EMISSION REDUCTION POTENTIAL OF USING BIOFUELS

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Abstract. One of the primary reasons for expanding the production and use of biofuels is the potential environmental benefit that can be obtained from replacing fossil fuels with fuels derived from renewable biomass resources. This investigation examines the impact of biofuels on the environment directly from the practical view point analysing how the internal combustion engine emission concentration changes using the most common first-generation biofuels in Latvia – biodiesel, rapeseed oil and bioethanol. Laboratory experiments were performed on a chassis dynamometer *Mustang MD1750*, but the content of exhaust gases components was determined by the *AVL SESAM FTIR* measurement system. Investigation shows that the trends of different exhaust gas component changes, which would be the same for all investigated fuels, don't exist, i.e., each vehicle and biofuel type or blend is particular and has to be analysed separately. In comparison with fossil diesel, running the car *VW Golf* on rapeseed oil the average reduction of NO_x was 10%, but SO_2 – 59%. The CO, CO_2, unburned hydrocarbon and mechanical particle emissions were higher. Running the car *Opel Vectra* on biodiesel the amount of NO_x in comparison with fossil diesel increased in average by about 12%, the amount of mechanical particles and unburned hydrocarbons decreased quite significantly, but just a small increase of CO and SO_2 was observed. Testing the car *VW Passat* on gasoline-bioethanol blends increase of the bioethanol content in the fuel blend increased also the NO_x content in exhaust gases, but the content of CO, CO_2 and NH_3 decreased.

Key words: biofuels, biodiesel, rapeseed oil, bioethanol, exhaust emissions.

Introduction

Liquid biofuels made from biomass are attracting increasing interest worldwide. The major drivers of biofuel development are changes in world oil prices, care about energy security, and concerns about climate change from greenhouse gas (GHG) emissions, caused primarily by the burning of fossil fuels. For developing countries the production of biofuels is also the way to stimulate rural development, create work places, and save foreign currency. Transportation, including emissions from the production of transport fuels is responsible for about 27% of total energy-related GHG emissions in the USA (including 42% of carbon dioxide emissions) and 28% of total emissions in the European Union (EU) (Biofuels for Transport..., 2007).

For petroleum products, such as gasoline and diesel, a life-cycle analysis of the climate impact includes all GHG emissions associated with the production, transportation, refining, storage, distribution and retail of oil; the fuelling of a vehicle; and the evaporative and exhaust emissions using the fuel in a vehicle. For biofuels, the stages to be considered include the planting and harvesting of crops; processing the raw materials into biofuel; transporting the raw materials and the final fuel; storing, distributing and retailing biofuel; and, finally, the impacts of fuelling a vehicle and the evaporative and exhaust emissions resulting from combustion.

The climate impact of biofuels depends mainly on their fossil energy balance, i.e., how much energy the biofuels contain versus how much fossil fuel energy was required to produce them. In opposition to fossil fuels, which contain carbon stored beneath the Earth's surface, biofuels have the potential to be 'carbon neutral'. This is because biofuels are produced from biomass, and exactly the same amount of carbon dioxide (CO_2) that is absorbed from the atmosphere by the plants through photosynthesis is emitted during combustion. As an example the research carried out in Denmark can be mentioned. The research results show that rapeseed oil fuel has strongly positive energy balance and rapeseed oil is genuinely CO_2 neutral because the rape straw alone gives a CO_2 saving which by far exceeds the total CO_2 emission from cultivation and processing (Bugge, 2000).

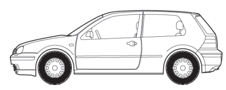
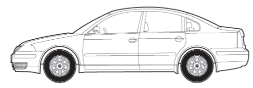
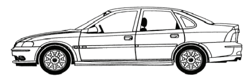
With the exception of a few investigations that report associated increases in GHG emissions, most studies find a significant reduction in global warming emissions from biofuels relatively to conventional transport fuels. Ethanol has the greatest air-quality benefits where vehicle fleets are old, as is often the case in developing countries. It helps to reduce the exhaust emissions of carbon monoxide and hydrocarbons, especially in cold climates. Biodiesel reduces emissions of carbon monoxide, hydrocarbons, and particulate matter, but can slightly increase emissions of nitrogen oxides (Kojima and Johnson, 2006).

