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EXPERIMENTAL EVALUATION OF LOW LEVEL BIOETHANOL-GASOLINE BLENDS ON ENGINE PERFORMANCE AND EMISSIONS

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Abstract: The paper presents the results of experimental research of two low level bioethanol-gasoline blends E5 (5% bioethanol, 95% gasoline) and E10 (10% bioethanol, 90% gasoline) tested on Toyota Corolla vehicle on chassis dynamometer. The analysis of obtained results has showed that the increase of engine power and fuel consumption is slightly higher for both blends compared to gasoline, showing better perspectives for E5 than E10. Emission tests have shown increase of CO_2 and NO_x emissions for all mentioned fuels and testing conditions, as also decrease of CO and HC. The addition of bioethanol has left a positive impact on unregulated emissions, showing better reduction than for regulated emissions.
Keywords: bioethanol, gasoline, emissions, power, fuel consumption

INTRODUCTION

The use of ethanol as a transport fuel has a large history. Firstly it was used as a fuel for German's inventor Nicholas Otto prototype of today's well known four stroke Otto-cycle internal combustion engine, but the largest popularity it gets after the use in Henry Ford's model T in 1908, and also in other designed automobiles for ethanol use in 1920-s, which were designed to use corn alcohol. Different ethanol-gasoline mixtures were popular between World War I (WWI) and WWII and were used as an octane booster and were also in demand during WWII due to a fuel shortage.

One of the most popular blends, which were used in last century and is also used nowadays, is E10 or also known as "gasohol", which is a fuel mixture of 10% anhydrous ethanol and 90% gasoline and practically can be used also in modern SI engines without any modification of the engine or fuel system. Therefore, nowadays it is also used in more than 20 countries around the world. Other well-known blends are E5 and E7. First one is widely used around the Europe as it is introduced as mandate blend in many EU countries, even in Latvia, to increase the share of biofuels in the conventional gasoline and fulfil Biofuels Directive (Directive 2003/30/EC). Despite of that, new increase could be possible in the future to achieve Renewable Energy Directive (Directive 2009/28/EC) target reaching 10% share of renewable energy in transport till year 2020, which is also outlined in National Action Plans of EU Member States. In previous period reaching of outlined plans was not realized fully therefore EU Member States have to find a way how to increase biofuel consumption in their countries based on a new Directive.

There are different solutions on how it could be realized: expanding the use of biofuels in non-road transport, applying high blends in road transport in niche application or increase the current blending limits till 10% (Kampman et al, 2013). The last one option is most promising, but performing it still has some barriers (Smigins and Shipkovs, 2014), especially those ones connected with customers – drivers usually are looking cautiously on any new fuel (like, E10) despite of slightly lower price, explaining it with fears to damage engines resulting the loss of the warranty on the car.

In any case introduction of such type of fuel could help to increase the market for bioethanol, but only in combination with a reduction of the price. It is known that E10 practically does not leave any damage to the fuel system and can be used in largest part of vehicles available on the market, but for many customers there are still unknown reasons for usage of such fuel type.

Many researchers have studied the impact of the addition of oxygenates, mainly focussing on engine performance and gaseous emissions (Bielaczyc et al, 2013; Elfasakhany, 2015). Results are different and could be affected by vehicle model, age and effectiveness. Besides of that, some researchers observed the generation of a variety of organic compounds during the combustion process of gasoline-bioethanol blends, which could be attributed to the bio-part in the blend (Manzetti and Andersen, 2015). Totally, ethanol addition leaves positive impact on engine performance increasing torque, power and thermal efficiency, as also reduces the amounts of different components. Researchers have observed reduction in NO_x emissions testing various low level of ethanol-gasoline blends (Yao et al, 2011), but others have found increase of NO_x (Durbin et al, 2007). Similar situation was also observed according to HC and CO emissions, but their results are more convincing.

This paper shows investigation realized by researchers of Latvia University of Agriculture when testing different bioethanol-gasoline blends, like E5 and E10, compared to gasoline, in unmodified vehicle. Results include engine dynamical, economic and ecological factors using mentioned fuels in different testing conditions. Attention was devoted also to the unregulated emissions, which could be also included in the legislation in future.

MATERIAL AND METHOD

The impact of bioethanol added to gasoline on emissions and engine performance was tested on a Toyota Corolla vehicle. The main engine specifications are listed in Table 1. The engine used in the tests is a four-cylinder, four stroke, water cooled, 10.5:1 compression ratio engine with industrial application. Tests were realized in the Alternative Fuels Research Laboratory of the Latvia University of Agriculture.

