In Service Emission Test of LPG Passenger Cars in the Republic of Croatia

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Abstract

In service emission test is used to check the efficiency and proper operation of vehicle's emission control system. In the Republic of Croatia in service emission test is mandatory for most of the passenger cars, but LPG powered vehicles are exempt from the test. To assess the condition of LPG passenger cars exhaust gas aftertreatment system, in the cooperation with the Centre for Vehicles of Croatia in service emission test of the LPG powered passenger cars was carried out. After the data analysis, it was concluded that 41.3% of tested vehicles failed test when powered by LPG and 39.3% of the vehicles failed the test when powered by gasoline. Over 31% of the study fleet failed the in service emission test regardless of the fuel used, which indicates that the test should be mandatory for LPG vehicles as well.

Introduction

Transport represents a crucial sector of the economy, but also represents almost a quarter of greenhouse gas emissions in the European Union with continuously rising trend. Road transport sector accounts for 72.8% of all GHG emissions from transport in 2014 [1]. One of the options for Europe to reduce the GHG emissions from transport and oil dependency are alternative fuels like liquefied petroleum gas (LPG) and methane [2]. In Europe, LPG propels 7 million passenger cars (PCs) thus being the most widely used alternative fuel [3]. Specific advantages of LPG as alternative fuel are highly developed supply system, easy adaption of existing gasoline engines and relatively low price.

Passenger Cars Fleet in the Republic of Croatia

In the Republic of Croatia 1.5 million passenger cars were registered in 2015. Over 96% of fleet is powered by conventional fossil fuels. In alternative fuels, liquefied petroleum gas has a dominant share of 3.78%, while other alternatives like CNG or electric vehicles are practically negligible. Similar situation was recorded at the EU level where the share of LPG vehicles in 2015 was 4.2% [4]. With an average age of 12.5 years, passenger cars fleet in Croatia is relatively old, compared to the average 9.7 years of the passenger cars fleet in the EU [5].

European emission standards (Euro standards) are an important instrument in controlling vehicle emissions as the vehicle technology advances. Progressively introduces increasingly stringent Euro standards have main goal to reduce emissions from road vehicles [6].

Structure of passenger cars fleet in the Republic of Croatia according to emission level and fuel type is shown in Figure 1. According to Centre for Vehicles of Croatia database, majority of passenger cars in the Republic of Croatia, about 29%, meet the Euro 3 emission level. Diesel powered passenger cars have almost the same share of Euro 4 (28%) as Euro 3 vehicles and 17% of Diesel PCs complies to higher Euro 5 and Euro 6 emission level. Unlike the Diesel, in the gasoline passenger cars fleet there is still significant amount, over 22% of Euro 2 vehicles. Most of LPG fleet fulfil the Euro 4 level, but like gasoline fleet, still there is significant amount of Euro 2 vehicles, 23.7%. From this distribution, it can be concluded that the Croatian passenger cars fleet comply with lower emission levels, but that is not telling much about the real in-service emissions from these vehicles.

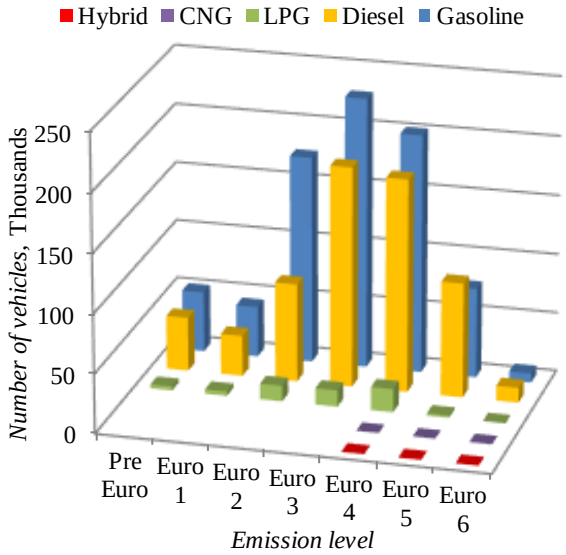

Figure 1 Passenger car fleet by emission level and fuel type

While real emissions mainly depend on the fuel type and vehicle technology level, a significant impact on emissions has a condition of the IC engine and exhaust gas aftertreatment system and overall vehicle maintenance. Several authors [7], [8] pointed out that in-service emission differences between well maintained and poorly maintained vehicles are larger than the age-dependent deterioration of emissions and

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a small portion of malfunctioning vehicles are responsible for high portion of total emissions.