However, figures vary widely due to differing assumptions about factors such as assumptions about the feedstock used, crop management (including use of fertiliser and tilling of soil), crop yields, the relative efficiencies of gasoline and ethanol (diesel and biodiesel, including blends, have about the same vehicle efficiency), and the methodologies used to calculate total life-cycle emissions. Most studies consider emissions of CO_2, nitrous oxide (N_2O) and methane, but many omit other components of exhaust gases.

This investigation examines the impact of biofuels on the environment directly from the practical viewpoint analysing how the internal combustion engine emission concentration changes using the most common first-generation biofuels in Latvia – biodiesel

Table 1

The main technical data of experiment objects

Vehicle	**VW Golf** 	**VW Passat** 	**Opel Vectra** 
Year of manufacture	1992	1997	1998
Engine characteristics	Diesel engine, capacity – 1896cc, turbo diesel, output power – 55 kW at 4200 rpm	Otto engine, capacity – 1781cc, 20 valves, output power – 92 kW at 5800 rpm	Diesel engine, capacity – 1994cc, turbo diesel, output power – 60 kW at 4300 rpm
Fuel system	Modified for use of rapeseed oil	Standard fuel system, lambda – closed loop control	Standard diesel fuel system, Bosch VP44 injection pump
Used fuels	Fossil diesel, rapeseed oil	Fuel mixtures from A95(E0) to E85	Fossil diesel, biodiesel
Test modes	Idling; constant speeds – 50, 90, 110 km^{-1}; cycles – IM240 and 'Jelgava'		

(rapeseed methyl ester), rapeseed oil and bioethanol. The actuality of use of these biofuels confirms also the results of European Commission supported project 'Clean Views on Clean Fuels', that conventional biofuels – straight vegetable oil (SVO), biodiesel and bioethanol remain the lowest cost options until 2020 with a gradually increasing market share for future biofuels based on lignocelluloses (Wakker et al., 2005).

Materials and Methods

As three different biofuels has been studied, three different cars were chosen for experiments. The first of them is *VW Golf* equipped with a 1.9-liter diesel engine, the second one – *VW Passat* with a 1.8-liter spark ignition engine, but the third – *Opel Vectra* with the 2.0-liter diesel engine. The main technical data of experiment objects as well as used fuels and test modes are given in the Table 1.

The choice of experiment objects is based on the fact that these models represent some of the most popular cars in Latvia in both – diesel and spark ignition engine classes. Besides that selected automotive engines are wide spread not only in specific cars, but also in other car brands and models.

The *VW Passat*, which is being used for the investigation of bioethanol fuel mixture use, is equipped with a standard Otto engine without any rebuilding or adaptation for biofuel use. Electronic engine management system based on a closed lambda loop control provides certain mixture enrichment, increasing the ethanol concentration in ethanol-gasoline fuel blend.

The *VW Golf* is equipped with a standard diesel engine, but is adapted to run on rapeseed oil. The car was modified using *ELSBETT* one-tank conversion kit at the Scientific Laboratory of Biofuels (Latvia University of Agriculture) during recent investigations (Dukulis et al., 2009a).

Laboratory experiments were performed on a chassis dynamometer *Mustang MD1750*, but the content of the exhaust gases components was determined by the *AVL SESAM FTIR* multicomponent exhaust gas measurement system. The main technical data of used equipment are given in the Table 2.

