

## REGULATED EMISSIONS FROM SPARK IGNITION ENGINE ADAPTED FOR USE OF E85 FUEL

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**Abstract.** Experimental study was conducted to test emissions of carbon monoxide (CO), unburned hydrocarbons (HC) and nitrogen oxides (NO<sub>x</sub>) using gasoline-ethanol blend (E85) as fuel in adapted regular gasoline automobile. The aim of the research was to assess capability of E85 adapted automobile to meet existing EC emission normative for regular inspection. The results were compared to emissions from use of regular gasoline. Automobile with production spark ignition engine was placed on roll type chassis dynamometer and tested at idle speed and two simulated driving modes – at 50 km·h<sup>-1</sup> and 90 km·h<sup>-1</sup>. Original engine control module was replaced with programmable one to adjust engine operating parameters for different test fuels and conditions. Exhaust gas composition was analysed using Fourier transform infrared spectrometer AVL SESAM. HC and NO<sub>x</sub> emissions were reduced when E85 fuel was used instead of gasoline. CO emissions were increased at idle speed but reduced at tested driving conditions when E85 fuel was used instead of gasoline. From test results, it can be concluded that regular gasoline automobile, adapted to be fuelled by E85, will meet EC emission normative if stoichiometric air/fuel ratio will be maintained.

**Keywords:** regulated exhaust emissions, biofuel, ethanol, air fuel mixture.

### Introduction

Fossil fuels, such as gasoline and diesel fuel, became dominating energy source in transportation vehicles during 20<sup>th</sup> century. Growing demand for energy has raised concerns about energy security due to limited accessible reserves of fossil crude oil, coal and natural gas [1]. Use of fossil fuel in internal combustion engines has caused pollution of environment with combustion products and additives. There is ongoing search for alternative products which might serve as fuels for internal combustion engine. Increasing use of bio-fuels is part of European strategy to replace fossil fuels [2]. Ethanol is long known as fuel for spark ignition engine. Its use as energy source is somewhat controversial. Ethanol is mostly made from agricultural products, such as wheat, corn and sugar cane. It may be considered as carbon dioxide emission neutral, as CO<sub>2</sub> is absorbed during growing of the crops and released again during use as the fuel. It may also contribute to rise of global food prices. Use of pure ethanol as spark ignition engine (SI) fuel is complicated due to cold start difficulties in temperature below 13 °C [3]. To improve cold start properties, blend of approximately 85 % anhydrous ethanol and 15 % gasoline, designated E85, is used in United States and Europe. In Latvia E85 is offered in 4 service stations [4, 5]. Use of E85 requires specially designed vehicles, known as Flexible Fuel Vehicles (FFV). FFV vehicle can be powered with E85 or regular gasoline, or mixture of those fuels at any ratio. Vehicles, built for use with gasoline, can be adapted for use with an alternative fuel, such as liquefied petrol gas (LPG), natural gas (CNG) or E85. Adapting of vehicle to another fuel is a complex task. Safety, reliability, performance and fuel economy of the adapted vehicle must be within acceptable limits. One of the aims of vehicle adapting is achieving required emission levels. Regulated tailpipe emissions from light passenger and commercial vehicles is defined in regulation EC 715/2007 of the European Parliament and of the Council [6]. In case of spark ignition engine, regulation defines limits of carbon monoxide (CO), non-methane hydrocarbons (NMHC), total hydrocarbons (THC) and nitrogen oxides (NO<sub>x</sub>) emissions. Emission content is specified for gasoline or LPG fuels [6]. If alternative fuel is being used, emission composition and ratio will be different and other harmful emission components may be released. Unburned ethanol emissions and some emissions which are forming during combustion of ethanol are not regulated. Only regulated emissions are addressed in this research.

