COST OF ETHANOL WHEN USED IN DIESEL ENGINE

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Abstract. In the course of transition towards using biofuels as motor fuel the farmers are generally interested in the cost of biofuel in comparison with traditional fuel. Another issue is related to the production of bioethanol. What would a competitive price of bioethanol be in case of small-scale production? Based on the engine tests carried out with particular machinery it is possible to choose the type of bioethanol fuel with a suitable price. In order to choose the production technology that would ensure an acceptable cost price of bioethanol, one has to analyse the use of bioethanol with different concentration and price in internal combustion engines. When using other types of fuel, the properties of which differ from traditional fuels, we are interested not only in the price of the fuel, but also in the fact that the specific fuel consumption (EUR·ha^{-1}) during agricultural works should not exceed the specific fuel consumption occurring when using traditional fuel. A solution has been provided by preparing a relevant model, making calculations and performing an analysis. The necessary data have been collected as a result of practical measurements carried out in the engine testing laboratory of the Estonian University of Life Sciences.

Keywords: internal combustion engine with compression-ignition, comparative characteristics of fuel cost and price.

Introduction

The primary purpose of the present paper is to study possible use of hydrous bioethanol as motor fuel in compression-ignition engines. Research for developing the production technologies of anhydrous bioethanol has been carried out at the Latvia University of Agriculture. Production of anhydrous ethanol is a complex and costly process [1].

The main target group interested in using bioethanol includes farmers and agricultural undertakings, which, however, does not mean that the outcome cannot be applied to the transportation sector to meet the requirements set by the EU Directive 2009/28/EC [2]. Farmers are generally interested in the cost of machine work, which consists of expenses on tractor work and expenses on various work machines. One part of tractor work consists in the cost of fuel used [3]. Our main interest is to study how the selection of the bioethanol production technology affects the cost of fuel consumed in the internal combustion engine and the impact of the price of the used fuel on development of a suitable production technology. The study performed on the basis of using bioethanol provides the fuel manufacturer with the information necessary to produce bioethanol fuels at a comparable price.
The main issues when using bioethanol as fuel for internal combustion engines include the following: change in the cost of the used fuel when calculating the cost of tractor work; change in the substances found in exhaust gases; fuel impact on engine components.

The product cost is as important in agriculture as in any other industry, because it ensures sustainable management.

Expenses on certain field area unit (1) generally include depreciation (a_T, a_M), technical maintenance and repairs (p_T, p_M), cost of fuels and lubricants and wages. These costs are together called the specific cost of fieldwork C_F. Reintam A. has discussed the specific cost of fieldwork as follows [4]:

$$C_F = \frac{1}{W}\left[\frac{B_T(a_T + p_T)}{100T_T} + \frac{B_M(a_M + p_M)}{100T_M} + \frac{q_T \cdot v_p \cdot R_x \cdot c_f}{\eta_T \cdot \xi} + c_p\right], \tag{1}$$

where formula part

$$\frac{q_T \cdot v_p \cdot R_x \cdot c_f}{\eta_T \cdot \xi} \tag{2}$$

describes the cost (2) of fuel and lubricants. The parameter required for determination of the fuel cost is the fuel price c_f, EUR·kg^{-1}.

Our goal was to examine the impact of using bioethanol on fuel consumption, therefore, we must consider only the cost that describes the specific cost of the consumed fuels C_f and allows analysing the change in the specific cost of fuel. The following relation applies to the specific cost of fuel C_f (EUR·h^{-1}) and fuel price c_f (EUR ·kg^{-1}):

$$c_f \frac{B_f}{C_f}, \tag{3}$$

where B_f – hourly fuel consumption kg·h^{-1} or kg·ha^{-1}.

In general, the fuel consumption is calculated by using two factors: quantity of measured fuel (l or kg) and distance travelled (km), performed work hours (h) or area of the cultivated field (ha). Considering that our approach is more agricultural, but still based on laboratory tests, we decide to use work hours and therefore observe the hourly fuel consumption B_f, kg·h^{-1}. The constant factor in testing consists in the engine torque T_m or power P_m. If necessary, the units can be replaced and calculations performed by using values of our choice, such as the fuel consumption per field area, EUR·ha^{-1}. The variable factor in calculating the cost of the consumed fuel is the fuel price, formation of which is affected by the chosen production technology. Selection of the production technology affects not only the fuel price, but also its physical and chemical properties. Using ethanol fuels with different physical and chemical properties as motor fuel has a different impact on the engine output parameters. The relation between the price and physical and chemical properties of ethanol fuel might not be linear. The same applies to relations between the properties of ethanol fuel and changes in the engine power output parameters. Comparison of the cost of the fuel quantity used for particular work allows choosing suitable bioethanol fuel depending on the machine in order to reduce the expenses on machine work hour and thus on the cost price of the product.

