Fuel Consumption Studies of Spark Ignition Engine Using Blends of Gasoline with Bioethanol

V. Pirs, D. Berjoza, G. Birzietis, and I. Dukulis

Motor Vehicle Institute, Faculty of Engineering, Latvia University of Agriculture,
5 J. Cakstes boulv., Jelgava, LV-3001, Latvia; e-mail: vilnis.pirs@llu.lv;
dainis.berjoza@llu.lv; gints.birzietis@llu.lv; ilmars.dukulis@llu.lv

Abstract. The increased oxygen content in blends of gasoline with bioethanol causes the necessity for increasing fuel supply to the engine. Car oxygen sensor, reacting to the presence of oxygen in the exhaust gases, increases the amount of injected fuel. Consequently, the higher concentration of bioethanol in fuel blends usually also increases fuel consumption. This study explores how an increase in bioethanol concentration in fuel blends affects the standard car's fuel consumption and determines which elements of the system limit the maximum possible concentration of bioethanol in the blend with gasoline.

Key words: bioethanol, fuel consumption, air-fuel ratio, spark-ignition engine

INTRODUCTION

The decrease of fossil fuel stocks and the increase in their prices, as well as climate change, requires scientists to devote more attention to renewable energy sources and their application researches. Bioethanol (C_2H_5OH) is one of the renewable forms of energy that is produced from biomass. Cereals, corn, sugar beet and sugar cane, potatoes, wood, etc. could be used as raw material for ethanol production. One of the main applications of bioethanol in vehicles is its use as a fuel for Otto engines. There is a number of ways in which bioethanol or its blend with gasoline can be used:

- use of pure bioethanol or with special additives without fossil fuel presence (an example of Brazil, where most vehicles use unhydrated bioethanol with 4% water content);
- use of ethanol-gasoline fuel mixtures with high ethanol content (up to E85) in Flexible Fuel Vehicles (FFV) or adapted gasoline engine cars designed specifically for this purpose;
- use of ethanol-gasoline fuel mixtures with low ethanol content (up to E20) in non-adapted cars. As mentioned in F. Yüksel & B. Yüksel investigations (2004), gasoline-ethanol mixtures, which contain up to 20% ethanol by volume, can be safely used without causing any damage to the engine.

The physical and chemical properties of bioethanol are different from the fossil fuel properties; therefore its use in Otto engines also differs. Ethanol will corrode mechanical components, especially those made of copper, brass and aluminium due to the water solubility in bioethanol (Wu et al., 2004). The lowest calorific value of bioethanol is about one third less than the calorific value of gasoline, so for the engine to develop the same power as when using gasoline, it is necessary to supply about one third more fuel. But on the other hand, bioethanol has better anti-knock properties. In different studies an octane number of ethanol is mentioned in the range of 106 to 111, but the gasoline octane number, depending on the brand is from 88 to 100 (RON). The better anti-knock properties of ethanol allow increasing engine compression ratio, thereby increasing engine efficiency and reducing fuel consumption. From the view point of the combustion nature, the self-ignition temperature and flash point of bioethanol are higher than those of gasoline, which make it safer for transportation and storage (Yüksel & Yüksel, 2004). These and many other properties of biofuel alter Otto engine operating characteristics. The higher the ethanol content in used ethanol-gasoline blend, the more engine construction changes and regulations are needed.

One of the most important automotive exploitation characteristics, which is of interest for every driver is fuel consumption. A lot of different studies on ethanol-gasoline fuel mixture use and their impact on the environment worldwide are being carried out. Most of them are related to fuel consumption either at constant engine speed modes, or modes, which do not reflect the use of the car in real road conditions.

This investigation was conducted to determine fuel consumption and other parameters of the car, simulating real motion modes on a chassis dynamometer, using a standard non-customized car and fuels A95 (E0), E10, E20, E30, E40, E50 and E85. For comparison the studies performed by M. Koç et al. (2009) can be mentioned. The effect of ethanol-unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine was determined. Specific fuel consumption of a single-cylinder four-stroke spark ignition engine at different compression ratios (10:1 and 11:1) at the engine speed range from 1,500 to 5,000 rpm was analyzed. The used fuels in this study were E0, E50 and E85. The results show that the average specific fuel consumption at 10:1 compression ratio for E50 and E85 fuels, in comparison with the E0 fuel, was increased by 20.3% and 45.6% respectively. At the compression ratio of 11:1 the increase was 16.1% and 36.4% respectively. It means that specific fuel consumption mainly depends on the percentage of ethanol in ethanol-gasoline fuel mixture. To reduce fuel consumption using high ethanol content blends, it is necessary to increase the engine compression ratio.