Canacki et al. tested 1.4 L SI engine in vehicle on chassis dynamometer. They used steady state conditions at different speed and power points and tested dependence of various engine output parameters on amount of ethanol and methanol in gasoline. Pure gasoline was used as the reference fuel. Blends of gasoline with anhydrous ethanol and methanol in 5 % and 10 % (vol/vol) ratios were used as test fuels. Exhaust gas samples were taken upstream the catalytic converter. They found decrease of CO emissions using E5 and E10 fuel, comparing to pure gasoline, at lower speed range,

but increase of CO emissions on higher speed and lower power conditions. Significant decreasing trend of unburned HC emissions in all test conditions was reported. NO<sub>x</sub> emissions were decreased in all test conditions using E5 and E10 fuel, comparing to use of pure gasoline [7]. During testing air-fuel equivalence ratio ( $\lambda$ ) was not kept constant, and that could have an impact on emissions

Melo et al. tested 1.4 L SI Flex-Fuel engine on dynamometer. Original ECU was replaced by a programmable one, to allow specific engine calibration for each fuel and provide air-fuel ratio in wider range than stoichiometric. Mixture of gasoline with 25 % (vol/vol) anhydrous ethanol and 100 % hydrous ethanol was used as a reference fuels. Hydrous ethanol was blended with base fuel at volume ratio 30 %, 50 % and 80 %. Engine was tested in steady state conditions at fixed operating points. Ignition advance adjusted to maximal brake torque, output torque was kept at partial load 60 Nm and high load 105 Nm. At load 60 Nm, air-fuel equivalence ratio ( $\lambda$ ) was kept to 1, and at load 105 Nm,  $\lambda$  was set to 0.9. They reported reduction trend of CO in all tested conditions, except at stoichiometric air-fuel ratio and high engine speed at 3875 rpm, where no significant change was observed. Increase of ethanol content in fuel led to decrease of emission of HC at all testing conditions. Reduction of NO<sub>x</sub> with increase of ethanol content was observed only at stoichiometric air-fuel ratio and engine speed 1500 and 2250 rpm. Tests in other conditions returned mixed results on amount of NO<sub>x</sub>, with no distinctive trend [8].

Investigation of engine out emissions of 1.6 L SI engine fuelled with various alcohol/gasoline blends was conducted by Costagliola et al. Tests were performed at 9 steady state speed/load points, at stoichiometric air-fuel ratio and optimised ignition advance for each tested fuel. In all test conditions decrease of CO, HC and NO<sub>x</sub> emissions were observed with increase of ethanol content in fuel [2].

Most researchers agree on reduction of HC emission with increase of ethanol content in fuel. Results on CO and NO<sub>x</sub> emissions are somewhat controversial. Some results are obtained in rarely possible conditions, which normally does not occur in regular driving. To clarify this issue, authors of this research performed testing of conventional 1.2 L SI engine using commercially available fuels. Influence of E85 fuel comparing to regular gasoline on regulated engine emissions were investigated. The aim of the research were to evaluate capability of E85 adapted automobile to meet existing EC emission normative for regular inspection.

## Materials and methods

Commercially available fuels – gasoline (A95) of EN228 standard and biofuel E85 were used for testing. Main specifications of the engine and the vehicle are summarized in Table 1. Original engine control module Sirius 32 (ECU) was replaced by a programmable ECU VEMS V3. The original fuel injectors were replaced by the injectors with similar design but larger fuel flow to meet the requirements of E85 air/fuel ratio. The original oxygen sensor was replaced by a wideband sensor Bosch LSU 4.2 to ensure control over air/fuel ratio outside stoichiometric boundaries. The cooling fan was connected to the external power source to avoid fluctuations of the engine load.

Table 1

**Main specifications of test automobile**

Parameter	Value
Model	Renault Twingo
Date of production	30.04.2003
Engine	Type D7F 702, 4-cylinder 8-valve, 1149 cm <sup>3</sup>
Piston bore/stroke, mm	69.0/76.8
Volumetric compression ratio	9.65
Gearbox	Type JB1 517, 5-gear manual
Gear ratios	Final drive 3.866; 4th gear 0.966; 5th gear 0.820

Before testing in the laboratory, road tests were carried out to obtain engine load conditions for two typical driving modes: at 50 km·h<sup>-1</sup> and 90 km·h<sup>-1</sup>, steady driving on flat road. Load conditions were simulated in the laboratory on the roll type chassis dynamometer Mustang MD1750. Exhaust gas temperature (EGT) was measured in the engine exhaust manifold. Engine exhaust emission gas samples were taken before the catalytic converter and from the tailpipe. Composition of exhaust gas

was analysed with Fourier transform infrared spectrometer (FTIR) AVL SESAM. Constant wheel rotation speed was set by dynamometer controls. The throttle valve was fixed at the required engine load, to simulate road driving conditions. Tests at idle speed were also conducted.

