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On-board measurement of emissions from liquefied petroleum gas, gasoline and diesel powered passenger cars in Algeria

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ABSTRACT

On-board measurements of unit emissions of CO, HC, NOx and CO_2 were conducted on 17 private cars powered by different types of fuels including gasoline, dual gasoline–liquefied petroleum gas (LPG), gasoline, and diesel. The tests performed revealed the effect of LPG injection technology on unit emissions and made it possible to compare the measured emissions to the European Artemis emission model. A sequential multipoint injection LPG kit with no catalyst installed was found to be the most efficient pollutant reduction device for all of the pollutants, with the exception of the NOx. Specific test results for a sub-group of LPG vehicles revealed that LPG-fueled engines with no catalyst cannot compete with catalyzed gasoline and diesel engines. Vehicle age does not appear to be a determining parameter with regard to vehicle pollutant emissions. A fuel switch to LPG offers many advantages as far as pollutant emissions are concerned, due to LPG's intrinsic characteristics. However, these advantages are being rapidly offset by the strong development of both gasoline and diesel engine technologies and catalyst converters. The LPG's performance on a chassis dynamometer under real driving conditions was better than expected. The enforcement of pollutant emission standards in developing countries is an important step towards introducing clean technology and reducing vehicle emissions.

Introduction

Thanks to its chemical composition, such as the H/C ratio, and to its physicochemical properties, such as calorific capacity (Díaz et al., 2000; Lim et al., 2006), liquefied petroleum gas (LPG) is often considered as a clean alternative fuel to liquid ones, and hence widely used in many countries (Johnson, 2003; Karamangil, 2007). In 2010, the LPG vehicle fleet in the world was estimated at roughly 17 million (WLPGA, 2012), and roughly 0.3 million vehicles have been converted to LPG in Algeria (Boughedaoui, 2007). The environmental benefits of LPG have been widely described in scientific articles based on either engine bench or chassis dynamometer emission measurements (Bayraktar and Durgun, 2005; Li et al., 2007; Lai et al., 2009). However, very few on-road measurements of LPG-powered passenger cars have been performed in real driving conditions to assess the environmental performance of LPG fuel in comparison with gasoline and diesel (Lau et al., 2011; Oprešnik et al., 2012).

Initially, chassis dynamometer measurements were designed to test vehicle emissions in view of certification, using a standardized driving cycle. However, standardized driving cycles are not representative of real traffic conditions (André and Rapone, 2009). Alternative techniques to perform on-road measurements of emissions were developed, widely tested and compared with the standard method (Franco et al., 2013). Pelkmans and Debal (2006) conducted measurements on the NEDC standard European cycle in real traffic in two European cities. The emissions measured in real traffic were higher than on the standard driving cycle by at least 60% and 30% for diesel and gasoline vehicles, respectively, for almost all

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pollutants. Nitrogen oxide (NOx) emissions in real traffic were found to be 2 to 4 times higher than emissions measured on the NEDC (Pelkmans and Debal, 2006; Rubino et al., 2007; Daham et al., 2009; Weiss et al., 2011). Strong acceleration is not considered in the NEDC, making it unrepresentative of real traffic conditions (Weiss et al., 2012). Acceleration, among other driving and environmental conditions, contributes to increase the emission of all pollutants versus emissions measured with NEDC. Finally, it has been shown (Daham et al., 2009; Weiss et al., 2011; Franco et al., 2013) that carbon dioxide (CO_2) emissions measured using a chassis dynamometer were underestimated by 10% to 50% in comparison with real emissions measured with a PEMS (Portable Emission Measurement System) for different vehicles with emission standards from Euro 1 to Euro 4.

It has been noted that emissions are significantly underestimated by chassis dynamometer measurements compared with on-board techniques, which increases the uncertainty of pollutant emission estimation. This calls into question the representativeness of chassis dynamometer measurements with respect to real emissions. On the other hand, real kinematics are still difficult to reproduce on a test bench taking into account all environmental parameters.

Only a few measurements with LPG-powered vehicles have been performed on-board to evaluate pollutant emissions under real driving conditions. A vehicle fuel switch from gasoline to LPG was found to decrease CO_2 emissions measured on a chassis dynamometer by 14% (Ristovski et al., 2005; Yang et al., 2007), and carbon monoxide (CO) and total hydrocarbons (THC) by 71% and 89%, respectively. Using the remote sensing technique, Ning and Chan (2007) were able to measure and compare pollutant emissions for LPG, gasoline and diesel powered vehicles. The CO and THC emissions from LPG-powered vehicles were lower than those from gasoline and higher than those from diesel.

