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ALCOHOL FUEL IN PASSENGER CAR

Adam Polcar[1], Vojtěch Kumbár[1], Jiří Čupera[1]

[1] Department of Technology and Automobile Transport, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

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The present article studies the effects of combustion of high-percentage mixture of bioethanol and gasoline on the output parameters of a passenger car engine. The car engine has not been structurally modified for the combustion of fuels with higher ethanol content. The mixture used consisted of E85 summer blend and Natural 95 gasoline in a ratio of 50:50. The parameters monitored during the experiment included the air-fuel ratio in exhaust gasses, the power output and torque of the engine and also the specific energy consumption and efficiency of the engine. As is apparent from the results, E85+N95 (50:50) mixture combustion results in lean-burn ($\lambda > 1$) due to the presence of oxygen in bioethanol. The lean-burn led to a slight decrease in torque and power output of the engine. However, due to the positive physicochemical properties of bioethanol, the decrease has not been as significant as would normally be expected from the measured air-fuel ratio. These findings are further confirmed by the calculated energy required to produce 1 kWh of energy, and by the higher efficiency of the engine during the combustion of a 50% bioethanol mixture.

Keywords: spark-ignition engine, bioethanol, air-fuel ratio, engine output, specific energy consumption, engine efficiency

INTRODUCTION

The growing vehicle numbers have logically lead to an increase in fuel consumption. Fuels used for transportation are, however, mostly based on petroleum. It is thus necessary to search for alternative fuels which would reduce the dependency on petroleum fuels. One of the potentially viable alternatives is biofuels. Biofuels are fuels which have been partially or entirely produced from renewable resources, i.e. in a way which is very environment friendly. Renewable energy sources include wind energy, solar energy, geothermal energy, as well as energy produced from the soil, air, biomass, landfill gas, sewage gas or biogas. The definition of the term biofuel has first been established in the Green Paper published by the European Commission. The Green Paper called *Towards a European strategy for the security of energy supply* sets out the goal of replacing 20% of conventional fuels by alternative fuels in road transport by 2020. The intended share of biofuels on this number should amount to 8% (Čížek, 2009).

In recent years, the importance and popularity of ethanol, or bioethanol, has been growing. Bioethanol represents more than 94% of the world's production of biofuels (Demirbas, 2009). It is produced from biomass containing carbohydrates or substances which can be transformed into carbohydrates. These include, for instance, saccharose and polysaccharides such as starch or cellulose (Hromádko *et al.*, 2010). In the Czech Republic, bioethanol is mainly produced from sugar beet, which is responsible for 77.4% of the country's total bioethanol production (Jurečka *et al.*, 2014). Bioethanol is used both for spark-ignition engines and for compression ignition engines (Matějovský, 2005).

Combustion of fuels containing a high percentage of ethanol is problematic due to lower calorific value of ethanol when compared to gasoline. The calorific value of ethanol is 26.9 $MJ \cdot kg^{-1}$ (Vlk, 2006) which is approximately 37% less than in the case of gasoline. The lower calorific value is caused by the presence of oxygen, which, on the other hand, helps support better combustion and thus lowers the production of harmful emission components (Koç *et al.*, 2009). The higher oxygen content leads to lean-burn ($\lambda > 1$). Lean-burn at high revolutions carries the risk of increasing the temperature in the combustion chamber and thus possibly causing thermomechanical damage to the engine. With a $\lambda < 1$ value (rich mixture), the imperfect transformation of hydrocarbon leads to internal cooling of the combustion chamber. In this respect, the E85 fuel has a significant advantage due to its more than double heat of evaporation and thus better cooling of the combustion chamber during the refilling cycle. Today, engines are being fitted with automatic injection dose correction, which automatically adjusts the injected dose of fuel based on the operating conditions, such as oxygen content in exhaust gasses, so that the engine works with the desired air-fuel ratio. However, the correction of the injected dose has its limit values. As some studies state, for example Laurin (2007), using a gasoline mixture with up to 20% volume units of ethanol does not require a modification of the engine. During combustion of high ethanol percentage gasoline mixtures, however, it is necessary to intervene in the engine electronics.