AVL SEESAM analyser in applied setup provides simultaneous measurement of 31 gas component with sampling rate 1Hz. The resulting output is concentration timeline in volume unit share, parts per million (ppm). The results are not directly comparable to emission limits, defined EC directives. For that reason, results are compared between use of gasoline and E85 in similar load and speed conditions. Exhaust gas temperature was registered with ECU monitoring software VEMSTune.

Experimental setup is presented in Fig. 1.

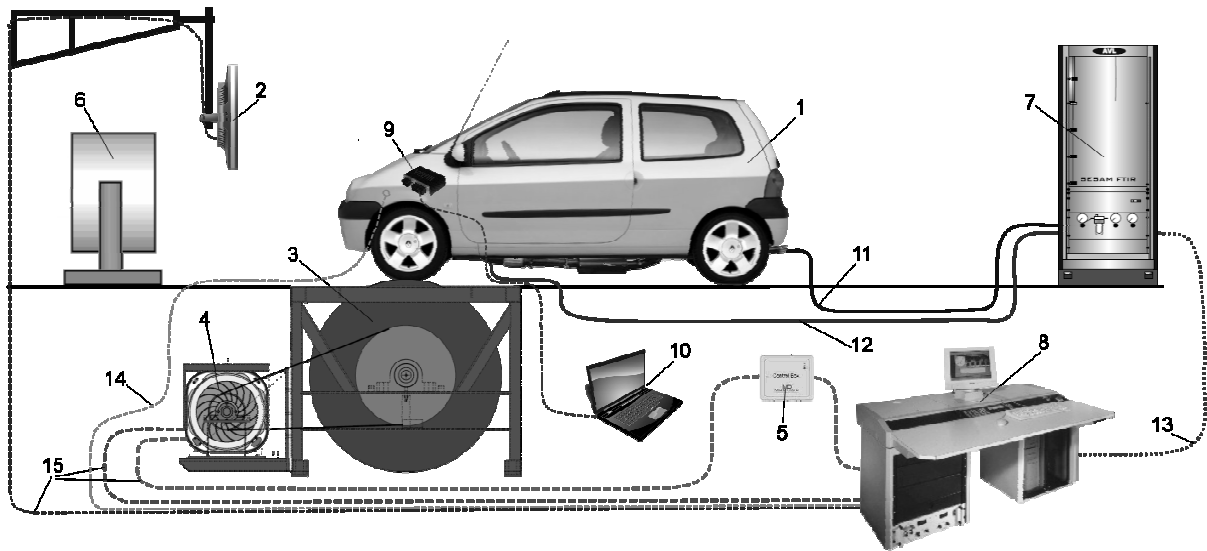


Fig. 1. **Experimental setup:** 1 – experimental car; 2 – test cycle simulation screen; 3 – chassis dynamometer Mustang MD-1750; 4 – power absorber unit (PAU); 5 – dynamometer control box; 6 – air blower; 7 – multicomponent exhaust gas measurement system AVL SESAM FTIR; 8 – Mustang chassis dyno control module & PC with special software AVL & data recording; 9 – programmable ECU VEMS V3; 10 – PC with special software VEMS Tune & data recording; 11 – heated gas line for exhaust gas measurement from the exhaust tailpipe ; 12 – heated gas line for exhaust gas measurement before the catalytic converter; 13 – AVL date communication cable; 14 – engine RPM sensor cable; 15 – Mustang dyno data communication cable & dyno control circuit & screen communication cable

Ignition advance was set at vehicle manufacturer's base values. Air/fuel ratio was set at three different equivalence ratio –  $\lambda$  (0.95; 1; 1.05). Detailed test conditions are listed in Table 2. Volumetric ratio of three exhaust gas components were measured and analysed -  $\text{NO}_x$ , CO and THC.