To identify such a high emitting vehicles with malfunctioning emissions control system emissions inspection was implemented in periodical technical inspection of vehicles [9]. As part of periodical technical inspection (PTI) emission testing was first introduced in some Member States of the EU in the early 1980s, and in 1996 basic requirements were included in the consolidated roadworthiness Directive 96/96/EC [10]. The purpose of the PTI emission test is to allow authorities to check that in-service vehicles are well maintained and conform as far as possible to their design emission levels [11], keeping the environmental impact of vehicles under certain legally prescribed level [12].

In the Republic of Croatia in service emission test is mandatory for most of the passenger cars, but from some reason (unknown to the authors) LPG powered vehicles are exempt from the in service emission test. That means that for more than 55,000 passenger cars in Croatia one knows nothing about the condition of their exhaust aftertreatment system. If the average age of LPG passenger car fleet, emission level, and total mileage are considered, it can be assumed that the correct operation of their exhaust gas aftertreatment system is questionable.

Specific Objectives

To assess the condition of LPG fleet exhaust gas aftertreatment system, in cooperation with the Centre for Vehicles of Croatia (CVH), in service emission test of the LPG powered passenger cars was carried out. A random sample of 1000 LPG passenger cars were tested in some of the 161 vehicle technical inspection stations throughout the Republic of Croatian. All in service emission tests were made as an additional test during the regular periodical technical inspection of vehicles that participated in this the survey.

The main objective of the study was to check the condition, proper operation and effectiveness of emission control system. Since the LPG vehicles can be propelled by gasoline or LPG, each vehicle is tested with both fuels. For each vehicle two emission test were made, first test with one fuel, for example gasoline, and immediately afterwards one test with another fuel, LPG or vice versa first LPG and then gasoline.

In that way, influence of fuel type on test results is reduced, and the focus remained on the emission control system. Such methodology should identify vehicles with defective emission control system (highly polluting vehicles) more easily.

Methodology

All emission tests in this research are made according to the current EU legislation on in service emission test contained in Directive 2014/45/EU [13]. In service emission test consist of two main steps. First one is a visual inspection of exhaust emissions control system fitted by the vehicle manufacturer. During the visual inspection it is determined if the system is absent, modified or obviously defective and checked for any leaks which would affect the emission measurements. Once the system is checked, second step is measurement of gaseous emissions. For vehicles with an advanced emission control system, such as a lambda-controlled three-way catalytic converter, after a reasonable period of engine conditioning (warming up), exhaust emissions are measured at the engine idle speed and at the high idle speed. For vehicles without advanced emission control system, exhaust emissions are measured only when the engine is idling. In any of these measurements, no external load is applied to the engine. Using a sample probe in the exhaust tailpipe, concentration of CO, CO_2, HC and O_2 in exhaust gas are measured using appropriate (approved) gas analyser and lambda value is calculated. Infrared spectrometry is used for CO, CO_2 and HC measurements while electrochemical detection is used for measurements of O_2. Additionally, during the test, engine speed and engine temperature are measured.

Apart from the measured values of emissions, engine speed and engine temperature, for every vehicle data such as engine capacity, emission level, production year, mileage, and if available, emission limit values set by the vehicle manufacturer were collected. All acquired data were stored on a central shared server for further processing.