Experiments were carried out based on the experimental methodology developed by the authors (Dukulis et al., 2009b), which estimates the duration on each experiment, repetition times, methods of data processing and evaluation etc. The test modes used in

Table 2

The main technical data of used equipment

Measurement equipment	**Chassis dynamometer**	**Emission measurement system**
Model	*Mustang MD1750*	*AVL SESAM FTIR*
Measuring characteristics	Maximum measurement capability – 1287 kW; peak absorption – 294 kW; maximum measurement speed – 362 km h^{-1}; maximum axle weight – 4535 kg	Measurable components: up to 25 gases (CO_2, CO, H_2O, SO_2, NO, NO_2, N_2O, NH_3, CH_4, C_2H_4 etc.); response time – 1 second; measurement method – optical

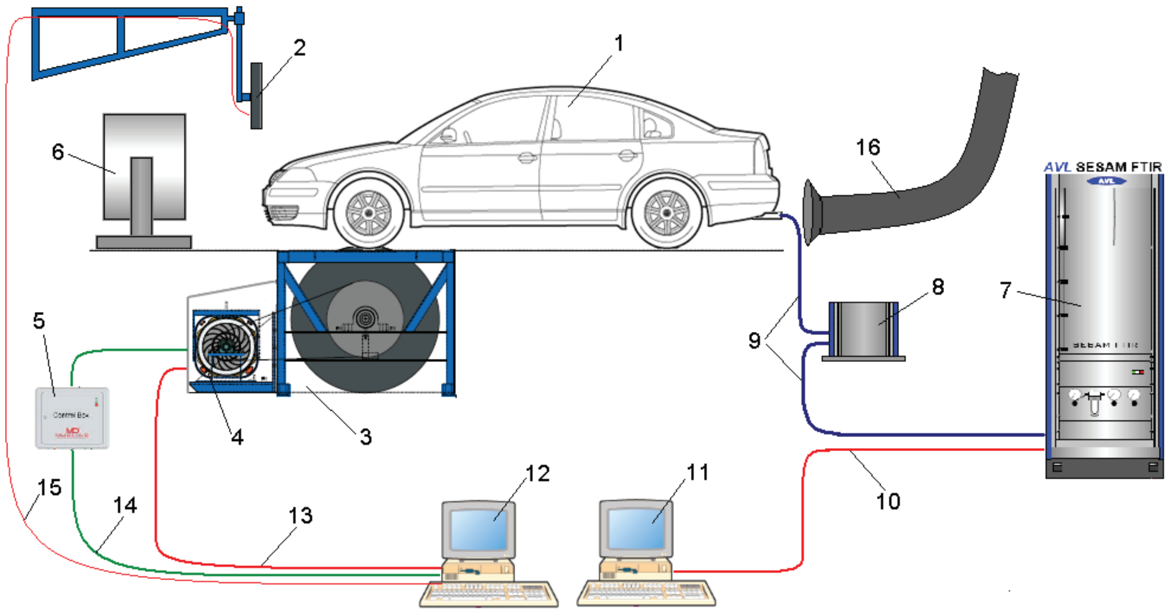


Figure 1. Block diagram for the emission test routines: 1 – tested car; 2 – simulation screen; 3 – chassis dynamometer *Mustang MD-1750*; 4 – power absorber unit; 5 – dynamometer control box; 6 – air blower; 7 – multicomponent exhaust gas measurement system *AVL SESAM FTIR*; 8 – heated filter; 9 – heated gas line; 10 – AVL date communication cable; 11 – PC with special AVL software; 12 – Mustang chassis dyno control and data recording PC; 13 – dyno date communication cable; 14 – dyno control circuit; 15 – screen communication cable; 16 – exhaust extraction pipe.

these tests were: idling; driving at constant speeds of 50, 90 and 110 km h^{-1}; cycles – IM240 and 'Jelgava'. The IM240 cycle is a chassis dynamometer schedule used for emission testing of in-use light duty vehicles in inspection and maintenance programs implemented in a number of countries. It is a short, 240 second test representing a 3.1 km route with an average speed of 47.3 km h^{-1} and a maximum speed of 91.2 km h^{-1}. The 'Jelgava' cycle is a driving schedule that represents the real driving conditions in the city Jelgava (360 seconds, 2.3 km, average speed – 23.3 km h^{-1}, maximum speed – 50.0 km h^{-1}) and is developed at the Scientific Laboratory of Biofuels (Dukulis and Pirs, 2009c).

