Study of potential uses for farmstead ethanol as motor fuel

A. Küüt[1], K. Ritslaid[2] and J. Olt[1]

[1]Institute of Technology, Estonian University of Life Sciences, Kreutzwaldi 56, EE51014 Tartu; e-mail: arne.kyyt@emu.ee
[2]Estonian Aviation Academy, Kreutzwaldi 58A, EE51014 Tartu, Estonia

Abstract. In recent years the use of ethanol and mixtures thereof as a fuel in internal combustion engine has been studied at Estonian University of Life Sciences. In the course of the research there have occurred new problems and issues to solve. Ethanol fuels in this study include bioethanol produced in farm environment, hereinafter referred to as *farmstead ethanol*. *Farmstead ethanol* is simply bioethanol obtained by applying a simpler (cheaper) production method. Such a production process does not adhere to or comply with the requirements set out for potable spirit. The first part of the article provides an overview of the production and properties of ethanol fuel. The second part contains comparative test results, analysis and conclusion concerning the use of ethanol, farmstead ethanol and gasoline (regular fuel) in Otto motor.

Key words: Bioethanol, farmstead ethanol, production methods, use in internal combustion engine.

INTRODUCTION

Bioethanol is the most common biofuel in the world. Owing to widespread availability, biorenewable fuel technology will potentially result in the employment of more people than fossil-fuel-based technology (Demirbas, 2006).

Utilizing ethanol as a fuel is not a recent invention, but has been practiced for almost a century and a half. Early on, pioneers of the automotive industry were inspired by this 'fuel of the future' as Henry Ford called it.

The use of ethanol played a crucial role in two major developments that helped to determine the future of the automotive industry. As early as in the 1860s, Nikolaus August Otto used ethanol as the fuel to drive the prototypes of his combustion engine, and almost 50 years later Henry Ford designed the car that revolutionized production in the automotive industry and his legendary Model T helped him understand that ethanol could be used to fuel this 'car of the people'. As for its commercial use, ethanol has been sold in Germany since 1925 as an octane enhancer (Handbook of Fuels, 2009).

It is known that bioethanol has high octane number and great detonation stability. Oxygen content in its molecule allows cleaner combustion process at relatively low temperature and reduces the content of CO, unburned hydrocarbons and NOx in exhaust emissions. Bioethanol has lower vapour pressure than gasoline, which ensures lower vaporisation loss upon storing.

As ethanol has higher vaporising heat and lower energy content than gasoline (calorific value of 1 litre ethanol constitutes 69% of relevant value of one litre of gasoline), it is possible to use mostly ethanol-based fuel only in customised engines.

New flexi fuel vehicles, the total number of which exceeds 6 million (mostly in Brazil, USA, and Sweden) may operate on 85% ethanol mixture. Gasoline with minimum 22% bioethanol content is used in Brazil. Bioethanol has high octane number, greater compression and improved combustion, which means reduced fuel consumption (in energetic units) and exhaust emission. In comparison with gasoline, ethanol has lower combustion temperature, which is partially due to lower value of energy content by volume. Higher volumetric fuel consumption, however, ensures better cooling, as it burns slower and at lower temperature.

The quality of fuels and biocomponents thereof has been subject to studies by many authors, such as: Jeuland et al. (2004), Li et al. (2005), Thirouard & Cherel (2006), Demirbas (2006), Agarwal (2007), Albrect et al. (2007), Arsie et al. (2007), Butkus et al. (2007), He et al.(2003); Lebedevas et al. (2007a, 2007b), Raslavičius and Markšaitis (2007), Al-Hasan and Al-Momany (2008), Boychenko et al. (2008); Lebedevas and Lebedeva (2009), Raslavičius (2009), Török (2009), Petrović et al. (2009), Dukulis et al. (2009), and Demirbas (2009).

Parallel to the aforesaid, it is necessary to promote the use of bioethanol made from local renewable resource in Estonia as well. Until now the main attention has been paid to biodiesel as an alternative fuel. The research carried out at Estonian University of Life Sciences aims at the production of ethanol in farm environment, its feasibility and use as motor fuel.

MATERIALS AND METHODS

Properties of and requirements for bioethanol

Low-quality grain was used as the feedstock for farmstead bioethanol. Organoleptic analysis confirms the existence of fusel oils (C3-C5 Spirits), organic acids (butyric acid, isobutyric acid), esters (isobutyric acid, ethyl ester; isovalerian acid, ethyl ester) et al. in bioethanol.