MATERIALS AND METHODS

Experiments were carried out using the standard 1.8 litre spark ignition engine car VW Passat. The main car and engine technical data are given in Table 1.

Table 1. The technical characteristic of the experiment object

Model	VW Passat
Production year	1997
Engine	4-cylinder 20-valve SI 1781 cc engine
Compression ratio	10.3
Fuel & ignition system	Bosch Motronic M3.8.2

Engine power, kW (Hp)	92 (125)
Engine control	Closed-loop control
Gearbox	5-gear manual

Fuel consumption measurements were carried out by running the car on the chassis dynamometer Mustang MD-1750 in the following modes: idle running, at a constant speed of 50 km h^{-1} in 4th gear, at constant speeds of 90 km h^{-1} and 110 km h^{-1} and in 5th gear, as well as in the IM-240 cycle mode and a specially developed urban traffic cycle, which corresponds to the real driving conditions of the Latvian city Jelgava (Dukulis & Pirs, 2009). The high-precision system AVL KMA Mobile was used as the fuel consumption measurement device. Its main technical data are given in Table 2 (AVL KMA Mobile Fuel Consumption Measuring System, 2008).

Table 2. AVL KMA Mobile technical characteristic

Parameter	Unit	Value
Measuring range	l h^{-1}	0.35–150
Fuel density range	g cm^3	0.5–2
Measuring error	%	0.1

Statoil A95 gasoline and bioethanol produced at Jaunpagasts Plus Ltd. Company were used as fuels for these experiments. By mixing the corresponding proportions the following experimental fuel blends were obtained: A95 or E0 (pure gasoline), E10, E20, E30, E40, E50 and E85.

In addition to fuel consumption, air fuel ratio (AFR) according to the oxygen sensor data as well as exhaust gas temperature (EGT) (approximately 200 mm from the exhaust valves) was measured. The measuring devices for these data are included as optional units in dynamometer, and the data values are recorded into the bench control platform software. The block diagram of measuring system is shown in Fig. 1.

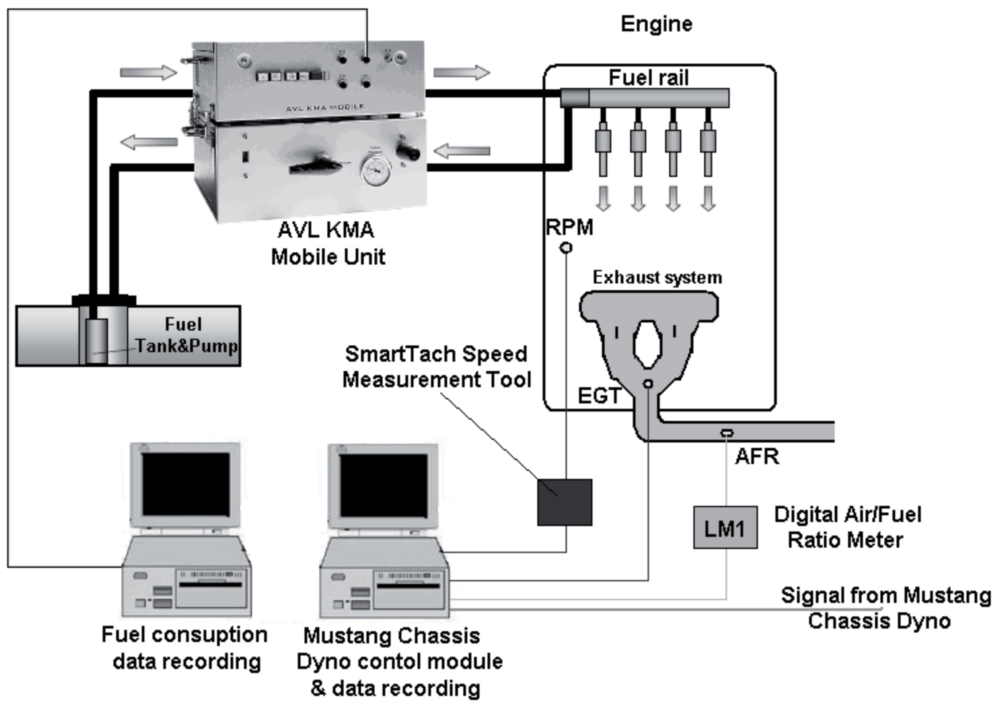

Fig. 1. Block diagram of measuring system.