Table 1. Technical characteristics of the tested vehicle

Parameter	Characteristics
Name	Toyota Corolla
Production year	2007
Engine capacity	1598 cm3
Cylinder number and arrangement	4, in line
Compression ratio	10.5
Maximum power	81 kW at 6000 rpm
Maximum torque	150 Nm at 4800 rpm

The schematic diagram of the experimental setup used for studying engine emission characteristics, and also fuel consumption are shown in Figure 1.

Fuel consumption was measured on a laboratory chassis dynamometer MD-1750 by the AVL KMA mobile fuel measuring system. The device measures the volumetric consumption within very short measurement time and high precision (0.1% accuracy of reading). One of the main pieces of equipment is also chassis dynamometer, which is used to apply a load to the test vehicle. During the tests was obtained the power curve, necessary for engine power analysis for mentioned fuels.

Fuel consumption and emission tests were realized at idling, IM-240 cycle, 50 and 90 km/h. The choice of last ones was done because it corresponds to the maximum allowed speed in Latvian urban and suburban areas. Constant speed measurements were performed for 2 minutes with reading step of 1 second. Additionally was realized a combined cycle IM-240, which simulates not only urban driving conditions, but also driving in non-urban area. The duration of the test is 240 seconds.

Emission measurements were realized by AVL SESAM FTIR multi-component exhaust gas measurement system, which allows to measure up to 25 gases simultaneously and some components can be calculated from this process. During research all those gases were fixed, but more detailed analysis was done only for the most essential regulated exhaust gas components: nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (HC), as also unregulated exhaust gas components: ammonia (NH_3), methane (CH_4), acetylene (C_2H_2) and ethane (C_2H_6).

The drivability of the vehicle was unimpaired during tests; vehicle was tested with all the fuels in random order and each reading was repeated three times. The results of these three replications were averaged to decrease the uncertainty and reported.

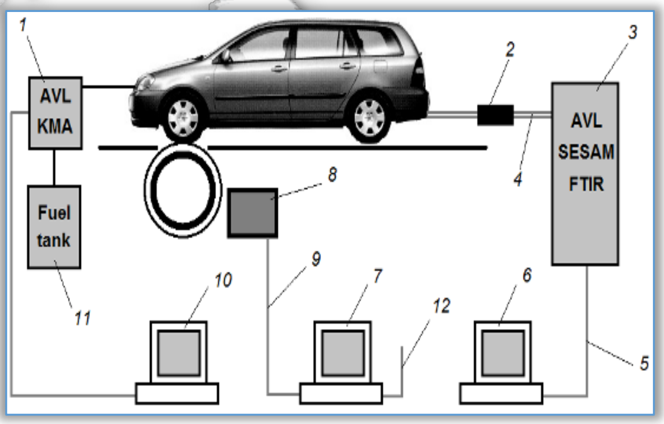

Figure 1 – Schematic diagram of the experimental setup
1 – AVL KMA Mobile Unit; 2 – heated filter;
3 – multicomponent exhaust gas measurement system AVL SESAM FTIR; 4 – heated gas line; 5 – AVL data communication cable; 6 – PC with special AVL software; 7 – Mustang chassis dyno control and data recording PC; 8 – power absorber unit; 9 – dyno date communication cable; 10 – fuel consumption and data recording; 11 – fuel tank; 12 – screen communication cable

The engine was operated on the gasoline (E0), meeting EN 228:2004 standard, and two blends containing:

- 5% (v/v) of bioethanol with 95% (v/v) of gasoline (mixture code: E5);
- 10% (v/v) of bioethanol with 90% (v/v) of gasoline (mixture code: E10).

Tested blends were prepared just before the experiments by splashing mixing technique in the proportions mentioned before.

RESULTS

The experimental data which characterize the variation of engine dynamical, economic and ecological factors using different fuels could be seen in figure below. According to test results, it could be seen increase in power with the addition of bioethanol, which could be explained by the density of the mixture and the engine volumetric efficiency, which increases based on the concentration of bioethanol increase and resulting in engine power increase.

In current research it was observed the largest increase in power in range of 2000 till 3000 rpm, which is 5.2% at 2000 rpm for E5 and 5.6% at 3000 rpm for E10 (see Figure 2). There was not observed significant increase in engine power in other speed ranges.