Previous study performed by these authors (Olt et al., 2009) provided engine tests with bioethanol, gasoline 95, E15, E30, E50, and E85. Analogous studies have been performed at Latvian University of Agriculture to develop testing methods (Dukulis et al. 2009). Pursuant to the test protocol Analytical report SB 090701 by Analiit-AA in 2009, concerning bioethanol E85 used in engine tests, it appeared that bioethanol that was used for producing E85 was manufactured on the basis of production licence of the Republic of Latvia LV 1000380004. Test protocol reveals that the bioethanol sold at the filling station was produced from very pure 99.6% ethanol which does not contain other oxygenates (ethers, methanol, higher alcohols, etc.). This is clearly a waste of resources because the ethanol used as motor fuel does not require the purity of potable spirit. Pursuant to standards bioethanol may contain up to 5.2% ethers by volume, 2% higher (C_3-C_8) alcohols by volume, and minimum ethanol content if bioethanol E85 is 75%. Another important factor is that higher alcohols increase the energetic value of bioethanol. According to the standard, added unleaded gasoline content may be within the range of 14 to 22% by volume (European Standard CWA 15293, 2009).

Table 1 and Table 2 provide the parameters for Bioethanol E 85 and farmstead bioethanol and the European requirements for E85 and requirements for fuel ethanol in the United States of America.

Table 1. Comparison of initial ethanol for producing bioethanol E85 and biogasoline with farmstead bioethanol.

Property	Units	Limits E85*	Test method	Bioethanol E85 of Statoil petrol station**	Denaturated ethanol ASTM D 4806	Bioethanol farmstead ***
Higher alcohols (C3-C8)	V/V %	max 2.0	EN1601/EN 13132	0		
Ethanol content	V/V%				92.1	94.51
Ethanol+higher alcohols	V/V%	min 75		85,1		
Methanol	V/V %	max 1.0	EN1601/EN 13132	0	max 0.5	0.55
Ethers (5 or more atoms)	V/V %	max 5,2	EN1601/EN 13132	2.49		
Premium grade unleaded petrol as specified by EN228:2008	V/V %	14-22	Calculated	14.64		
Water content	V/V %	max 0.3	ASTM E 1064	0.265	1.0	6.94
Solvent washed gums: unwashed washed	mg/100ml	5.0				 65.0 33.0
Inorganic chloride content	mg l^{-1}	max 1.0	ISO/6227/ ASTMD 512	0.192	max 32mg l^{-1}	

*Limits preferred SVENSK STANDARD SS 155480:2006 and European Standard CWA 15293:2005.
** – analyzed Analiit-AA OÜ
*** – analyzed Saybolt Eesti AS. Tested ex 95% fraction and water content not deducted.

Laboratory also determined the density, fraction composition, ethanol content, and other parameters of farmstead bioethanol (see Table 2). It appears from the table that in terms of ethanol and methanol content, fraction composition (except for the deposit at the bottom of the piston), farmstead bioethanol complies with all the requirements. Resins and water content need to be reduced. Determination of higher alcohols was complicated because gas chromatographic method (EN 13132) did not allow product analysis. The results of the analysis reveal that produced bioethanol needs better distillation to get rid of heavier, default compounds, and reduce excess water content by using suitable method.

Table 2. Other properties of farmstead ethanol.

Property	Test method	Unit	Result	Limits
Density**, 15°C	ASTM D 4052	kg m^{-3}	816.2	No norms
Water content by Karl Fischer*		V/V%	6.94	0.3 –CWA15293:2005) 1,0 - (ASTM D 4806)
Ethanol content*	ASTM D 5501	V/V %	94.51	min 92.1
Methanol content*	ASTM D 5501	V/V %	0.55	max 0.5
Distillation** Initial boiling point, °C 10% (V/V) , °C 20% (V/V), °C 50% (V/V), °C 60% (V/V), °C 70% (V/V), °C 80% (V/V), °C 90% (V/V), °C 95% (V/V), °C 98% (V/V), °C 99% (V/V), °C Final boiling point, °C Residue, ml	ASTM D 3405	V/V %	 75.5 77 78 78 78.0 78.5 78.5 79.0 80.0 83.0 120.0 123.0 0.4; brown organic residue	
Acidity, (as acetic acid CH_3COOH)**, % (m/m)	ASTM D 1613		0.00575	0.005 – CWA15293:2005 0.007 – ASTM D 4806

* – analyzed at Saybolt Eesti AS
** – analyzed in the fuels and lubricants laboratory at Estonian University of Life Sciences