For comparison of exhaust emission content fossil diesel fuel, A95 gasoline, biodiesel, rapeseed oil and bioethanol blend with gasoline were used in these experiments. The block diagram for the emission test routines is shown in Figure 1.

Results and Discussion

Measurements at constant regimes were performed for 60 seconds with the reading step of 1 second (for driving cycles accordingly to the cycle duration). Three repetitions were made in each testing mode. The content of all 25 exhaust gas components was fixed but more detailed analysis was done only for the most essential emission components for each fuel type, i.e., for diesel, biodiesel and rapeseed oil – total nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbons (HCDiesel), sulphur dioxide (SO_2) and mechanical particles (MP), but for gasoline and bioethanol blend with gasoline – NO_x, CO, CO_2, ammonia (NH_3) and unburned hydrocarbons (HCGasoline).

Figure 2 shows exhaust emission comparison performing *VW Golf* simulation tests using rapeseed oil and fossil diesel fuel, but Figure 3 – *Opel Vectra* simulation test results using biodiesel and fossil diesel fuel.

In comparison with fossil diesel, running on rapeseed oil the average reduction of NO_x was 10% and decrease of NO_x was observed in all driving modes. The amount of SO_2 in exhaust gases was also lower by an average of 59%. The CO, CO_2, unburned hydrocarbon and mechanical particle emissions were higher with pure rapeseed oil fuel comparing with fossil diesel fuel. If CO_2 increase (compared to fossil diesel fuel by an average of 5%) is irrelevant, because the plants (in this case, rape) take it back from the atmosphere and consume in growth process providing a neutral carbon balance, then the mechanical particle amount, compared to fossil diesel fuel, increased approximately 2.7 times, CO – 1.2 times, but the unburned hydrocarbons – 1.8 times. The injection timing in these tests was set as it is required by the vehicle specification for fossil diesel, i.e., 10.5°. As more detailed investigations of rapeseed oil and one-tank system usage (Dukulis et al., 2010) show, the content of different exhaust gas components can be improved by changing the ignition timing. For example, the optimal injection timing, running the car *VW Golf 1.9TD* on rapeseed oil fuel is 18.5°, because there is the power and torque peak, the