Table 2

Test conditions

Parameter	Settings 1	Settings 2	Settings 3
Driving speed, $\text{km}\cdot\text{h}^{-1}$	50	90	Idling
Engine rotation, $\text{min}^{-1}$	1859	2834	750
Gear	4th	5th	-
Wheel brake torque, N·m	23.50	39.60	-
Wheel brake power, kW	4.57	11.74	-
Ignition timing advance, nominal setting, degrees CA BTDC	31.5	31.0	5.0
Air/fuel equivalence ratio, $\lambda$	0.95; 1; 1.05		

The vehicle was driven on the chassis dynamometer in selected conditions for 340 seconds before actual measuring started. Following stabilization period the gas sampling lasted 40 seconds.

Arithmetic mean of 5 repeated valid test results was used for further analysis. Confidence intervals were calculated for 95% confidence level.

## Results and discussion

Directive 2010/48/EU requires that this particular testing automobile meets following tailpipe emission norms during scheduled mandatory inspection – CO – max 0.3 % and HC – max 100 ppm at idle speed. Engine management system ensures stoichiometric air/fuel ratio at idle speed.

Results of the emission gas testing at idle speed are presented in Figure 2. Volumetric ratio of CO does exceed maximal value limited by directive 2010/48/EU, using both test fuels, except the conditions with fuel rich air/fuel ratio ( $\lambda$  0.95). Using E85 fuel, CO emission at idle speed is increased. CO is not direct component of the fuel but rather product of combustion reaction chain. Higher temperature in combustion chamber contributes to oxidation of CO to CO<sub>2</sub> [9]. Use of E85 might decrease combustion temperature due to higher latent heat of evaporation of ethanol.

Total HC emissions at idle speed exceed regulatory values. Emissions were reduced when engine ran with E85 fuel. Increased HC emissions can be linked to higher flow injectors, which operate in unfavourable conditions when short opening time is required. Results obtained with spectroscopic analysis, which is used in this study, are not directly comparable to the results, obtained by flame ionization detector (FID), the recommended tool for the certification.

Emissions of NO<sub>x</sub> at idle speed are not being specified by directive 2010/48/EU. Use of E85 reduced amount of NO<sub>x</sub> emissions when E85 was instead of fossil fuel, at air/fuel equivalence ratio  $\lambda$  set at 0.95 and 1.

