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Emissions of modern light duty ethanol flex-fuel vehicles over different operating and environmental conditions ☆

Christos Dardiotis *, Georgios Fontaras *, Alessandro Marotta, Giorgio Martini, Urbano Manfredi

European Commission, Joint Research Centre, Institute for Energy and Transport, Ispra (VA), Italy

HIGHLIGHTS

- Various ethanol blends tested in 2 Flex Fuel Vehicles of different fueling system.
- Tests performed at 22 °C and −7 °C, under certification and more transient cycles.
- At 22 °C CO emissions decreased using E85, HC emissions were practically unaffected.
- NO_x emissions presented different behavior over NEDC and CADC for the 2 vehicles.
- At −7 °C both regulated CO and total HC emissions increased with the use of E75.

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ABSTRACT

In 2012 some 2.8 million toe of bioethanol were introduced in the European gasoline market. The introduction of ethanol blendstocks in the European fuels market should take place without undermining pollutant emissions or vehicle engine performance. According to the Euro 5 certification procedure the properties of three different ethanol blends supplied in the European market (E5, E75, E85) should be taken into account when testing for exhaust emissions. In this study the latest procedure established for emissions certification is assessed, shedding light on the gaseous regulated emissions and CO_2 – energy/fuel consumption performance of two Flex Fuel Vehicles with different fueling strategies (Direct/Port Fuel Injection) and different Euro standards (Euro 4 and Euro 5). Both legislative and non-legislative "real-world" driving cycles were used in the study. The analysis is completed with a comparison with existing emission factors for Flex Fuel Vehicles in Europe. At 22 °C CO emissions decreased over all conditions tested with the use of the high ethanol content fuel (E85), compared to the E5 performance. Total HC emissions were practically unaffected by the fuel type. NO_x emissions decreased for both vehicles over the New European Driving Cycle, while over the Common Artemis Driving Cycle the vehicles exhibited different NO_x behavior. At −7 °C both regulated CO and total HC emissions increased with E75 fuel. However, the Euro 5 vehicle exhibited emission performance below the current legislative limits for both CO/total HC over the cold-start urban part of the cycle. Results were found to be in line with existing emission factors used in Europe for ethanol-fueled vehicles.

Abbreviations: CADC, Common Artemis Driving Cycle; COPERT, computer programme to calculate emissions from road transport; CVS, Constant Volume Sampling; EC, Energy Consumption; ECU, Engine Control Unit; EU, European Union; EMEP/EEA, European Monitoring and Evaluation Programme/European Environmental Agency; EUDC, Extra Urban Driving Cycle; Euro #, emission standard; FC, Fuel Consumption; FFV, Flex Fuel Vehicle; FID, Flame Ionization Detector; G-DI, Gasoline Direct Injection; GHG, Greenhouse Gas; JRC, Joint Research Centre; NEDC, New European Driving Cycle; NMHC, Non Methane Hydrocarbons; PFI, Port Fuel Injection; TWC, Three Way Catalyst; UDC, Urban Driving Cycle; VELA, Vehicle Emission Laboratory.

☆ The views expressed are purely those of the authors and may not in any circumstance be regarded as an official position of the European Commission.

* Corresponding authors at: AVL List GmbH, Hans-List-Platz 1, 8020 Graz, Austria. Tel.: +43 (0) 316 787 3942; fax: +43 (0) 316 787 140 (C. Dardiotis). T.P. 230, Via Enrico Fermi 2749, 21027 Ispra (VA), Italy. Tel.: +39 0332 786425; fax: +39 0332 786671 (G. Fontaras).

E-mail addresses: christos.dardiotis@avl.com (C. Dardiotis), georgios.fontaras@jrc.ec.europa.eu (G. Fontaras).

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1. Introduction

The use of biofuels in Europe has been promoted for the past ten years in an effort to reduce road transport generated Greenhouse Gas (GHG) emissions and strengthen energy security. So far one of the most popular biofuel has been biodiesel but biomass derived ethanol has also gained an important market share in various European countries, reaching a total European Union (EU) wide production of 2.8 million toe in 2010 [1]. Ethanol has been proposed as a potential fuel for gasoline engines since the early 20th century, due to some favorable characteristics such as its high octane number. With respect to GHG savings, stoichiometric combustion of Ethanol delivers more energy for each kilogram of Carbon Dioxide (CO_2) produced (14.1 instead of ~13.5 MJ/kg CO_2) [2]. However the availability of fossil gasoline at a relatively low price, until recently, has limited the use of ethanol as an automotive fuel. Meanwhile, concerns about urban air quality and the adverse health effects associated with road transport generated emissions, have led to the adoption of increasingly more stringent pollutant emission limits during the past 30 years, which have driven the evolution of exhaust after-treatment systems and internal combustion engine technologies to high levels of efficiency and optimization. The recent introduction of ethanol blendstocks in the fuels market should take place without undermining pollutant emissions or vehicle engine performance.