Engine tests

In order to describe the properties and potential use of farmstead ethanol fuel, engine tests were carried out in the engine testing laboratory at Estonian University of Life Sciences. For better analysis and description of the results of the engine tests a comparative method upon using three different fuels was used. The tests were performed by using gasoline 95 (regular fuel), ethanol (96.3%) and aforesaid farmstead ethanol (94.51%) as a fuel. In order to determine the dynamic and economic parameters of the engine at different modes (load and speed modes), diagrams based on experimental data were used (characteristics). Using the speed characteristic allowed us to describe the relation between the parameters related to engine power and economy (net power P_e, hourly fuel consumption B_f, specific fuel consumption b_e, average net pressure $p_{e,}$ torque M_t) depending on crankshaft rotational speed n_m. Audi A4 (OTTO) engine was used as test engine. In order to enable the test engine to work on bioethanol fuels, Flexi Tune Sequential bioethanol device was connected to the electronic engine control system circuit between engine control unit (ECU) and injectors (Flexi, 2009). Bioethanol device was also connected to ë-sensor. Attached bioethanol device allows using petrol, ethanol, and their mixture in any ratio as fuel. Bioethanol device uses longer exposure of electronically controlled injectors to compensate lower energetic value of ethanol.

Engine test stand Dynas3 LI250 manufactured by Schenck GmbH was used for loading the engine Audi A4 ADR. Stand brake consists of asynchronous engine, the rotation speed of which is altered by frequency converter. Nominal power of the stand P_n = 250kW, nominal intensity I_n = 390 A, nominal speed n_n = 4,980min^{-1}, torque at maximum nominal speed M_n = 480N·m (Butkus et al., 2007). Control device of the test stand was used to control the test: to start and stop the test engine, to adjust choke position and engine load. Control device of the test stand enabled to check crankshaft rotational speed n, min^{-1}, engine torque *M*, N·m, power *P*, kW, and choke position.

According to manufacturer's data the maximum torque of Audi A4 is 173N•m, at 3,950min^{-1}. At the aforesaid crankshaft rotational speed the choke position was 34% when not loaded. Choke position 34% was thus selected as one of the test modes. In order to obtain partial speed characteristic, the following test was performed with every test fuel: constant choke position at 34%; crankshaft rotational speed was changed by braking engine at fixed intervals *n* = 1,350...3,950min^{-1}.

In the course of the tests the engine load was increased until the crankshaft rotational speed decreased to the limit where the engine was still running steadily. The following parameters were measured at ten different crankshaft rotation speeds: torque M_t (Fig. 1), fuel consumption B_f, test duration τ_f, air pressure p_{env}, air humidity φ_{env}, air temperature t_{env}, temperature of exhaust gases t_{egt}, position of injectors τ_i, ignition timing advance α_i, air consumption V_a, temperature of cooling liquid t_w. The information obtained was used for calculating the following parameters: net power P_e, actual air consumption B_a, specific fuel consumption b_e, engine power efficiency η_e, effective pressure p_e.

RESULTS AND DISCUSSION

Comparative analysis prepared on the basis of test results and calculations is given below. Fig. 1 shows that gasoline has the highest and farmstead ethanol has the lowest toque in the entire diagram.

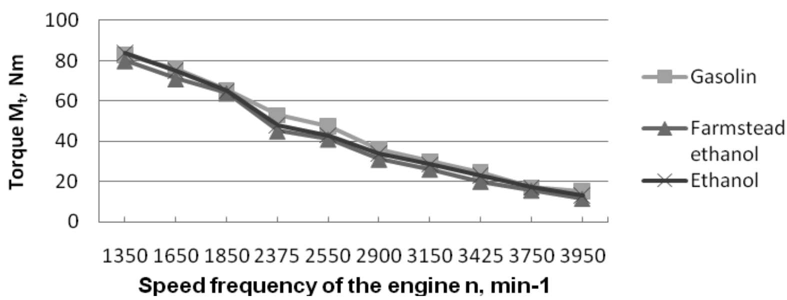

Figure 1. Torque M_t depending on the speed frequency of the engine n in case of different fuels.

Average engine power in case of given fuels was approximately the same (Fig. 2). Engine power was calculated by using the following formula (Pulkrabek, 1997):

$$P_e = \frac{2\pi N M_t}{1000}, \qquad (1)$$

where: P_e – power kW;
N – rotational speed s^{-1};
M_t –torque Nm.