Criteria used to assess if the vehicle pass the in service test in this study are the same as the criteria given in the Directive. Vehicles without advanced aftertreatment system will fail the in service emission test if the CO emission exceeds the specific level prescribed by the vehicle manufacturer. If this data is not available, CO content at normal idle speed must not exceed 4.5% for vehicles first registered in 1986 and before or 3.5% for vehicles first registered in 1987 and later. If vehicle is equipped with an advanced emission control system, CO concentration must not exceed limit value given by the manufacturer. If this information is not available, the CO content must not exceed 0.5% at the engine idle speed and 0.3% at the engine high idle speed or 0.3%, at the idle speed and 0.2% at the high idle, according to the date of first registration or use. Also, for controlled vehicles, lambda must be in the range of $1 \pm 3\%$, or as stated in the manufacturer's specifications.

Results and Discussion

All collected data, primarily measurements, were evaluated before data processing. Data sets with insufficient or incomplete information were rejected. From 1000 of tested vehicles, 914 of them had all necessary measurements and data values and were analysed and presented in results below.

As previously mentioned, all vehicles tested in the study were selected randomly during the regular periodical technical inspection, so the structure of the

tested vehicle is very diverse. After the data processing, a comparison of the tested vehicles with the total LPG fleet in the Republic of Croatia was made to check the extent to which tested vehicles represent the total LPG fleet.

Distribution of the LPG passenger cars by Euro emission level is given in Figure 2. Orange bars show the distribution by Euro emission level of overall LPG passenger cars in the Republic of Croatia and blue bars show the distribution of LPG cars tested on in service emission test in this study.

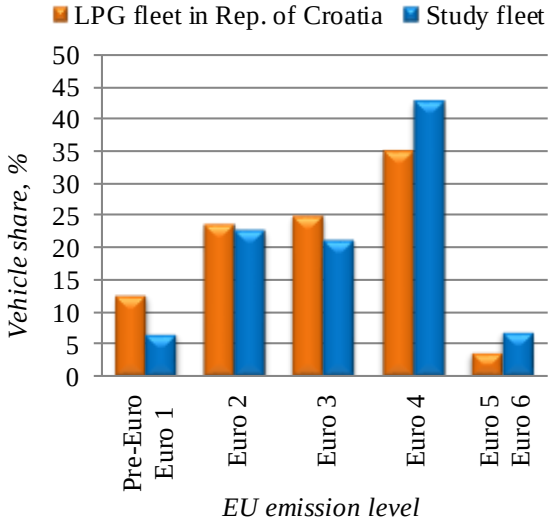

Figure 2 Comparison of LPG fleet in the Republic of Croatia and study test fleet

In this study most represented LPG passenger cars on the emission test with the share of 42.9% were the one with the Euro 4 emission level. They are followed by the Euro 2 PCs with the share of 22.8% and Euro 3 PCs with 21.1%. With slightly over 6.5% share of the Euro 1 and Pre-Euro PCs is identical to the share of Euro 5 and Euro 6 passanger cars.

Like in the test study fleet, the largest share, 35.2%, of overall LPG passenger cars fleet in the Republic of Croatia meets the Euro 4 standard. Although they have the largest share, the structure of the overall LPG fleet is very unfavourable due to the large number of vehicles with no emission control system or vehicles with low-technology emission control system like Pre-Euro, Euro 1 and Euro 2 vehicles. These vehicles represent almost 36% of the fleet and with the Euro 3 vehicles account for over 62% of the entire fleet while market share of the latest Euro 5 and Euro 6 passenger cars with 3.6% is practically inappreciable.

If distributions of test fleet and overall LPG fleet shown in Figure 2 are compared, it can be concluded that there is a sufficiently good agreement and that vehicles tested are good representative of the entire LPG fleet.

Vehicles included in this study were of different age. As shown in Figure 3 oldest vehicle was 40 years old and the youngest was only a year. Only 3.7% of test vehicles are up to 5 years old. 40% of the tested vehicles are between 5 and 10 years old, 25% of them are between 10 and 15 years old, while 30% are over 15 years old. With the average age of 12.7 year test study fleet is in the line with the average age of the overall LPG fleet.