The "Cold-start Carbon Monoxide (CO) and total Hydrocarbons (HC) performance for gasoline vehicles, at low ambient temperature conditions", conducted at −7 °C (Type VI test) is one of the legislative emission type-approval tests for new light duty vehicles in the EU. The test is run over the urban part of the New European Driving Cycle (NEDC) and is applicable only to spark ignition vehicles. The current emission limits for this test are 15 and 1.8 g/km for CO and total HC respectively, carried over since the introduction of Euro 3/4 requirements [3], in 2000. The European Commission has been requested to update these limits [4], in order to be consistent with the Euro 5/6 Type I test (measured at an ambient temperature from 20 to 30 °C). Meanwhile, the current emission limits and Type VI test requirements have been extended also for Euro 5 Flex Fuel Vehicles (FFV) [5] while operating on both fuels (E5 and E75), since up to Euro 3/4 only the mono-fuel gasoline vehicles where applicable to such a certification test. This paper discusses the performance of two FFVs tested also over the Type VI test for Ethanol Flex Fuel Vehicles.

In the literature some studies have already investigated the performance of Euro 3/4 FFVs under low temperature conditions (−7 °C) [6–8], but all the emissions and fuel consumption have been calculated according to the Euro 4 procedure [3]. This affects the results, as it will be discussed in detailed in this paper, since according to the Euro 5 certification procedure [5,9], the different ethanol blend (E5, E75, E85) properties are taken into consideration, in terms of unburned hydrocarbon density, fuel density, and fuel consumption carbon balance formula. In this study the latest procedure is followed, shedding light on the gaseous regulated emissions and CO_2 – energy/fuel consumption performance of the two vehicles tested, of different emission certification (Euro 4/5) and different injection strategy (Port Fuel/Direct Injection), under legislative and non-legislative "real-world" driving cycles. The analysis is completed with a comparison with existing emission factors for FFVs in Europe.

2. Experimental

2.1. Vehicles and fuels

Two gasoline FFVs were investigated in this study: The first vehicle (henceforward V1) was a late technology Euro 5 compliant Gasoline Direct Injection (G-DI) and turbocharged, while the second (V2) was a Euro 4 Port Fuel Injection (PFI) vehicle. Table 1 provides the main characteristics of these vehicles

Both vehicles were equipped with a Three Way Catalyst (TWC) for the control of regulated gaseous pollutants, CO, HC and Nitrogen Oxides (NO_x). By the time when the experimental campaign was taking place (1st quarter of 2011), only one Euro 5 FFV was available in the market. Thus, it was decided that a 2nd vehicle to be included in the campaign, a Euro 4 compliant one (V2).

V1 had mileage below 3000 km at the beginning of the experimental campaign. UNECE Regulation 83 [9] requires that for type approval purpose the vehicles must have been driven at least 3000 km prior to emission testing. In the current testing campaign, due to the limited number of repetitions the limited mileage was expected to have a reduced influence in respect to the objective of the study.

Three fuels differing for the ethanol content were used in this study. The reference fuel (henceforward E5) was a blend of gasoline and 5% v/v ethanol, the second fuel (E75 from now on) had an ethanol content of 75% v/v and the third fuel (E85) an ethanol content of 85% v/v. E5 and E85 were used and evaluated over tests performed at 22 °C, while at low ambient temperature conditions (−7 °C) the E5 and the E75 were used. In Europe, during winter time, E85 fuel for FFV vehicles is replaced by a lower ethanol content blend (E75) in order to avoid problems associated with engine starting. The specifications of E75 reference fuel are defined in Commission Regulation No. 566/2011 [5]. Table 2 presents the main specifications of the fuels used in this study.

The fuel drain/re-filling was done according to the respective procedure described in [10]. After this procedure the vehicle was preconditioned running one UDC and two EUDC part cycles on the vehicle dynamometer. Additionally, for V1, the adaptation of the engine's fuel injection system on the new fuel was verified reading the "Alcohol percentage in fuel" of the Engine Control Unit (ECU) recording at the end of the preconditioning driving protocol.

2.2. Driving cycles and measurement protocol

The vehicles were tested over the New European Driving Cycle (NEDC) and the Common Artemis Driving Cycle (CADC) at two temperatures (22 °C & −7 °C). The NEDC is the cycle employed in EU since 2000 for certification of light-duty vehicles. It consists of the urban part, commonly indicated as Urban Driving Cycle (UDC), which includes four repetitions of the Elementary Urban Cycle, and the Extra-Urban Driving Cycle (EUDC) [9]. The CADC is a hot start cycle developed in the framework of the EU funded Artemis project [11]. It consists of three segments representative of typical urban, rural and motorway driving conditions in Europe (with an average speed of 17.5 km/h, 60.3 km/h and 116.4 km/h, respectively).

For V1 the daily test sequence consisted of one cold start NEDC (at least 12 h soak time), and one hot start CADC, conducted as soon as possible after the NEDC (~30 min).

The daily test sequence of V2 was different: Each testing day consisted of one cold start NEDC and one cold-start CADC (6 h soak

Table 1
Flex fuel gasoline vehicles' data and specifications.

Vehicle	Emission standard	Injection system	Engine capacity/rated power	Mileage (km)	CO_2 emission (type approval) (g/km)
V1	Euro 5	G-DI	1984 cc/132 kW	1411	154
V2	Euro 4	PFI	1798 cc/92 kW	11,772	177