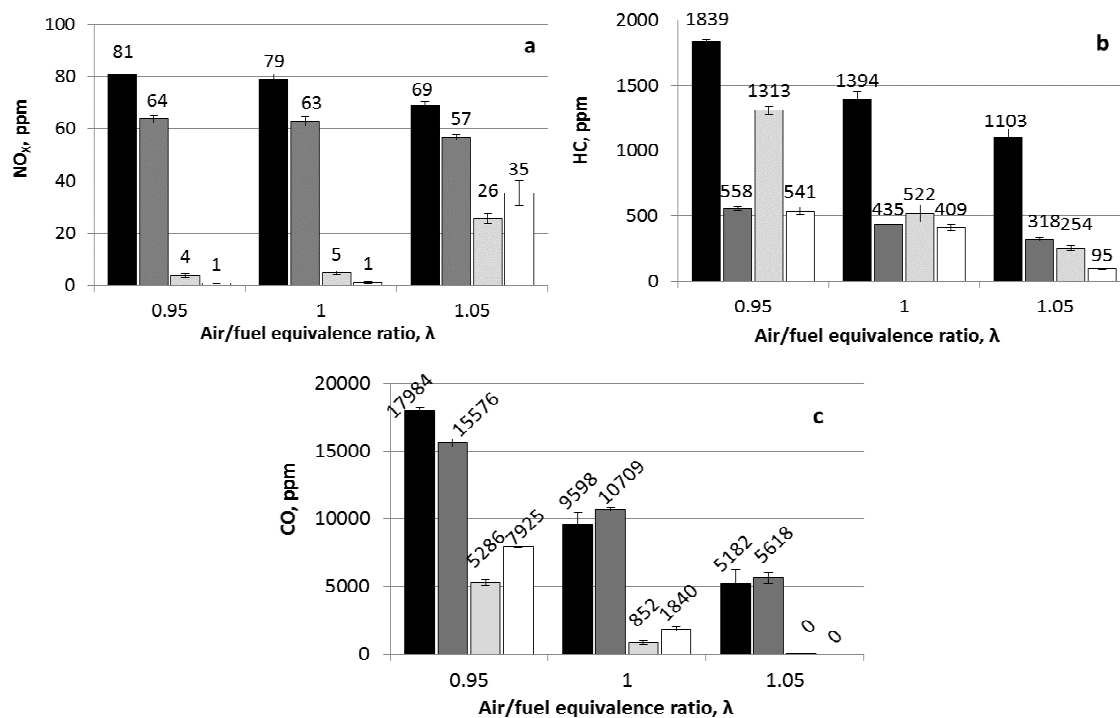


Fig. 2. Exhaust gases concentration at idling: a – NO<sub>x</sub>; b – HC; c – CO;  
 ■ – A95 engine-out; ■ – E85 engine-out; ■ – A95 tailpipe; □ – E85 tailpipe

Temperature of exhaust gases was lower by approximately 4 % when E85 was used instead of gasoline. Causes and effects for this outcome are explained in further text.

Overall trend of variations of regulated emissions is related in both tested driving modes. (50 km·h<sup>-1</sup> and 90 km·h<sup>-1</sup>). Amount of NO<sub>x</sub> engine-out emissions is reduced up to 11 % using E85 fuel, comparing to gasoline use. By adding alcohol in gasoline, the combustion temperature is decreased due to high latent heat of evaporation, lower heating value and oxygen content. This leads to the reduction in NO<sub>x</sub> emissions [7].

Engine-out emissions of  $\text{NO}_x$  increased with leaning of fuel/air mixture using both fuels. Sharp increase of  $\text{NO}_x$  tailpipe emissions were noticed when mixture was leaner than stoichiometric. Unfavourable conditions in catalytic converter was the main attributor of increased  $\text{NO}_x$  emissions. Operation of the engine with lean mixture is not advised regarding reduction of  $\text{NO}_x$  emissions. Results of the emission gas testing at driving simulation are presented in Fig. 3.