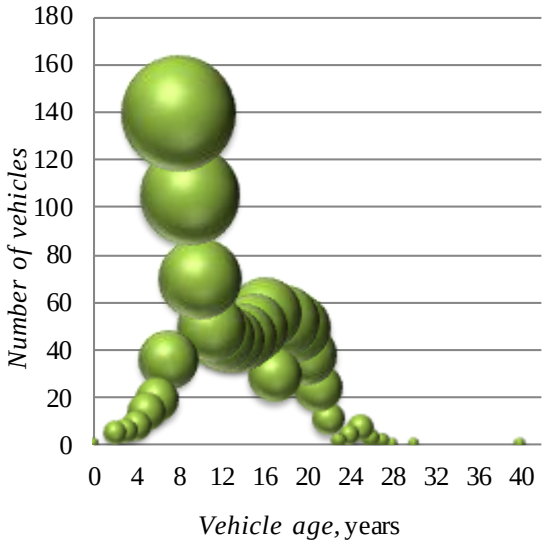

Figure 3 Test fleet vehicle age

Along with the vehicle age and technology level, considerable, and maybe even higher, impact on emissions has vehicle usage. In this study usage of tested vehicles was not presented on annual level, but total mileage or total distance travelled of vehicles is given (Figure 4). Average total mileage of 191,900 km suggests that LPG fleet in Croatia consists of vehicles with a highly accumulated mileage what can be also observed in the distribution of vehicles. Only 19 of 914 tested vehicles had total mileage below 50,000 km, while 105 of them had mileage between 50,000 and 100,000 km. 178 vehicles had mileage in the range from 100,000 to 150,000 kilometres. Most of the vehicles, 205, had travelled from 150,000 to 200,000 km. The rest of the test fleet, 407 vehicles had over 200,000 km. The greatest distance travelled had the vehicle with over 625,000 km on the odometer.

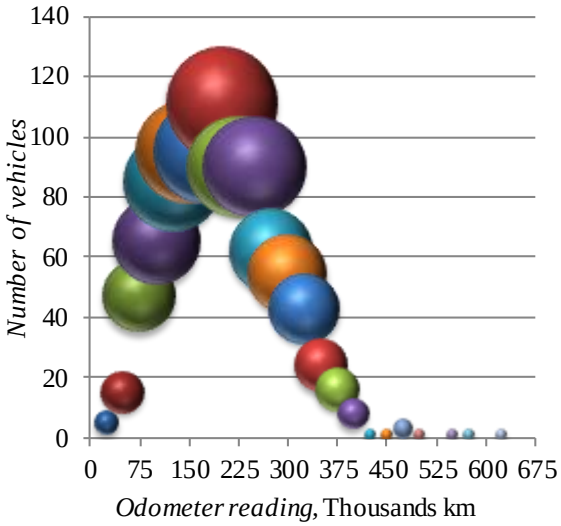

Figure 4 Test fleet vehicle mileage

Influence of vehicle emission level, which is related to technology and vehicle age, on results of in service emission test is best shown in the diagram given in Figure 5. Results of emission testing when passenger cars are powered by LPG are displayed in green bars, while blue bars represent results when tested cars are powered by gasoline. Red bars show passenger cars that failed the emission test regardless of the fuel used. These vehicles failed the emission test when driven by LPG and when driven by gasoline meaning that their emission control system is defective and these vehicles can be classified as highly polluting vehicles.

In example, 24.74% of passenger cars that meet the Euro 4 level did not pass the test with LPG and 22.96% of them when tested with gasoline. Without fuel influence 15.05% of passenger cars that meet the Euro 4 level failed. Euro 3 vehicles failed the emission test in the same percentage of 43% when powered by LPG and when powered by gasoline, but 34% of all Euro 3 vehicles failed the test regardless of the fuel used.