The aim of the present article is to analyse the output parameters of a combustion engine running on a mixture of gasoline and E85 fuel at a 50:50 ratio and monitor the oxygen content in exhaust gases of a passenger car whose engine and control system have not been structurally modified for ethanol combustion.

MATERIALS AND METHODS

To analyse the output parameters, we used the Škoda Felicia passenger car. The technical specifications of the engine are provided in Tab. I.

The vehicles were tested on chassis dynamometer in laboratory of the Department of Engineering and Automobile Transport of Mendel University in Brno (Fig. 1). The measured values were corrected to atmospheric conditions by provisions of the Czech standard ČSN 30 2008.

I: *Technical specifications of engine*

Engine	Spark-ignition engine, electronic multipoint injection
Stroke capacity	1298 cm^3
Maximal engine output	50 kW/5000 min^{-1}
Maximal torque	106 Nm/5000 min^{-1}
Compression ratio	10:1
Fuel (prescribed by manufacturer)	Unleaded petrol BA 95
Mileage of vehicle	135 166 km

1: *Tested Škoda Felicia vehicle on chassis dynamometer*

As mentioned in the introduction, the tested fuel was a mixture of E85 fuel and Natural 95 gasoline (hereinafter referred to as N95), at a ratio of 50:50. The N95 already contained a minimum of 4.1% volume units of bioethanol as per Act No. 201/2012 Coll., on Air Pollution. The E85 fuel is defined according to the technical standard ČSN P CEN/TS 15293 as a mixture consisting of 85% volume units of ethanol in accordance with EN 15376 and automotive gasoline in accordance with EN 228; it also includes the option for a variety of seasonal blends of gasoline and ethanol mixture with ethanol content higher than 50%. The E85 fuel summer blend consists of up to 85% bioethanol and 15% gasoline; winter blend increases the gasoline content to 30–35%. When preparing the E85+N95 mixture, we used the summer blend of E85.

The basic parameters evaluated included the air-fuel ratio in exhaust gases, and the power output and torque of the engine. Other parameters included specific energy consumption and thus also engine efficiency. Specific energy consumption was calculated as follows:

$$E_{pe} = \frac{M_{ph}}{P_e} \cdot Hu \text{ [MJ·kWh}^{-1}\text{]}, \quad (1)$$

where
P_e.........engine output [kW],
M_{ph} .....fuel consumption [kg·h^{-1}],
Hu.......net heating value [MJ·kg^{-1}].

The effective engine efficiency was subsequently calculated from the relation:

$$\eta_e = \frac{3.6}{E_{pe}} \cdot 100 \text{ [\%]}. \quad (2)$$

The calculation of the above parameters also required a measurement of fuel consumption. The measurement of fuel consumption was carried out by two differentially connected mass flowmeters Coriolis Sitrans FC MassFlo Mass 6000 (Fig. 1).

To monitor the immediate amount of oxygen in the exhaust gasses, we used a broadband lambda sensor, which was placed into a structurally modified exhaust system (Fig. 2). The modified exhaust system also contained an original bistable lambda sensor to relay information on the mixture richness to the control unit.

The communication between the additional lambda sensor and the external computer was performed using CAN protocol. Processing of measured values was performed using LabVIEW 2013 software by National Instruments designed specifically for tasks of this type. To facilitate the measuring process and fuel change, an external tank was used, containing a fuel pump identical to the one in the car's fuel tank.

