of X variables, statistically defining the sequence. X variables being mutually correlated and very numerous, to better characterize sequences and classify them into homogeneous groups, Principal Component Analysis and Cluster Analysis were utilized [19].

Vehicle operating conditions are in a first phase described by means of kinematic sequences; these are chosen in such a way that represent analogous conditions of speed and acceleration, taking further account of localization by means of GPS data. To each speed sequence, the emissions time series detected at the same time is related. After that by the application of various statistical methodologies and of a precise rules for the construction and the cutting of velocity profile, it is thus possible to identify driving cycles representative of real use. Finally, a comparison between regulated emissions of the engine power configuration, gasoline or CNG, is performed by comparing the speed