Fuel called "diesohol" has been developed for using in engines with compression-ignition, it contains diesel fuel (84.5 %), hydrated ethanol (15 %) and emulsifier (0.5 %). Hydrated ethanol is ethyl alcohol with approximately 5 % water content. Using "diesohol" as fuel increased the engine thermal efficiency by 8 % [5]. However, we are interested in using bioethanol with significantly higher proportion and water content in fuel.

Materials and methods

A model for assessing the impact of fuel properties on the fuel price is prepared by using two methods. The first assessment method is a classical method that allows estimating the specific cost of bioethanol fuel consumed in the chosen engine, depending on the properties of the fuel used (concentration).

The other method allows estimating the maximum limit price of bioethanol fuel in comparison with the price of regular fuel, so that the cost of bioethanol fuel would not exceed the cost of regular fuel when performing the same work (specific cost of fuel). In addition to that it is possible to assess the change in the required fuel amounts (specific fuel consumption), when bioethanol fuel is either fully or partially used.

In order to maintain or reduce the price of a product or a service, the relation (4) is manifested by using the specific cost of the consumed fuel in tests as follows:

$$c_{freg} \geq c_{fbio}, \tag{4}$$

where C_{freg} – specific cost of consumed fuel (diesel fuel or gasoline) EUR·h^{-1};
C_{fbio} – specific cost of consumed fuel in case of biofuel (fuel mixture) EUR·h^{-1}.

The result (fuel limit price) is particularly important if one desires to prepare bioethanol fuel on their own. In that case the model needs to be supplemented with another part describing the formation of the production price of bioethanol depending on the bioethanol quality.

When more than one type of fuel is used at a time, the cost of the consumed fuel is stated as follows (5):

$$c_f = c_{fdk} + c_{fet}, \tag{5}$$

where C_{fdk} –specific cost of consumed diesel fuel, EUR·h^{-1};
C_{fet} – specific cost of consumed ethanol, EUR·h^{-1}.

Our study observed both, the engines with compression-ignition and high-tension ignition, which means that the model has been prepared in view of certain specific features. Two-system feed equipment is used in engines with compression-ignition. Two-system supply system when using bioethanol is not required when using compression-ignition engines, if ignition enhancer is used.

Calculation of suitable bioethanol fuel limit price c_{fet}, formed depending on the specific cost of the consumed fuel(s) c_f, in high-tension ignition engine (one fuel type) is made in relation to (6) by formulas (9; 10):

$$c_{fc} \geq c_{fet}, \tag{6}$$

where specific cost of regular fuel C_{fc} , EUR·h^{-1} is stated by formula (7) and specific cost of bioethanol c_{fet}, EUR·h^{-1} is stated by formula (8).

$$c_{fc} = B_{fc} \cdot c_{fc}, \tag{7}$$

where B_{fp} –hourly consumption of regular fuel, kg·h^{-1};
c_{fc} – filling station price for regular fuel, EUR·l^{-1}.

$$c_{fet} = B_{fet} \cdot c_{fet}, \tag{8}$$

where B_{fet} – hourly consumption of bioethanol, kg·h^{-1};
c_{fet} – bioethanol limit price EUR·l^{-1}.

$$B_{fc} \cdot c_{fc} \geq B_{fet} \cdot c_{fet}. \tag{9}$$

$$c_{fet} \leq \frac{B_{fc} \cdot c_{fc}}{B_{fet}}. \tag{10}$$

In this study, however, a two-fuel supply system (on diesel engine) is used to supply the engine with fuel, which leads to the following relation (11):

$$B_{fdT1} \cdot c_{fdt1} \geq B_{fdT2} \cdot c_{fdT2} + B_{fetT2} \cdot c_{fet}, \tag{11}$$

where B_{fdT1} – hourly consumption of diesel fuel in regular test, kg·h^{-1};
B_{fdT2} – hourly consumption of diesel fuel in case of two-fuel supply system, kg·h^{-1};
B_{fetT2} –hourly consumption of bioethanol in case of two-fuel supply system, kg·h^{-1};
c_{fdT1} – filling station price for diesel fuel at regular test, EUR·l^{-1};
B_{fdT2} – filling station price for diesel fuel in case of two-fuel supply system, EUR·l^{-1}.