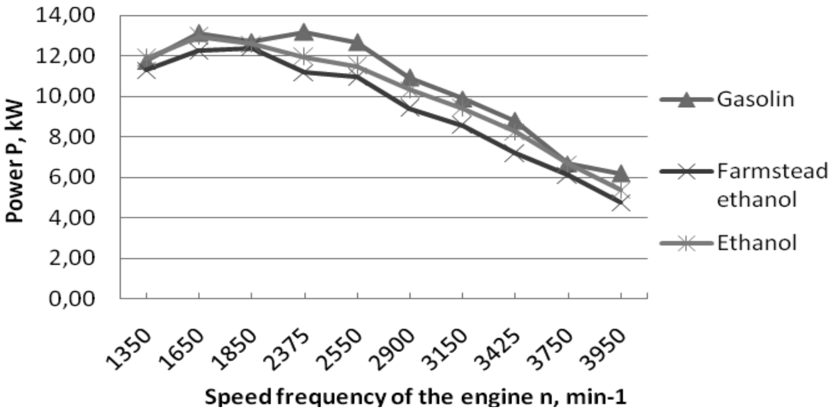

Figure 2. Power P_e depending on the speed frequency of the engine n in case of different fuels.

Based on test results the average values of studied parameters (f=average) are used to provide better characterisation of the fuels within the entire partial speed characteristic range (n = 1,350...3,950min^{-1}) and then expressed in percentage (Fig. 3). While, in comparison with gasoline, the loss of power was approximately 5% in case of ethanol, that parameter was 11.2% lower in the case of farmstead ethanol.

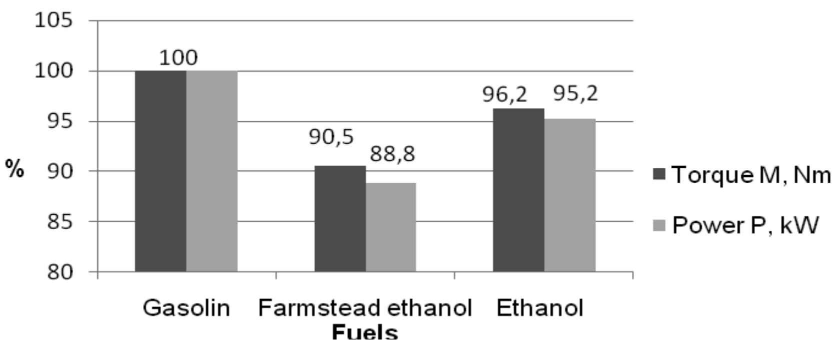

Figure 3. Ethanol fuels compared to gasoline.

The main typical parameters in the analysis of fuel use and in making recommendations in terms of economical use thereof include specific fuel consumption and engine efficiency. Hourly fuel consumption measured on the stand (Fig. 4) was used to calculate specific fuel consumption (formula a).

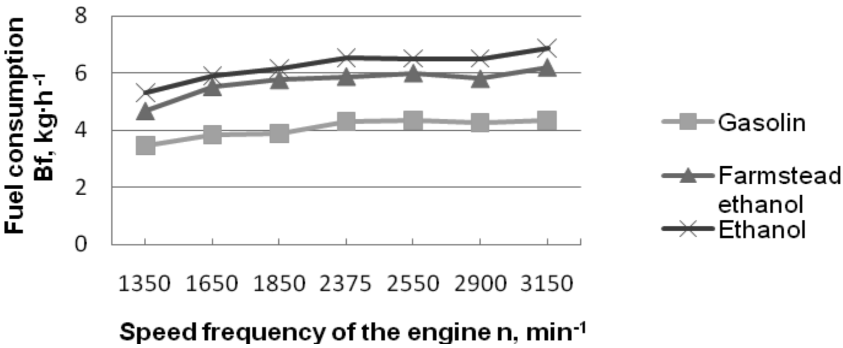

Figure 4. Fuel consumption B_f depending on the speed frequency of the engine n in case of different fuels.

Specific fuel consumption increased along with increased torque. Specific fuel consumption of farmstead bioethanol was on average 58% higher than gasoline and that of regular ethanol was 62% higher (Fig. 5).

Specific fuel consumption: $$\frac{b_s = B_f}{P_e},$$ (2)

where: b_s – specific fuel consumption, kg·(kWh) $^{-1}$;
B_f – fuel consumption kg·h $^{-1}$;
P_e – power kW.