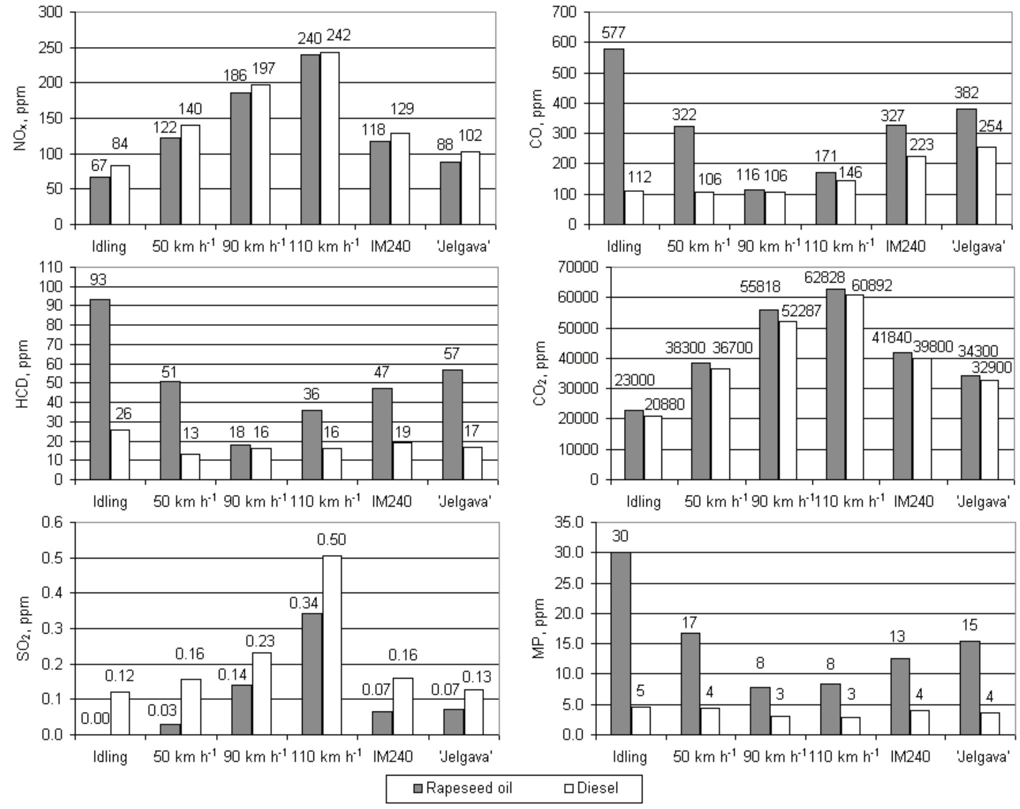


Figure 2. Exhaust emission comparison performing *VW Golf* simulation tests.

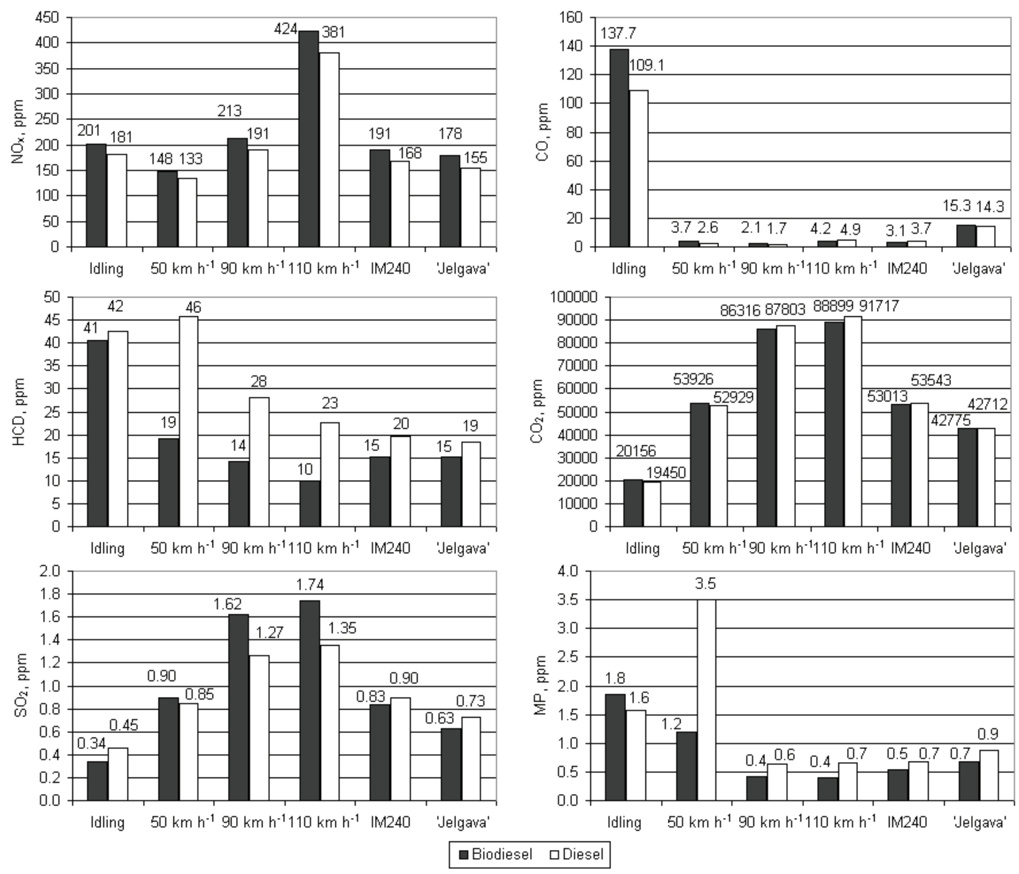


Figure 3. Exhaust emission comparison performing *Opel Vectra* simulation tests.

minimum CO content in exhaust gases (reduced about 35% comparing with the 10.5° injection timing), significantly reduced unburned hydrocarbon (66%) and mechanical particle (68%) content.