The sequence of experiments, the number of repetitions and other issues related to measurements are taken from the methodology developed and approbated in previous tests (Dukulis at al., 2009).

RESULTS AND DISCUSSION

The engine fuel supply system was managed using the closed loop control principle, which means that the fuel injection quantity was adjusted according to the oxygen sensor signal. Sensor was inserted into the exhaust manifold. Engine management system helps to prepare air-fuel mixture so that it would close to stoichiometric ratio, i.e., air-fuel ratio 14.7:1, or $\lambda = 1$. Since the ethanol molecule also has an oxygen atom, then by supplying such ethanol-gasoline blend into the fuel supply system fuel becomes leaner. The engine control unit responds to the oxygen sensor signal and adjusts the duration of the injection, increasing the fuel supply. Regardless of bioethanol content in the fuel mixture, engine control system will try to keep the air-fuel ratio to be stoichiometric.

The fuel consumption changes depending on the concentration of ethanol in the fuel blend and driving mode are shown in Fig. 2.

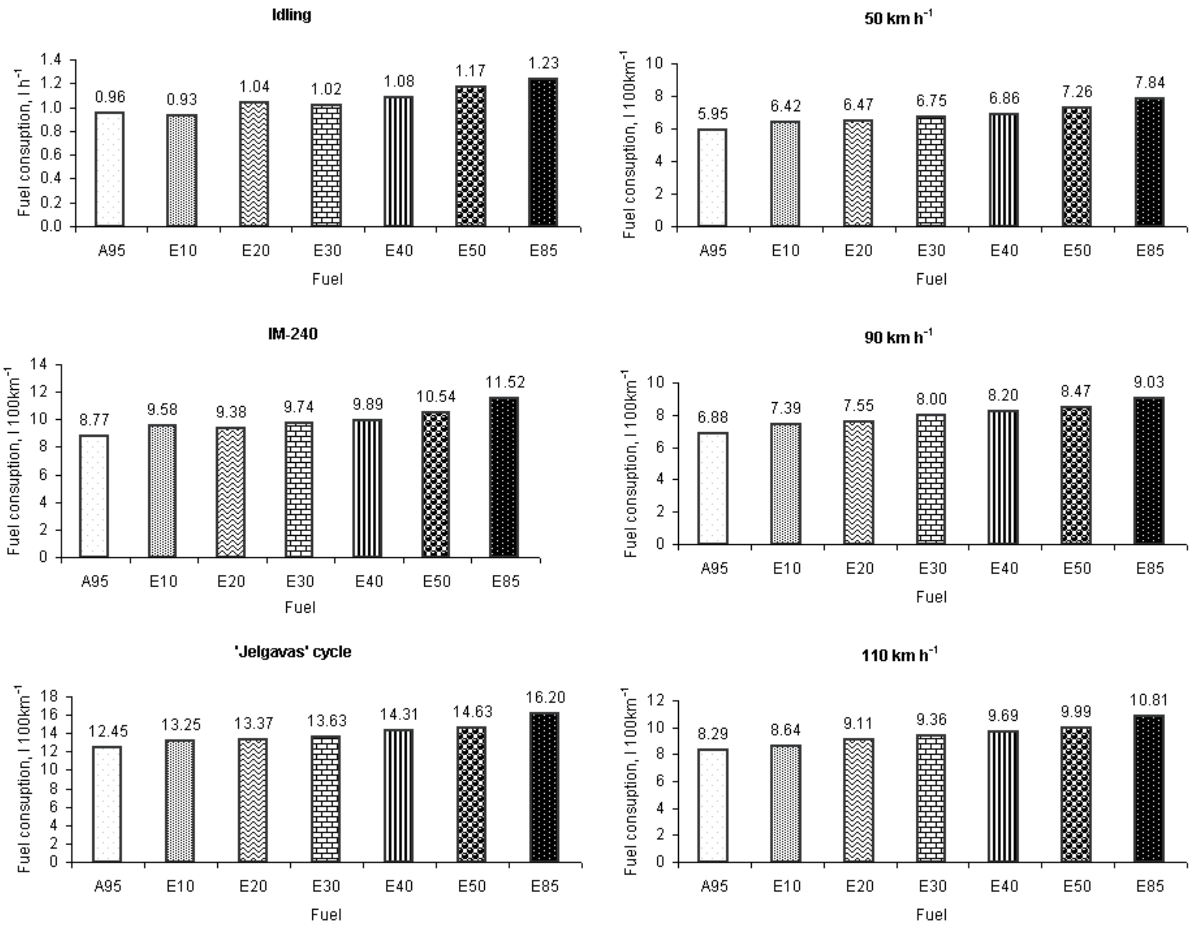

Fig. 2. Results of fuel consumption measurements.