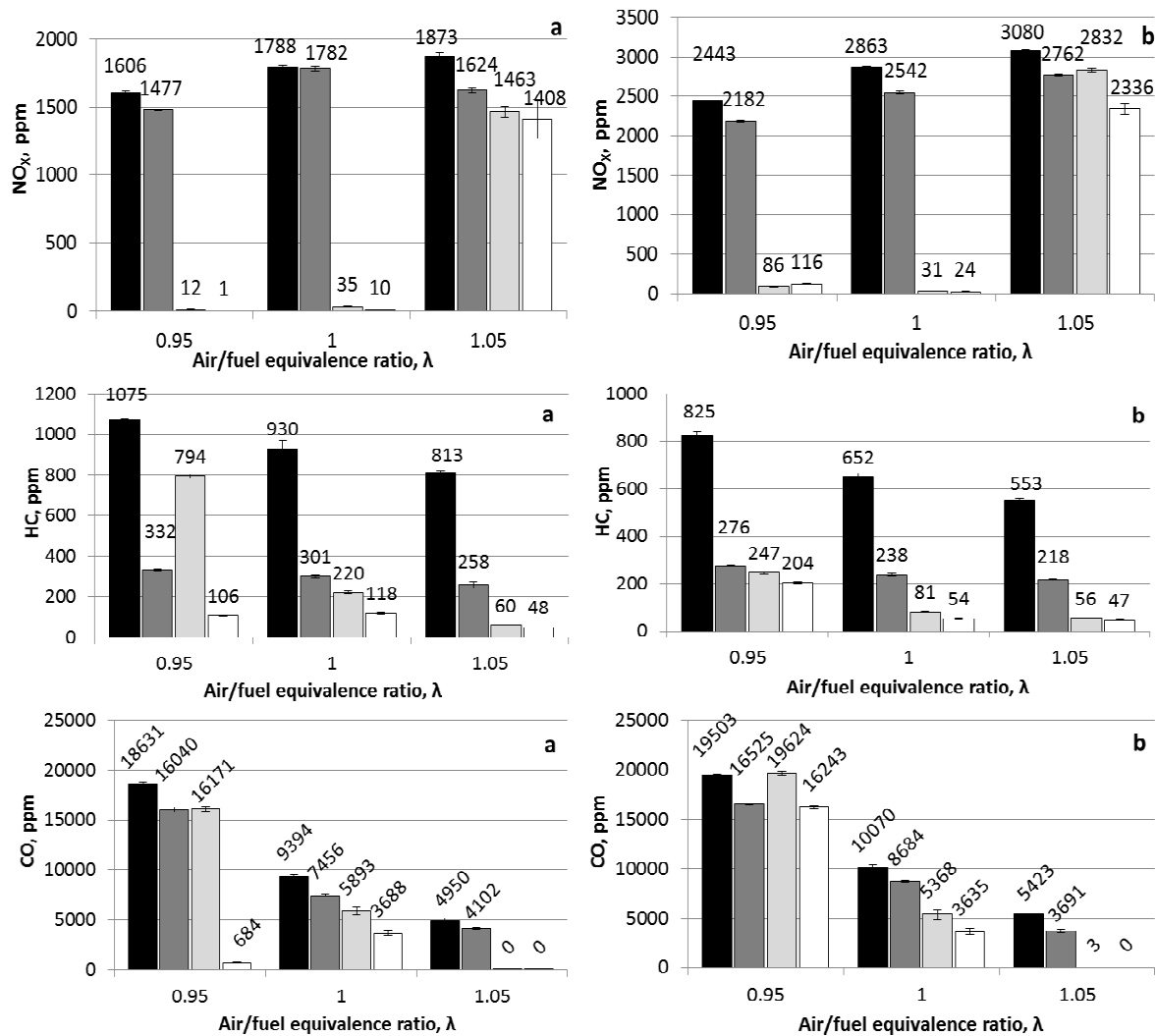


Fig. 3. Regulated engine emissions: a – 50 km h<sup>-1</sup>; b – 90 km h<sup>-1</sup>;

■ – A95 engine-out; ■ – E85 engine-out; ■ – A95 tailpipe; □ – E85 tailpipe

Engine-out emissions of unburned hydrocarbons were reduced by 63 - 69 % when E85 was used, comparing to gasoline use. The same trend was noted analysing tailpipe emissions. Burning of ethanol, which is the main component in E85, produces significantly less products, which are categorised as hydrocarbons. The oxygen content in the fuel is one of the attributors of this outcome. Therefore, from the point of regulated HC emissions, use of E85 results in reduced emissions. Leaning of air/fuel mixture had notable effect on reduction of HC emissions. Additional amount of oxygen is attributor to more complete combustion.

Emissions of CO, among other factors, are depended on air/fuel ratio and temperature of combustion. Unstable ratio of CO emission were found at rich air/fuel mixtures. At close to stoichiometric air/fuel ratio CO emissions were reduced when E85 fuel was used. It is opposite to what was found at idle speed emissions. It can be explained by higher combustion temperature at tested driving conditions comparing to idle speed conditions. Sufficiently high combustion temperature and more oxygen in E85 comparing to gasoline supports oxidation of CO to CO<sub>2</sub>.

## Conclusions

1. Leaning of air/fuel mixture using E85 fuel reduced emissions of CO and HC and increased NO<sub>x</sub> emissions.
2. HC and NO<sub>x</sub> emissions were reduced when E85 fuel was used instead of gasoline.
3. CO emissions were increased at idle speed but reduced at tested driving conditions when E85 fuel was used instead of gasoline.
4. Temperature of exhaust gases was lower by approximately 4 % when E85 was used instead of gasoline.
5. To meet EC emissions standards, stoichiometric air/fuel ratio must be ensured when adapting gasoline-fuelled automobile to use E85 fuel.

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