The given limit price for use or production of bioethanol in comparison with using regular fuel is shown in formula (12):

$$c_{fet} \leq \frac{B_{fdT1} \cdot c_{fdT1} - B_{fdT2} \cdot c_{fdT2}}{B_{fetT2}}. \tag{12}$$

The formula (12) is used in a simplified form (13), when diesel fuel at the same price is used $c_{fd} = c_{fdT1} = c_{fdT2}$ in the test T1 as regular fuel and in the tests T2…T5 as additional fuel with bioethanol.

$$c_{fet} \leq \frac{(B_{fdT1} - B_{fdT2})c_{fd}}{B_{fetT2}}, \tag{13}$$

where c_{fd} – filling station price for diesel fuel, EUR·l^{-1} .

Engine and fuel. Bioethanol is used, if fuels with different ethanol content and diesel fuel are used for assessing the fuel in compression-ignition engine. The components used for preparing the tested ethanol fuels included ethanol (96 % vol) and distilled water. Ethanol fuels were prepared by mixing, i.e., by adding distilled water to ethanol, which resulted in mixtures with spirit content of 60 %; 70 %; 80 % and 90 % (Table 1).

The engine testing was carried out in the engine testing laboratory of the Estonian University of Life Sciences by using the engine with compression-ignition D-120 and braking stand Dynas3 LI-250. The general test scheme is shown in Figure 1. The test engine was selected based on its structural characteristics. This engine is air-cooled and allows using additional supply-system and measuring devices. According to the obtained results comparative schedules were prepared and analysis was performed. An additional supply system was used for equipping the engine with different ethanol fuels. The main supply system was used for igniting the fuel mixture with regular fuel (diesel fuel), because of poor ignition properties of ethanol mixture. The additional supply device consisted in a carburettor connected between the intake manifold and air measurement system. The carburettor main jet throughput adjustment was used to determine the optimum pre-supply amount of ethanol fuel which ensured stability of engine operation. Carburettor adjustment characteristics for choosing the quantity of pre-supply of ethanol fuel were performed before [6] and are not further discussed here.

Table 1

Fuels selected for testing

Test	Fuel
T1	Diesel fuel
T2	Diesel fuel + ethanol 60 %(V/V)
T3	Diesel fuel + ethanol 70 %(V/V)
T4	Diesel fuel + ethanol 80 %(V/V)
T5	Diesel fuel + ethanol 90 %(V/V)

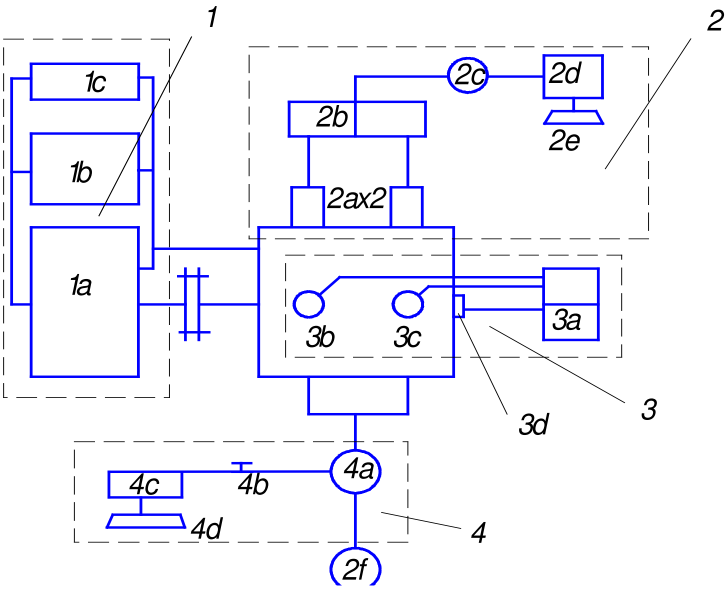


Fig. 1. **General scheme of testing different fuels and fuel mixtures in compression-ignition piston engine:** 1 – braking stand Dynas LI250 (1a – asynchronous engine, 1b – frequency converter, 1c – control automatics); 2 – supply system (2a – injectors, 2b – high-pressure pump (in-line), 2c – pre-supply pump, 2d – fuel tank, 2e – scales, 2f – air consumption reader); 3 – combustion process control module, AVL (3a – computer, 3b – pressure sensor, 3c – optical sensor, 3d – crankshaft angle sensor); 4 – module for supplying the engine with different fuels and fuel mixtures (4a – additional device for preparing fuel mixture, 4b – dosing valve, 4c – special fuel tank, 4d – scales)

The engine tests were performed at load mode $n_{e,t1} = 1800\ \mathrm{min}^{-1}$ and $T_{e,t2} = 90\ \mathrm{N{\cdot}m}$, without readjusting the engine. The measurements included fuel consumption b_f, air consumption b_a, temperature of exhaust gases t_{egt}, and oil temperature t_o.

