Science of the Total Environment 487 (2014) 506–520

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

European type-approval test procedure for evaporative emissions from passenger cars against real-world mobility data from two Italian provinces

Giorgio Martini [a], Elena Paffumi [a], Michele De Gennaro [a,*], Giorgos Mellios [b]

[a] European Commission — Directorate General Joint Research Centre, Institute for Energy and Transport, Sustainable Transport Unit, via Enrico Fermi 2749, Ispra 21027, Italy
[b] EMISIA SA, Antoni Tritsi 21, PO Box 8138, GR 57001 Thessaloniki, Greece

HIGHLIGHTS

- Two real-world driving patterns databases are analysed.
- The trip and parking events are characterised versus 12-hour diurnal time windows.
- The evaporative emissions have been derived for real-world driving data.
- The effectiveness of the current type approval test procedure has been evaluated.
- The evaporative emission control system could not efficiently work in real-world conditions.

ARTICLE INFO

Article history:
Received 28 January 2014
Received in revised form 24 March 2014
Accepted 14 April 2014
Available online 6 May 2014

Editor: P. Kassomenos

Keywords:
Evaporative emissions
Real-world mobility data
European type-approval test procedure
Passenger cars

ABSTRACT

This paper presents an evaluation of the European type-approval test procedure for evaporative emissions from passenger cars based on real-world mobility data. The study relies on two large databases of driving patterns from conventional fuel vehicles collected by means of on-board GPS systems in the Italian provinces of Modena and Firenze. Approximately 28,000 vehicles were monitored, corresponding to approximately 36 million kilometres over a period of one month. The driving pattern of each vehicle was processed to derive the relation between trip length and parking duration, and the rate of occurrence of parking events against multiple evaporative cycles, defined on the basis of the type-approval test procedure as 12-hour diurnal time windows. These results are used as input for an emission simulation model, which calculates the total evaporative emissions given the characteristics of the evaporative emission control system of the vehicle and the ambient temperature conditions. The results suggest that the evaporative emission control system, fitted to the vehicles from Euro 3 step and optimised for the current type-approval test procedure, could not efficiently work under real-world conditions, resulting in evaporative emissions well above the type-approval limit, especially for small size vehicles and warm climate conditions. This calls for a revision of the type-approval test procedure in order to address real-world evaporative emissions.

1. Introduction

Evaporative emissions from vehicles are Volatile Organic Compounds (VOCs) emitted by the fuel system and other vehicle's parts (e.g. tyres, internal trim, plastic components) and not directly related to the combustion process of the fuel in the engine. These emissions depend on a number of factors, such as the size of the tank, the fuel volatility, the material used for the tank and fuel hoses, the parking duration and the ambient temperature. Among these, the main factor determining evaporative emissions is the fuel volatility combined with the variation of the fuel temperature as a consequence of ambient temperature fluctuations, solar radiation and heat sources (e.g. engine), as per Stump et al. (1990) and Rubin et al. (2006). In general, evaporative emissions occur during the operation of the vehicle (i.e. running losses), immediately after the vehicle's engine is switched off after operation (i.e. hot soaks), during the refuelling, and during vehicle diurnal parking. In particular, this last source of VOCs is considered the predominant part, as outlined in Yamada (2013).

* Corresponding author. Tel.: +39 0332 789357; fax: +39 0332 786627.
E-mail addresses: giorgio.martini@jrc.ec.europa.eu (G. Martini), elena.paffumi@jrc.ec.europa.eu (E. Paffumi), michele.degennaro@jrc.ec.europa.eu (M. De Gennaro), giorgos.m@emisia.com (G. Mellios).

http://dx.doi.org/10.1016/j.scitotenv.2014.04.053

Nomenclature

Acronyms

CARB	California Air Resources Board
COPERT	COmputer Program to calculate Emissions from Road Transport
DVPE	Dry Vapour Pressure Equivalent
EPA	Environmental Protection Agency
EMS	Engine Management System
EUDC	Extra-Urban Driving Cycle
FID	Flame Ionization Detector
GMT	Greenwich Mean Time
GPS	Global Positioning System
GWC	Gasoline Working Capacity
LDV	Light Duty Vehicle
HDPE	High Density Poly-Ethylene
NEDC	New European Driving Cycle
OBD	On Board Diagnostics
PD	Probability Distribution
PFI	Port Fuel Injection
SUV	Sport Utility Vehicle
UDC	Urban Driving Cycle
US	United States of America
VELA	Vehicle Emission LAboratory
VOC	Volatile Organic Compound
WLTC	Worldwide Harmonised Light Vehicles Test Cycle

The current European legislation on evaporative emissions of vehicles dates back to the Council Directive 98/69/EC (European Parliament, 1998), which introduced the Euro 3 and 4 steps for Light Duty Vehicles (LDVs). As a result of the implementation of this piece of legislation, since the year 2000, gasoline vehicles for the European market have been equipped with an activated carbon canister placed on the vent of the tank. Its purpose is to trap the fuel vapours and avoid that these are released into the air. The carbon canister has a limited capacity and for this reason needs purging, therefore part of the combustion air is drawn through the canister when the vehicle is running, removing the hydrocarbons trapped in the canister which are then burned in the engine. The size of the carbon canister, the Gasoline Working Capacity (GWC) of the activated carbon and the purging strategy are key parameters affecting the efficiency of the evaporative emission control system. It is important to stress that evaporative emissions increase disproportionally when the carbon canister gets saturated as a consequence of extended parking events or insufficient purging.