Looking at the constant driving modes, an increase in driving speed, consequently also the engine speed and load, also increases fuel consumption. Dealing with fuel consumption during driving cycles (IM-240 and 'Jelgavas' cycle), higher fuel consumption with all fuels is using the 'Jelgavas' cycle, because the nature of this cycle is more aggressive – frequent driving up and stopping according to the city's traffic conditions. The trends of the fuel consumption change depending on the bioethanol content in fuel blend in all testing modes are similar, i.e., increasing the ethanol content of the fuel mix, fuel consumption will increase. Summarizing all experimental modes, the average fuel consumption change was calculated as a percentage compared to pure gasoline A95 (Fig. 3).

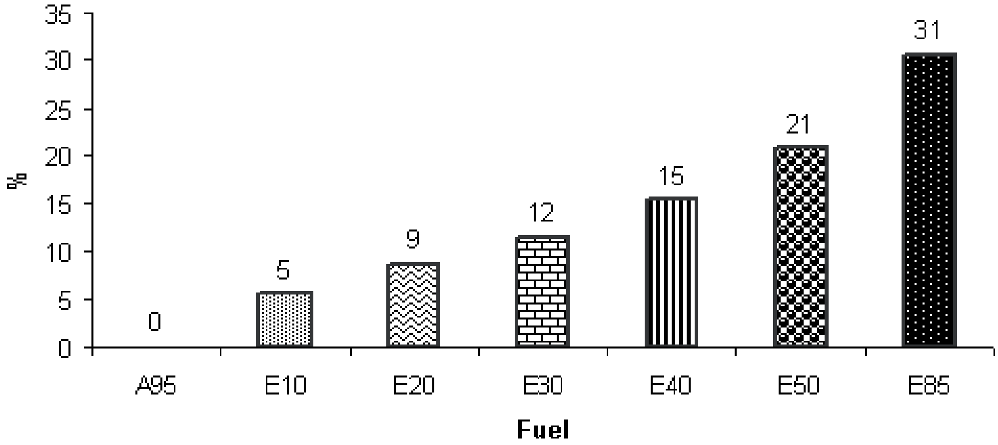

Fig. 3. Average fuel consumption changes depending on bioethanol content.

To ascertain that the ethanol-gasoline fuel mixtures used in non-modified cars with this type of fuel supply and management system do not cause major engine operation mode changes, two more important parameters were analyzed: the air-fuel ratio (AFR) determined by oxygen sensor signal, and the exhaust gas temperature (EGT). Fig. 4 shows the AFR and EGT value changes while driving at a constant speed (50 km h^{-1}, 90 km h^{-1}, 110 km h^{-1}), depending on the used fuel.