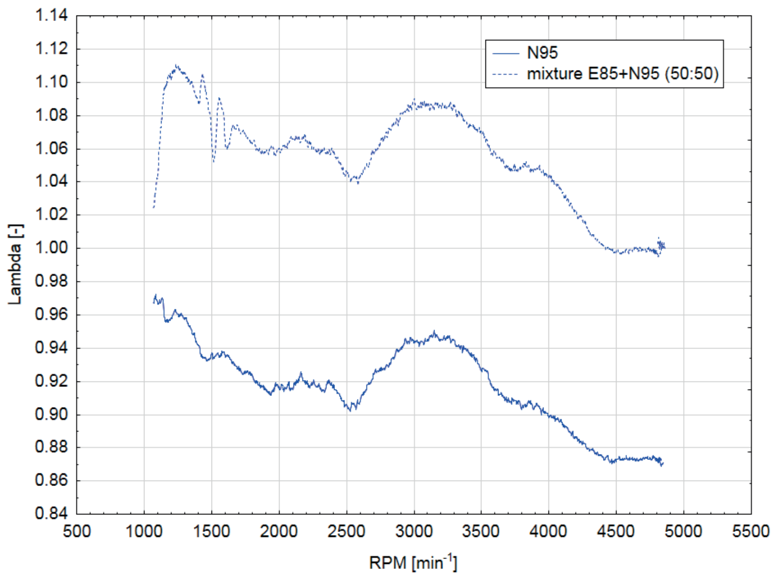
All measurements were performed via a dynamic method in three repetitions for result reproducibility.

2: *Modified part of exhaust system*

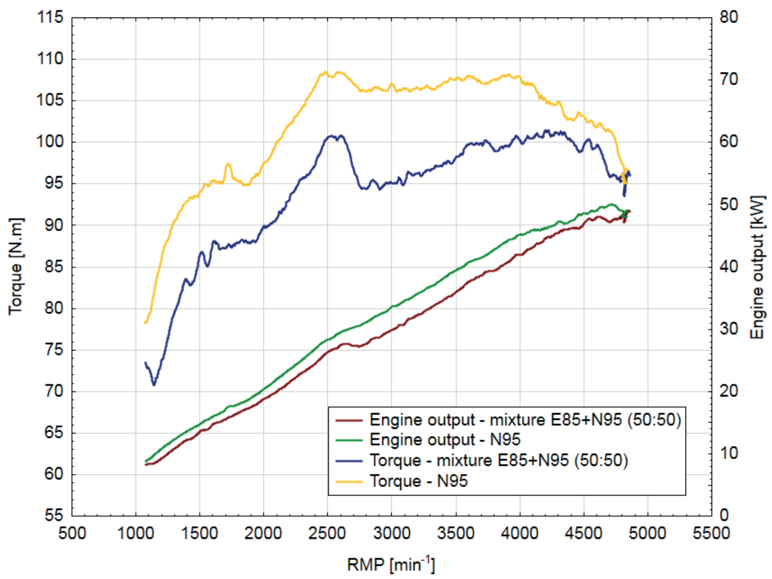
RESULTS AND DISCUSSION

Experimental measurements were performed in order to obtain information on the current richness of the mixture and on changes in output parameters of the spark-ignition engine during N95+E85 fuel combustion in a 50:50 ratio. Fig. 3 shows the course of air-fuel ratio during combustion of the E85+N95 mixture and of gasoline depending on revolutions.