Although the percentage of vehicles that failed the test was slightly higher when LPG was used, fuel cannot be the reason of failure, but only the condition of the emission control system. Number of vehicles that failed the test increase significantly as the emission level those vehicles lowers. If results without fuel influence are analysed, it can be proved that in case of Euro 5 and Euro 6 vehicles fail rate falls below 6.5%, while in case of Euro 3 vehicles emission test fail percentage increases to 34.2%. Results of vehicles with lower emission level, Euro 2 with the 59.65% of test fail and Euro 1 with a 74.47%, are quite disturbing. Such a clear increase in the test fail percentage proves that the technology or age of the vehicle has a substantial impact on emission test results.

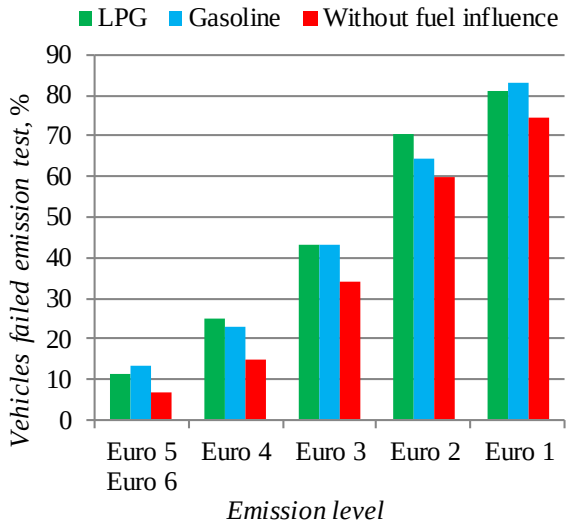

Figure 5 Emission test results according to vehicle Euro emisison level

Similar situation can be displayed for the emission test results depending on the mileage of vehicles, as given in Figure 6. Results of emission tests are presented like in the Figure 5, LPG in green bars, gasoline in blue, and regardless of fuel type used in red.

Like with the emission level, also there is a strong influence of vehicle mileage on test results. Practically with the same rate of about 14% vehicles with total distance up to 50,000 km travelled and vehicles with mileage between 50,000 and 100,000 failed the emission test. In the range from 150,000 to 200,000 kilometres 21.46% of vehicles failed, while in the distance range from 200,000 to 250,000 km 42.4% of vehicles failed. In the range over 300,000 km over 66.7% of vehicles failed the in service emission test.

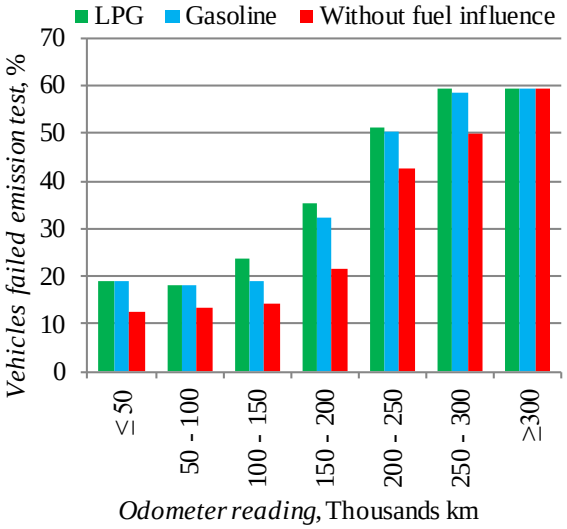

Figure 6 Emission test results according to vehicle mileage

Failures that affect the test results are specified in Directive and given earlier in the methodology section. The number of errors (malfunctions) recorded during the test for vehicle equipped with advanced emission control system is given in Figure 7. Failures occurred while tested with LPG are displayed in green bars, and failures during the operation with gasoline are displayed in blue.