Running on biodiesel in all driving modes the amount of NO_x in comparison with fossil diesel was increased (in average by about 12%), but as the analysis of other investigations show, the increase of NO_x is unavoidable disadvantage of biodiesel fuel use. Using biodiesel quite significantly (compared to fossil diesel fuel by an average of 30%), the amount of mechanical particles and unburned hydrocarbons was decreased. The content of CO_2 in exhaust gases stayed approximately the same, but a small increase of CO and SO_2 was observed. It should be noted that the change tendencies in different test modes slightly varied, for example, in idling the amount of mechanical particles using biodiesel in comparison with fossil diesel was higher, but in all driving modes – lower.

Figure 4 shows exhaust emission comparison performing *VW Passat* simulation tests using fossil gasoline A95 and gasoline-bioethanol blends. Mixing the corresponding proportions the following experimental fuel blends were used: A95 or E0 (pure gasoline), E10, E20, E30, E40, E50 and E85.

Analyses of the obtained measurement results show that increasing the bioethanol content in the fuel blend in all test modes except idling increase NO_x content in exhaust gases. The most significant increase of NO_x is in driving cycle modes, when a load and speed are variable. Conversely the content of CO, CO_2 and NH_3 decreases increasing the ethanol content of the fuel mixture. When using E85 fuel, the CO content in exhaust gases at variable load and speed modes reduces significantly, and its value is close to 0. Also the reduction of CO_2, which is the key component of greenhouse effect, is very important. So, for example, performing IM240 and 'Jelgava' cycle imitations the reduction of CO_2 compared to fossil fuel is about 3% using E50, and about 9% using E85 fuel.

Total unburned hydrocarbon emissions for a particular car at all test modes and using different fuels are relatively small, and their changes at different ethanol concentrations are not clearly identifiable.