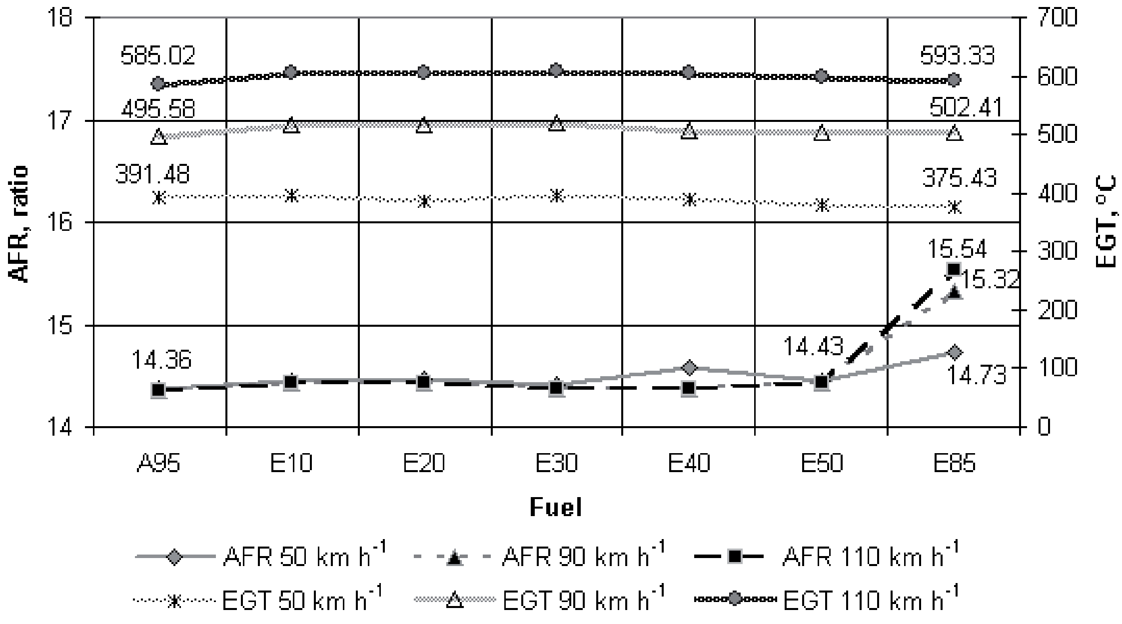

Fig. 4. AFR and EGT changes using different fuels.

As can be seen from Fig. 4, the exhaust gas temperature change is insignificant, regardless of used fuel content and driving speed. Temperature variation does not exceed 5% compared to the gasoline A95 exhaust gas temperature.

Air-fuel ratio change in the ethanol-gasoline fuel mixtures from E10 to E50 is very small (not more than 1.5% compared to the gasoline A95), while the E85 fuel in AFR variation in all experimental regimes is essential. At a constant speed of

50 km h^{-1} AFR value increases by 2.4%, at 90 km h^{-1} – by 6.7%, but at 110 km h^{-1} – by 8.2%. This means that when using E85 fuel in a non-modified car, the engine fuel system with closed loop control system cannot more provide an air-fuel ratio of 14.7:1, due to the fact that the productivity of nozzles or fuel pump is not sufficient for the used biofuel.

Despite the fact that the stoichiometric ratio of pure bioethanol is 9:1, as a result the stoichiometric ratio of ethanol-gasoline blend will be different from the optimal gasoline AFR (14.7:1), the car can use a fuel mixture with ethanol content up to 50% (E50). During the tests no factors affecting engine performance, including power loss, were observed.

CONCLUSIONS

1. The maximum ethanol content of the fuel mixture, which can be used in the non-modified car, differs from that of the car's model. Mostly it depends on the type of fuel system and its control peculiarities, as well on the fuel pump and nozzle productivity.
2. The fuel consumption test results show that until 100% of the nozzle load is not reached, by increasing the ethanol content of the fuel mixture by 10%, fuel consumption increases by 3–6%.
3. Analyzing AFR and EGT values using bioethanol fuel, it was proved that the standard car used in experiments without any conversion is able to run on bioethanol-gasoline fuel blends of up to 50% of ethanol content. If the E85 fuel is used in this car, then by increasing the engine load the fuel becomes too lean.
4. Using blends from E0 to E85, the required AFR value theoretically has to be within the limits of 14.7:1 to 9.0:1, but the experiments proved that the engine is able to operate without problems also with the leaner bioethanol-gasoline fuel blends.

ACKNOWLEDGEMENTS. The authors gratefully acknowledge the funding from EU and ESF (grant No. 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017 'Support for doctoral study programs').

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