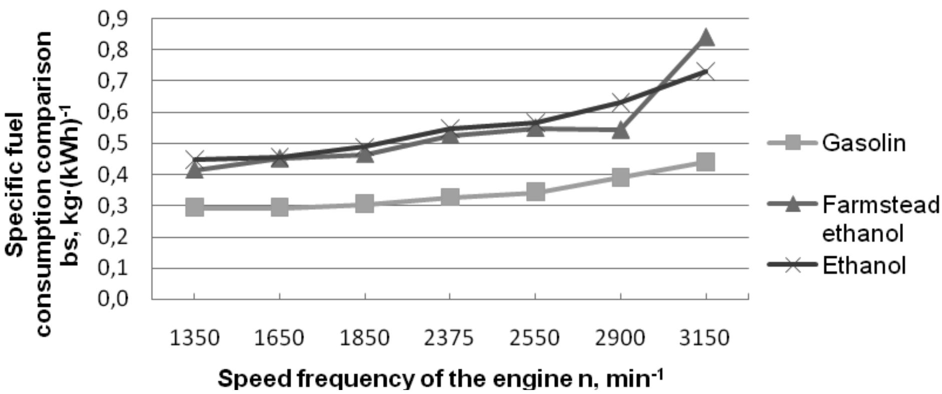

Figure 5. Specific fuel consumption b_s depending on the speed frequency of the engine.

In order to ensure maximum engine power and torque, it is necessary to improve engine efficiency and load line. Based on the calculation of net efficiency the following results were gained when using ethanol fuels (Fig. 6). The best net efficiency was found in farmstead ethanol – 28.8%. In comparison with gasoline, using ethanol resulted in average 2.51% increase in engine net efficiency. Calorific values of the fuels (lower) were as follows: gasoline 44MJ·kg^{-1}; ethanol 26.7MJ·kg^{-1}; farmstead ethanol 24.2MJ·kg^{-1}. The results were calculated by using the formula below.

Engine efficiency:

$$\eta_e = \frac{P_e \tau}{Q_l B_f} 100, \tag{3}$$

where: η_e – engine efficiency %;
τ – test time s;
P_e – power W;
Q_l – fuel calorific value (lower) J·kg $^{-1}$;
B_f – fuel consumption kg·h $^{-1}$.

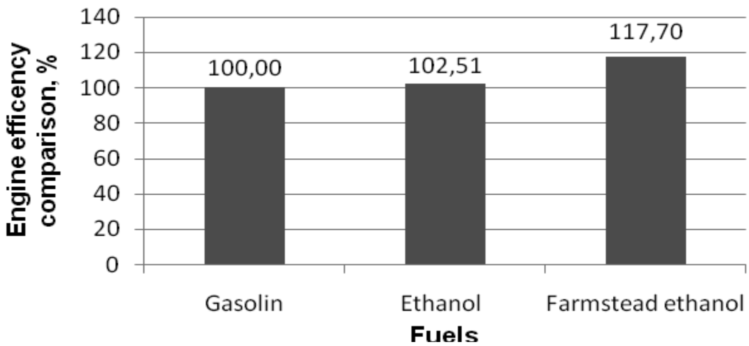

Figure 6. Engine efficiency η_e depending on the speed frequency of the engine n in case of different fuels.

CONCLUSION

As a conclusion to this study, we may say that the results met the expectations, but they also gave rise to various questions. The engine operated steadily, and there were no major deviations from work parameters. Although farmstead ethanol has lower ethanol content, its main additives include aldehydes (acetic acid, etc.), esters (formic acid ethyl ester, acetic acid methyl ester, acetic acid ethyl ester, etc.), methylated spirit, post-additives, such as higher alcohols (fusel oils) and iso-butyric acid ethyl, iso-valerian acid ethyl, acetic acid-iso-amyl, and iso-valerian acid-iso-amyl esters with similar boiling point.

The results gained upon testing ethanol and farmstead bioethanol were approximately the same, as seen from the diagrams. As for biofuels, better results in terms of power were achieved with ethanol, as its calorific value exceeded that of the farmstead ethanol. Meanwhile, engine efficiency was higher in case of farmstead bioethanol, which took into account the power, specific fuel consumption and calorific value. The results led to the conclusion that it is necessary to carry out additional tests with bioethanol based fuels both in spark ignition and pressure ignition piston engines. For better characterisation of the fuel it is necessary to constantly monitor the production process, which was lacking in this case. Therefore it is intended to develop a small production process, which would allow constant monitoring of fuel properties, and modify them where necessary and provide economic assessment to the production.

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