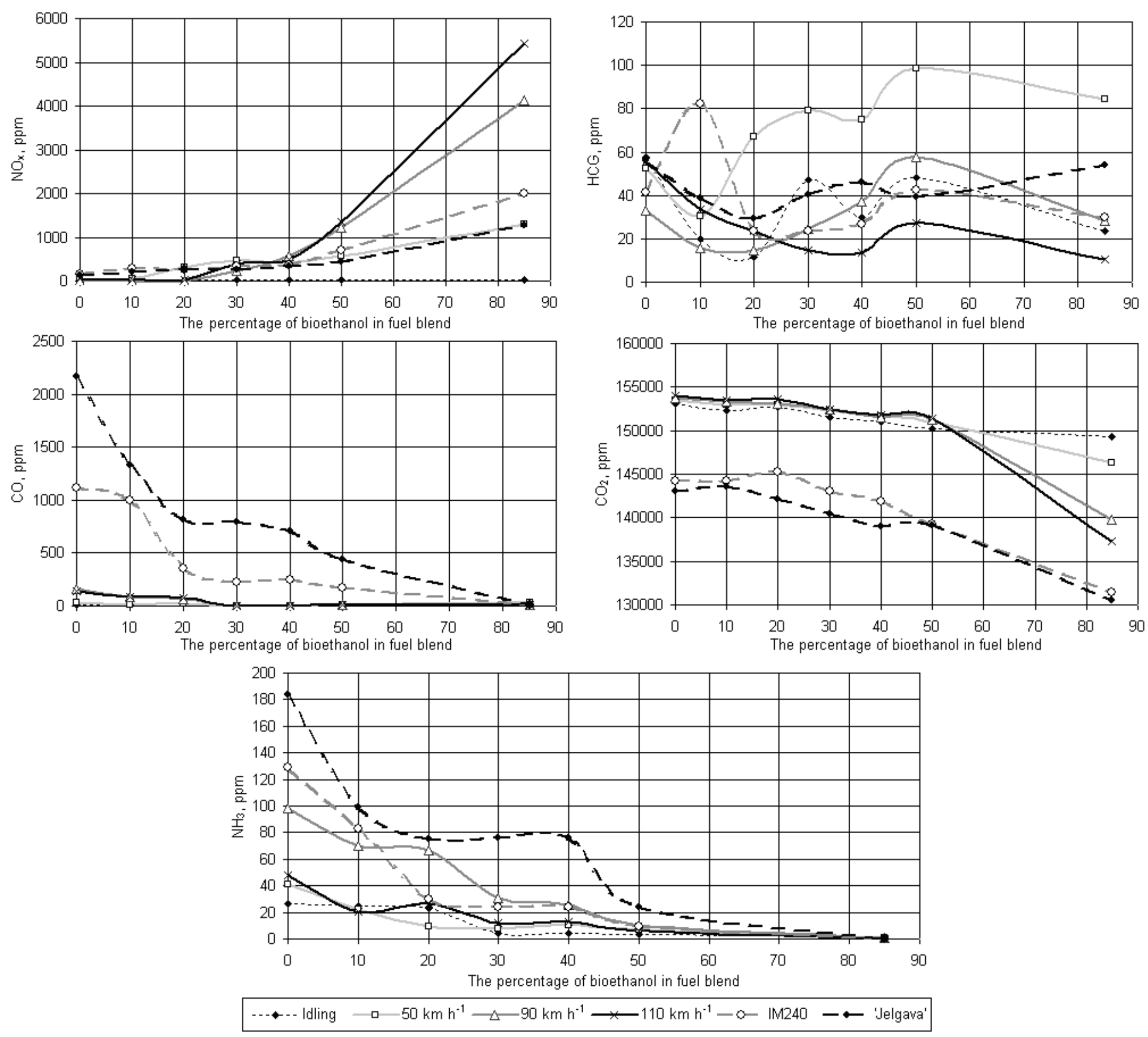


Figure 4. Exhaust emission comparison performing *VW Passat* simulation tests.

Conclusions

1. Investigation of the use of the most common first-generation biofuels in Latvia – biodiesel, rapeseed oil and bioethanol – show that the trends of different exhaust gas component changes, which would be the same for all investigated fuels, don't exist, i.e., each vehicle and biofuel type or blend is particular and has to be analysed separately.
2. In comparison with fossil diesel, running the car *VW Golf 1.9TD* on rapeseed oil the average reduction of NO_x was 10%. The amount of SO_2 in exhaust gases was also lower by an average of 59%. The CO, CO_2, unburned hydrocarbon and mechanical particle emissions were higher with pure rapeseed oil fuel compared to fossil diesel fuel.
3. Running the car *Opel Vectra* on biodiesel, the amount of NO_x in comparison with fossil diesel increased on average by about 12%. Using biodiesel, the amount of mechanical particles and unburned hydrocarbons decreased quite significantly. The content of CO_2 in exhaust gases stayed approximately the same, but a small increase of CO and SO_2 was observed.
4. Running the car *VW Passat* on gasoline-bioethanol blends and increasing the bioethanol content in the fuel blend in all test modes except idling, also increased the NO_x content in exhaust gases. The content of CO, CO_2 and NH_3 was decreased.
5. Since not all the contents of harmful components using biofuels decrease, to evaluate the effectiveness of their use, more detailed studies of engine construction, regulation and conversion kit impact on exhaust gases have to be carried out. To perform the complete fossil fuel and biofuel life-cycle analysis in further studies, it would be useful to evaluate detailed exhaust emissions during biofuel production corresponding to peculiarities of Latvia.

Acknowledgements

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