Recently, Lau et al. (2011) used PEMS to compare emissions from LPG-powered vehicles on the road and on a chassis dynamometer. The results from the on-road measurements showed higher levels of CO and THC emissions.

Researchers tend to consider the emissions of vehicles in real traffic as more representative for environmental study purposes. They can enhance road traffic emission inventory control, air quality modeling and air pollution abatement strategies for road transportation (Franco et al., 2013). The abovementioned measurement discrepancies call into question the standard method, whose results are not representative of real emissions under real driving conditions. Therefore, and for more realistic measurements, the purpose of this paper is to explore the environmental efficiency of LPG powered vehicles measured with an on-board system called mini-CVS (Boughedaoui et al., 2008) in real traffic conditions on 17 vehicles equipped with different conversion kits and injection technologies. Such measurements reflect the emissions from used vehicles that take into account real vehicle usage conditions, with a comparison with emissions from gasoline and diesel powered vehicles.

1. Experiments

1.1. Method

The methodology is based on sampling gaseous pollutants along the route with a mini-CVS. This technique was developed by the Warren Spring Laboratory, Stevenage, Herts (UK), then tested and validated by INRETS (France) and used by several research teams (Potter, 1987; Van Ruymbeke et al., 1993; Boughedaoui et al., 2008). The mini-CVS sampling system is a reduced and simplified version of the CVS system. It is installed on board the test vehicle and connected to the exhaust pipe (Figs. 1 and 2). The exhaust gas emitted by the vehicle passes through a tapered nozzle attached to the exhaust pipe. The nozzle is composed of 112 parallel tubes assumed to deliver equal flows. Only gases coming from one tube are diluted with ambient air in the dilution chamber and then collected in Tedlar bags. The bags are forwarded to the laboratory immediately after each circuit for analysis of the CO, THC, NOx and CO_2 composition. Emission of particles is not measured by this system and is not considered in this study.

1.2. Analytical instrumentation

The CO and CO_2 analysis was performed using infrared radiation absorption, with a Cosma-Environnement SA, Igny (France) Crystal 300 device. The NOx was analyzed by chemiluminescence using a Cosma-Environnement SA, Igny (France) Topaz 3010 mono-chamber device. The THCs were determined by flame ionization detection (FID) with a Cosma-Environnement SA, Igny (France) Graphite 750 device. All devices were calibrated daily with standard gases (purity 99.5%) supplied by Air Liquide, Paris (France) company. The mass of pollutants emitted during each test was converted into an emission factor, taking into account the distance traveled, the temperature, the atmospheric pressure and the humidity of the sampled gas.

1.3. Vehicles

The 17 vehicles were randomly selected and borrowed from private owners for the entire testing period. All of the vehicles were owned by individuals from different social and professional categories, and were used for both professional and personal purposes. The vehicles included 6 gasoline-powered, 4 diesel and 7 dual gasoline/LPG vehicles, whose characteristics are shown in Table 1. The subgroup of LPG vehicles was composed of 4 vehicles equipped with a multipoint injection kit and 3 vehicles with sequential multipoint fuel injection (Table 3). These vehicles were assumed to be representative of the Algerian passenger car fleet in 2011 in terms of brand, engine size and age. The tested LPG vehicles included vehicles with and without catalytic converters and with three types of injection systems: simple, multipoint, and sequential multipoint injection.

All 7 dual-fueled vehicles were of the same brand and model, with the exception of one, but they had different ages and mileages. This LPG sub-group allowed better comparison among vehicles by eliminating the variability factor between models and brands. Tests were performed on the vehicles without any prior maintenance.

The characteristics of fuels used in Algeria are the following: the sulfur content in Diesel is 500 ppm, the octane index is 96 for gasoline and 95 for unleaded gasoline, and the cetane index is 51 for diesel. The LPG composition is 96% propane during hot periods and decreases to 80% propane in cold periods. Díaz et al. (2000) determined that a mixture with 70% propane appears to be optimal, since it reduces CO and NOx emissions, yet it increases THC emissions.

1.4. Circuit selection

The road circuits were selected on the basis of kinematic measurements using a chase vehicle within the traffic