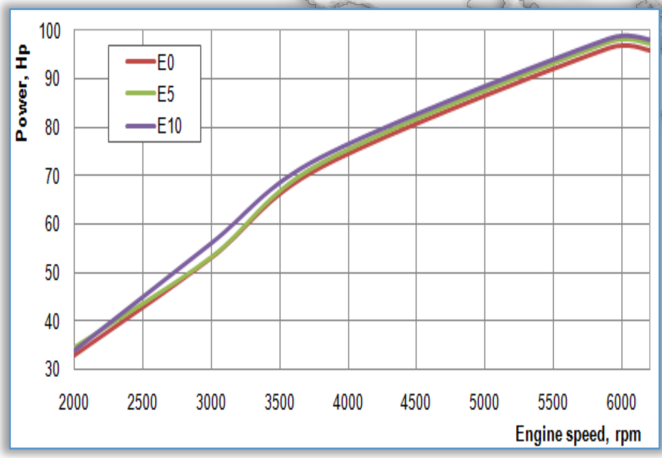

Figure 2 – Power curves for different fuels

Based on the fuel consumption data obtained in experiments and presented in Figure 3, it was observed an increase in fuel consumption with the addition of bioethanol in all testing conditions. Results for E5 were slightly similar comparing to gasoline and have not shown such rapid increase as E10.

Largest differences were observed during idling – increase by 0.53% for E5 compared to E0 and by 1.42% for E10 compared to E0 – and during operation in 50 km/h: increase by 0.55% for E5 compared to E0 and by 1.38% for E10 compared to E0. Increase of fuel consumption could be explained by lower heating value of each additional bioethanol-gasoline blend instead of gasoline.

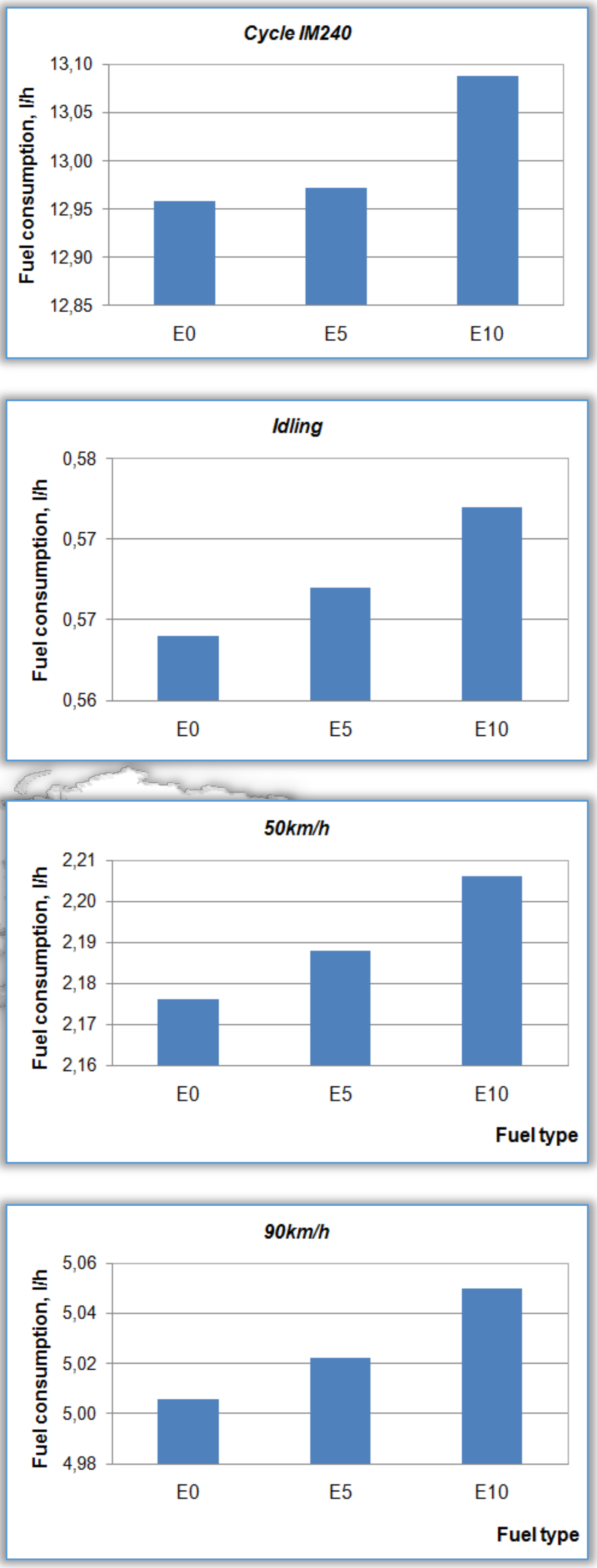

Figure 3 – Fuel consumption results
in different testing conditions

- **regulated emissions**

Positive effect of bioethanol addition firstly could be observed according to emission reduction due to its oxygen content, which favours the further improvement of gasoline combustion.