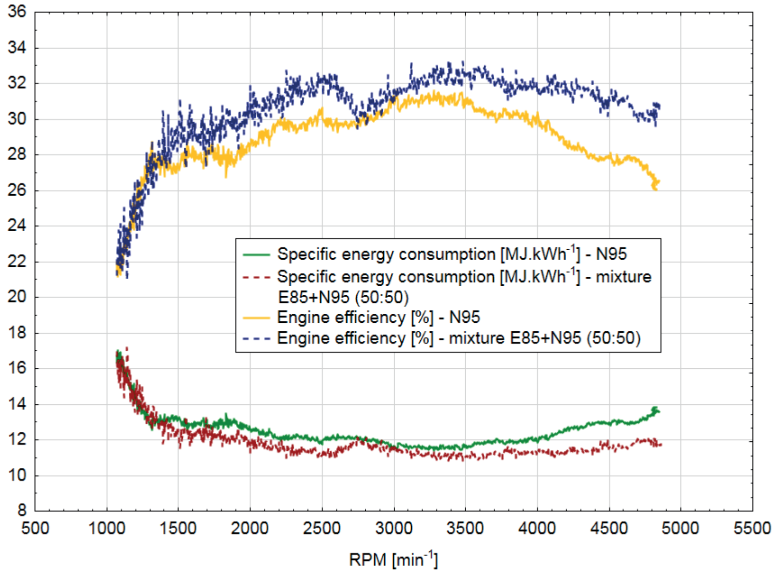
As is apparent from Fig. 3, combustion of a significantly leaner mixture occurs in the bioethanol and gasoline mixture compared to gasoline alone. The average air-fuel ratio in case of the E85+N95 mixture was $\lambda = 1.055$ while gasoline's values amounted to $\lambda = 0.916$. Lean-burn is a result of the above mentioned increased oxygen content in the fuel. It thus follows that the engine did not adapt and increase the fuel dose in order to maintain optimal efficiency of the catalytic converter. This is also evidenced by only a very slight increase in weight consumption of the E85+N95 mixture caused by its higher specific weight (see below). An article published by Vojtíšek *et al.* (2012) assesses, inter alia, the influence of E85 fuel combustion on the air-fuel ratio in a structurally unmodified engine as well. Their measurements show that the control unit, in an attempt to achieve a stochiometric mixture, extended the impulse length for the injector during E85 fuel combustion. Along with the air-fuel ratio course, it can thus be assumed that the engine adjusted and adaptively increased fuel dosage to ensure stochiometric combustion. The authors of the article also state that the adjustment



3: *Course of air-fuel ratio depending on engine revolutions*



4: *Course of torque and engine output depending on engine revolutions*



5: *Course of specific energy consumption and engine efficiency depending on engine revolutions*

and adaptation occurred only after several tens of minutes. This means that the vehicle measured during the present experiment could not adapt within such a short measuring period and could not ensure that a sufficient amount of fuel would be injected into the engine cylinder.

The adjustment and adaptive increase of the injected dose, however, may not be sufficient in general, since the control unit does not allow the increase in fuel dosage above a permitted level set by the maximum long-term correction limit. Another potential reason could be insufficient flow characteristics of the injection valves at a given fuel pressure.

Lean-burn in the tested vehicle also reflected slightly on the torque and power output of the engine (Fig. 4).

As the Figure shows, a slight decrease of both engine output and torque occurs across the entire range of revolution characteristics. The maximum engine output measured during gasoline combustion was 50.2 kW at 4,714 rpm, while for the bioethanol and gasoline mixture the maximum was 49.1 kW at 4,798 rpm, which is 1.1 kW less. Engine torque when using N95 fuel reached a maximum of 108.8 Nm at 2,477 rpm. When measuring torque with the E85+N95 mixture, a maximum torque of 102.5 Nm was recorded at 2,530 rpm, which is 6.3 Nm less. This decrease serves as evidence of lean-burn, or rather of a mixture with lower calorific value due to higher oxygen content.

Fig. 5 shows the course of specific energy consumption and effective efficiency of the engine depending on revolutions.

As mentioned before, these parameters stem from specific consumption and calorific value of the fuel. During combustion of the E85+N95 mixture, the weight consumption of the fuel increased only slightly. During combustion of N95 gasoline, fuel consumption at maximum engine torque reached 8.1 kg·h^{-1}, while E85+N95 mixture's reached 8.2 kg·h^{-1}. The slight increase in fuel consumption was caused by higher specific weight of the mixture. The specific weight for the E85 fuel at 20 °C is 791 kg·m^{-3} while gasoline's specific weight at the same temperature is 752 kg·m^{-3} (Kumbár *et al.*, 2015).