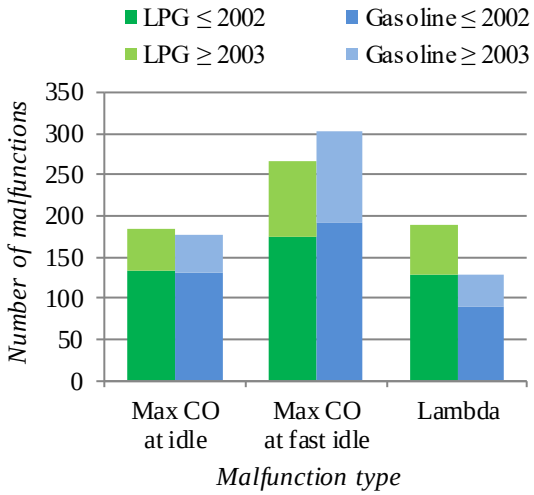

Figure 7 Failures responsible for emission test fail

In Figure 7 vehicles first registered in 2002 and before are shown in light colours (green for LPG, blue for gasoline), while vehicles first registered in 2003 and later are shown in dark colours. As it can be seen regardless of year of first registration in most of the test maximum prescribed CO level at fast idle speed was exceeded and was the reason of test failure. It should be noted that on some of the vehicles more than one failure occurred during the test. So far it has been shown that the emission level or vehicle age and mileage significantly affect the emission test results. If measured CO emission values are additionally analysed, it can be concluded that for vehicles which have passed the emission test, measured CO emission values are several times smaller than the prescribed limit value. Frequency distributions of measured CO emission values of all tested vehicles at normal idle speed are displayed in Figure 8 and Figure 9.

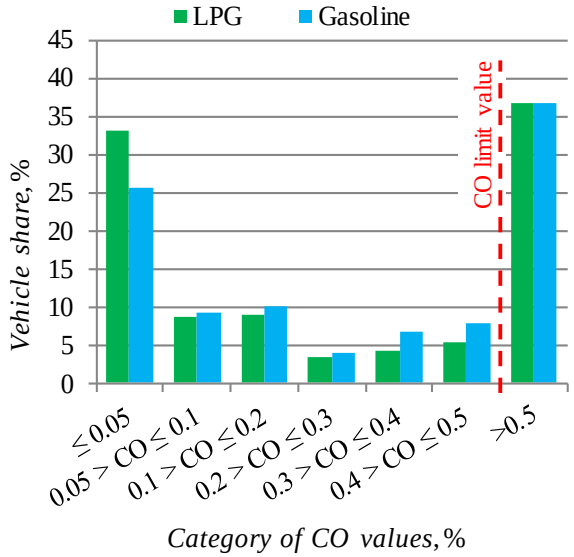

Figure 8 CO values at normal idle speed measured on vehicles first registered in 2002 and before

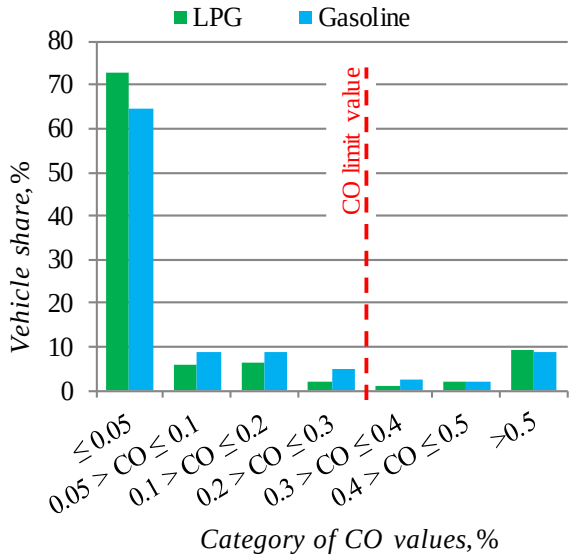

Figure 9 CO values at normal idle speed measured on vehicles first registered in 2003 and later

As shown in Figure 8 on over 30% of vehicles first registered in 2002 and before at normal idle speed CO emission was 10 times smaller than the legally required limit value (CO must not exceed 0.5%), while on over 70% of vehicles first registered in 2003 and later at normal idle speed measured CO level was 6 times smaller than the allowed limit (CO must not exceed 0.3%) as shown in Figure 9.

Results of the high idle emission test for tested vehicles first registered in 2002 and before are shown in Figure 10 while for vehicles first registered in 2003 and later are given in Figure 11. Even with the gradual deterioration of the emissions control system, CO values will not reach the permitted limits. On the other hand, on most of vehicles with defective emission control system measured CO emissions are at least two times higher than the allowed limit.