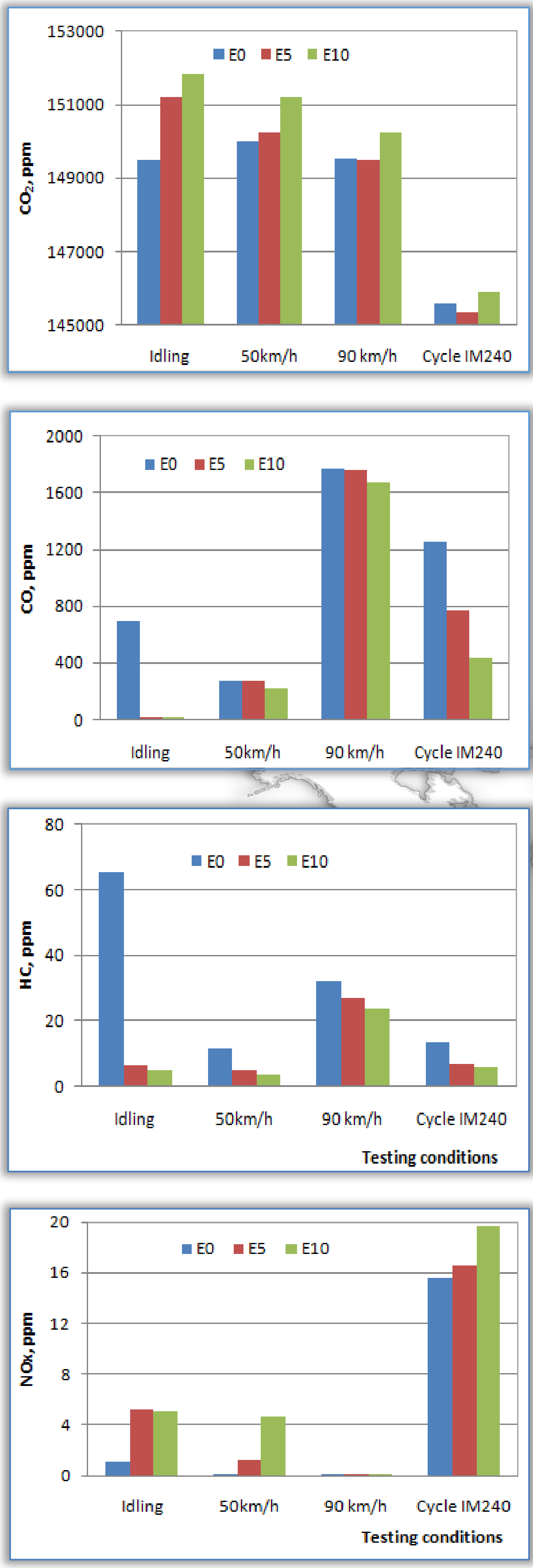

Figure 4 – Results of regulated emissions in different testing conditions

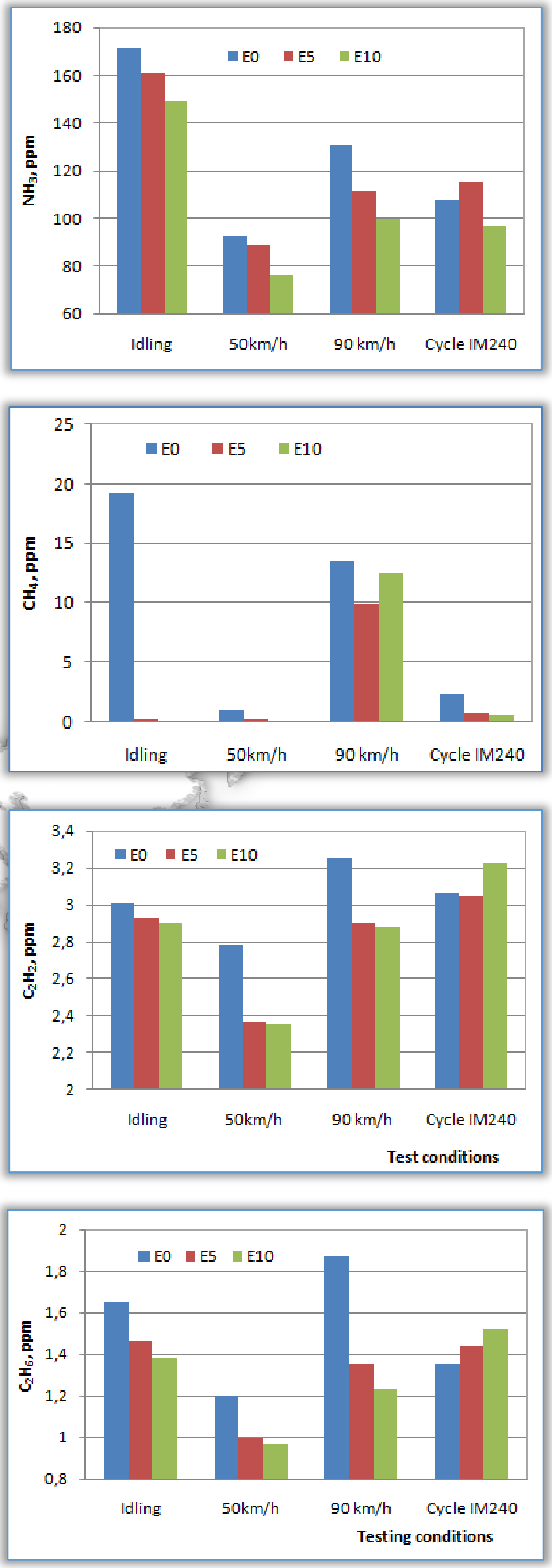

Figure 5 – Results of unregulated emissions in different testing conditions

This is observed also in current tests, where was found considerable decrease of CO and HC emissions in all testing conditions. Largest reduction of CO was observed in idling almost by 98% adding even 5% of bioethanol to gasoline. Largest values for almost all tested fuels were registered at 90 km/h, and, at the same time, impact of bioethanol addition was insignificant and results were similar to gasoline. The same situation was observed also with HC emissions showing reduction in all testing conditions.

Oxygen content in blends results with opposite effect on CO_2 emissions opposed to CO – slight increase of CO_2 was fixed for almost all testing conditions for E5 and E10 compared to E0. Largest increase of CO_2 was found for E10 in idling (by 1.55%). There was also observed increase of NO_x emissions for all mentioned fuels and testing conditions.

Largest increase was observed during idling and 50 km/h. Such increase in NO_x emissions could be explained by previously mentioned increase of the oxygen content in the blend resulted in increase in oxygen-to-fuel ratio in the fuel rich regions (Masum et al, 2013). This stimulates more complete combustion and increase of in-cylinder temperature, which affects increase of NO_x and decrease of HC. Additional factor is also higher flame speed of bioethanol, which also assists in completing combustion.

» **Unregulated emissions**