Specific energy consumption interprets energy consumption in the fuel to a unit of produced energy. Measurements have shown that combustion of N95 requires an average of 5.6% more energy than the E85+N95 mixture to produce 1 kWh. The efficiency of the E85 cycle is thus higher. This is also supported by the course of effective efficiency of the engine (Fig. 5). The effective efficiency of the engine at maximum torque has been calculated to 29.51% for N95 and to 32.02% for the E85+N95 mixture. Aside from the chemical properties, especially calorific value, the efficiency of a combustion engine is affected by fuel consumption and engine power output. Increasing the injected dose of fuel during ethanol fuel combustion is important due to differences in the mixing ratio between air and gasoline (ethanol already contains oxygen). On the other hand, increasing the richness of the mixture too much leads to an increase in engine power output, but a decrease in combustion cycle efficiency. The increase in engine power output is connected mainly to the heat of evaporation of the combustion mixture, which then influences the compression stroke and the entire combustion process. The evaporation of the fuel takes place after its injection into the engine cylinder during both the intake and the compression stroke. Combustion of a fuel with a high heat of evaporation (as is the case of fuels with a high ethanol content) leads to an increase in combustion chamber cooling, causing a drop in temperature of the operating mixture and thus also a decrease in the amount of vapours created. The amount of compression work is thus reduced due to a smaller increase in pressure, which results in higher engine power output (Park *et al.*, 2010), or rather its lower decrease than what would be expected in an E85+N95 mixture of the richness we recorded (50:50). A lower decrease in engine output can also be observed in other positive physicochemical properties of the fuel, specifically in the speed and quality of mixture combustion thanks to higher oxygen content in the mixture. Due to the mixture's homogeneous nature, the quality of combustion in the cylinder increases, which is then reflected by higher temperature efficiency and lower production of harmful emissions (Koç *et al.*, 2009).

One of the studies which tackled combustion of fuels with higher ethanol content, specifically the E85 fuel, was Park *et al.* (2010). Among other things, this study also evaluated the influence of mixture richness on engine efficiency. The authors also discovered that during lean-burn ($\lambda > 1$) of E85 fuel and air mixtures, the decrease in thermal efficiency of the engine was not as high as in the case of gasoline. According to the authors of the study, this phenomenon indicates a preservation of stability in E85 fuel combustion even at low mixture richness.

CONCLUSION

Bioethanol is currently the most widely used liquid biofuel for ignition engines. Based on mandatory implementation of the commitments of the European Union regarding gradual reduction of emissions, the Czech Republic and other EU countries have an obligation of adding a bioethanol admixture to gasoline. With the increasing efforts to reduce the dependency on petroleum fuels, these standards are likely to become stricter in the future and the bio-component (bioethanol) ratio in gasoline is likely to grow. It was the goal of this article to evaluate the options of using a fuel mixture consisting of E85 fuel and Natural 95 gasoline at a 50:50 ratio in a vehicle which has not been structurally modified for the combustion of this fuel type. As the measured results show, the use of such a mixture leads to combustion with a higher amount of excess air. This lean-burn carries with it risks regarding thermomechanical damage to the engine, especially during higher load and revolutions, where combustion temperatures reach their maximum. On the other hand, ethanol's heat of evaporation is higher than gasoline's, which helps decrease this risk, since higher heat of evaporation positively affects the internal cooling of the combustion engine. This also prevents significant decreases in engine power output, which would otherwise be expected considering the air-fuel ratio. In conclusion, we can affirm that bioethanol has a positive effect on engine output parameters, which is also reflected by higher engine efficiency. To utilize the properties of ethanol as a fuel to the maximum, its use should be preceded by a modification to the engine. This modification would consist of installing a "supplemental" control unit. The new unit would automatically determine the amount of ethanol in the combustion mixture based on the amount of oxygen in the exhaust gasses, and would adjust the injected fuel dosage accordingly. The optimization of ethanol fuel combustion, however, should not include only a change in the mixture preparation system. Due to the octane number of ethanol, the compression ratio, which serves as a basis for an increase in thermal activity of the combustion engine, should also be increased, or at least a modification to the ignition advance should be performed.

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Contact information

Adam Polcar: adam.polcar@mendelu.cz
Vojtěch Kumbár: vojtech.kumbar@mendelu.cz
Jiří Čupera: jiri.cupera@mendelu.cz