Since the introduction of this directive, neither the evaporative emission standards nor the test procedure has changed. It is now considered necessary to revise the European legislation on evaporative emissions in order to improve the performance of the emission control system in real-world driving conditions, as stated in several legislative documents, such as the article 4 of the regulation (EC) No. 715/2007 (European Parliament, 2007) and the communication 2008/C 182/08 (European Parliament, 2008). According to these documents, two main issues must be addressed:

- A more effective control of evaporative emissions under real-world driving conditions. This implies that real-world efficiency and durability of the evaporative emissions control system have to be addressed.
- The impact of ethanol fuel on evaporative emissions.

An attempt to quantify real-world evaporative emissions can be found in Ross et al. (1995) and Brooks et al. (1995). These papers refer to an experimental campaign carried out in the Phoenix area with 300 vehicles tested in real-world conditions, showing that approximately 15% had evaporative emissions above 2 g. For only 20% of these high-emitting vehicles the high emissions could be ascribed to a malfunction of the evaporative emission control system whilst for the remaining 80%, i.e. approximately 12% of the fleet considered, the high evaporative emissions were due to severe ambient conditions.

The objective of this paper is to address to what extent the test conditions specified in the current European evaporative emission legislative test procedure cover typical real-world driving/parking conditions by estimating the averaged emissions per vehicle type and ambient condition (i.e. calendar month) with the simulation software COPERT (Emisia, 2013). This study relies on large datasets of real-world activity data of LDVs (i.e. approximately 28,000 vehicles equivalent to 36 million kilometres, from the Italian provinces of Modena and Firenze). These data can be useful for different studies, such as electric vehicle usability (De Gennaro et al., 2013a) and energy demand (De Gennaro et al., 2014), or in combination with chassis dyno tests to calculate on-road driving emissions (Sturm et al., 2000). The innovative contribution of this work is their use, for the first time, to evaluate the effectiveness of the evaporative emission type-approval test procedure in controlling real-world emissions, in order to provide scientific evidences and quantitative data to support the improvement of the type-approval test-procedure.

The results of the analysis show that the evaporative emission control systems used in European vehicles, which are typically designed to comply with the European legislative evaporative emission test, do not adequately cover real-world conditions and how a large share of parking events could systematically lead to emissions well above the limit set by the type-approval test procedure, mainly as a consequence of canisters not sufficiently purged.

2. Background information

2.1. European type-approval test-procedure for evaporative emissions and comparison with the US legislation

The evaporative emission test (Type IV), laid down in the Council Directive 98/69/EC (European Parliament, 1998), is designed to determine hydrocarbon evaporative emissions as a consequence of diurnal temperature fluctuation during parking and hot soaks. Hot soak emissions are usually attributed to the evaporation of the petrol in the fuel and injection system immediately after the engine is switched off. Diurnal emissions are instead the evaporative emissions occurring from a vehicle whilst it is not being operated. The European test procedure consists of the following main phases:

- test preparation (i.e. canister and vehicle conditioning);
- hot soak loss determination (i.e. hot soak test, 1-hour duration);
- diurnal loss determination (i.e. 24-hour diurnal test).

Evaporative emissions are measured using an air-tight chamber able to contain the vehicle under test. The VOCs concentration inside the chamber is monitored by means of a Flame Ionization Detector (FID) analyser. The mass emissions of hydrocarbons from the hot soak and the diurnal loss phases are added up to provide an overall result for the test. Before starting the measurement of the evaporative emissions, both the vehicle and the carbon canister have to be properly prepared according to a specific conditioning described in the legislative procedure. The carbon canister has to be loaded with butane to the breakthrough condition, defined as the operation point when 2.0 g of hydrocarbons have been emitted by the canister. As far as the vehicle is concerned, the following conditioning steps have to be carried out:

- Fuel drain and refill: after the butane loading of the canister to the breakthrough condition is completed and the canister reconnected to the fuel system, the tank is filled with test fuel at a temperature of about 287 K (14 °C) to 40 $\pm$ 2% of the tank's normal volumetric capacity.
- Preconditioning drive: within 1 h from completing the canister loading, the vehicle has to be placed on a chassis dynamometer and driven