The addition of bioethanol has left a positive impact to unregulated emissions, like ammonia (NH_3), methane (CH_4), acetylene (C_2H_2) and ethane (C_2H_6). Figure 5 shows that all mentioned emissions decrease with the increasing bioethanol proportion in the fuel.

It is positive as ammonia is a toxic compound and a precursor in the formation of atmospheric secondary aerosols, classified under the European dangerous substances directive (67/548/EEC), and vehicles with internal combustion engines are considered as main source of NH_3 in the urban environment (Suarez-Bertoa et al., 2014). All other dominating hydrocarbons (methane, acetylene, ethan) presented in emissions showed great reduction for all blends.

CONCLUSIONS

The main objective of this experimental study was to analyze if the bioethanol addition of 5% and 10% into gasoline would have a positive effect on engine performance and emissions. The results showed positive tendency in bioethanol addition, but it also confirmed that E10 did not offer some essential advantages over the E5 in case of engine performance and regulated emissions.

Most promising results were observed according to unregulated emissions. Totally, it should be noted that only certain components showed good results in tests, which were done with one vehicle.

Further testing with larger number of vehicles is required, as also more detailed research in case of bioethanol-gasoline blends must be provided instead of ethanol-gasoline blends, as it emission profiles may differ in concentrations and types of emission products (Manzetti and Andersen, 2015).

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