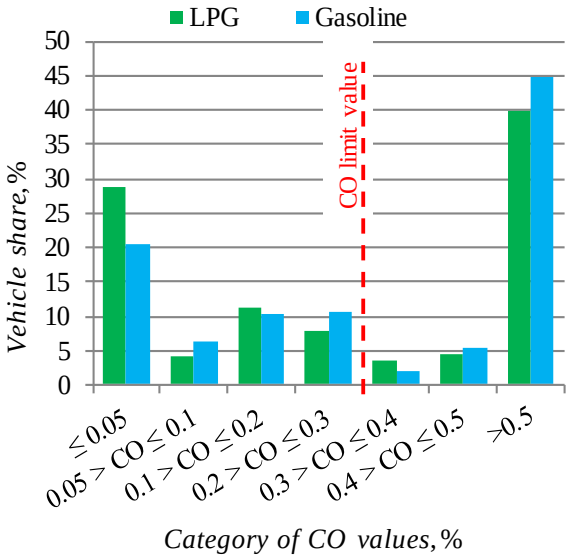

Figure 10 CO values at high idle measured on vehicles first registered in 2002 and before

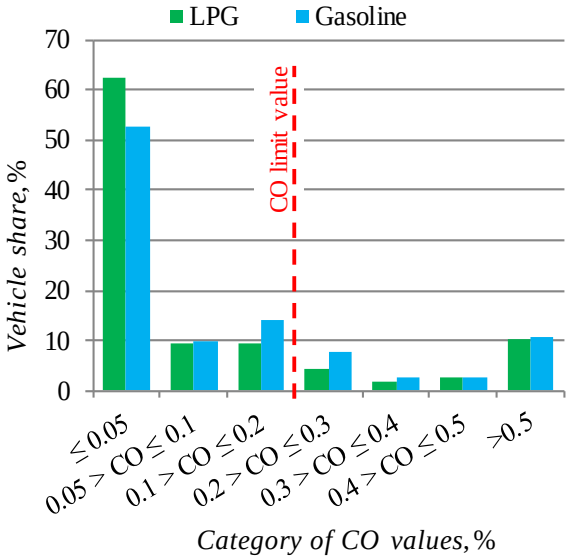

Figure 11 CO values at high idle measured on vehicles first registered in 2003 and later

Conclusion

In service emission test, as a part of periodical technical inspection, is used to check the operation and efficiency of vehicle's emission control system with the goal to maintain emissions in the prescribed level and to identify highly polluting vehicles.

In the Republic of Croatia in service emission test is mandatory for most of the passenger cars, but LPG powered vehicles are exempt from the in service emission test. In this study emissions were measured and analysed for 914 passenger cars powered by LPG and gasoline showing that 41.3% of tested vehicles failed the in service emission test when powered by LPG and 39.3% of the tested vehicles failed the test when powered by gasoline. Same test was failed by 31.7% of all tested vehicles regardless of the fuel used. From the results it can be concluded that emission level, vehicle age and mileage have great impact on emission test results. Passenger cars with lower emission level (Euro 1, Euro 2) have much higher rate of test failure, than the one with higher emission level (Euro 5, Euro 6). Similarly, with the increase in mileage, also increases the share of vehicles that failed the emission test.

Also, detailed analysis of CO emissions proves that the in service emission test can identify vehicles with the defective emission control system, because emissions of these vehicles are most often considerably higher than the prescribed limit value.

Considering the alarming high rate of vehicles that failed the test, it must be concluded that the in service emission test should be mandatory in the Republic of Croatia for LPG vehicles as well.

The second conclusion is that the LPG fleet in the Republic of Croatia consists of fairly old vehicles and high mileage vehicles or vehicles that comply with lower Euro emission levels. It is necessary to change such a structure through the renewal of the fleet through the incentives for the purchase of less polluting vehicles or the purchase of alternative fuel vehicles.

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