Fuel consumption was measured separately for diesel fuel used in case of pilot injection and for bioethanol fuel used in case of the engine with an additional fuel-supply device. The measurement results were registered by means of electronic scales. The measured results were used to calculate the hourly fuel consumption B_{fet} and B_{fdk}. The values of the specific cost of fuel consumption were calculated and ethanol limit prices were found.

Results and discussion

The results derived from the fuel cost and pricing of compression-ignition engine D-120. The specific cost of the fuel is estimated on the basis of the test results measured in case of fuels with different water content. The tests have been performed by measuring the amount of fuel at constant engine load and crankshaft rotation speed. The results are shown in Table 2 and Figure 2.

Table 2

Comparisons of the quantity of fuel consumption in the course of engine testing

Test	B_{fdk}, kg·h^{-1}	B_{fetabs}, kg·h^{-1}	B_f, kg·h^{-1}
T1	4.90	0.00	4.90
T2	2.82	5.18	8.00
T3	2.34	5.14	7.48
T4	2.16	5.47	7.63
T5	1.62	5.85	7.47

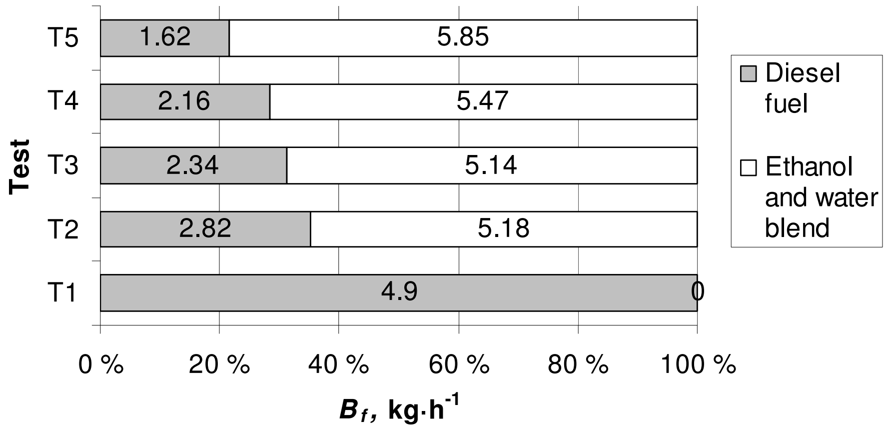


Fig. 2. **Absolute fuel quantities and relative proportion used in testing when comparing diesel fuel and ethanol**

Calculation of the bioethanol limit price in the model was based on the relative price of diesel fuel c_{fdk} = 1 unit. The comparison of the resulting limit price calculation, when using either bioethanol with different ethanol content or diesel fuel in compression-ignition internal combustion engine, is given in Figure 3. The figure shows calculated higher limit prices of (producing) bioethanol with different content that ensure equal cost of bioethanol fuels used in the tests in comparison with using regular fuel (diesel fuel).

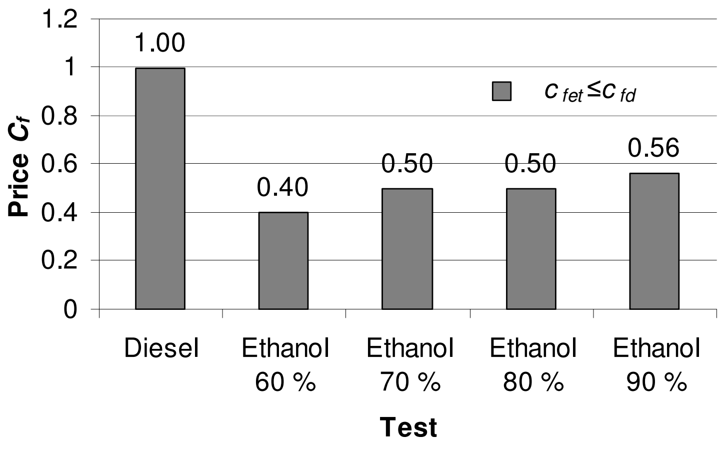
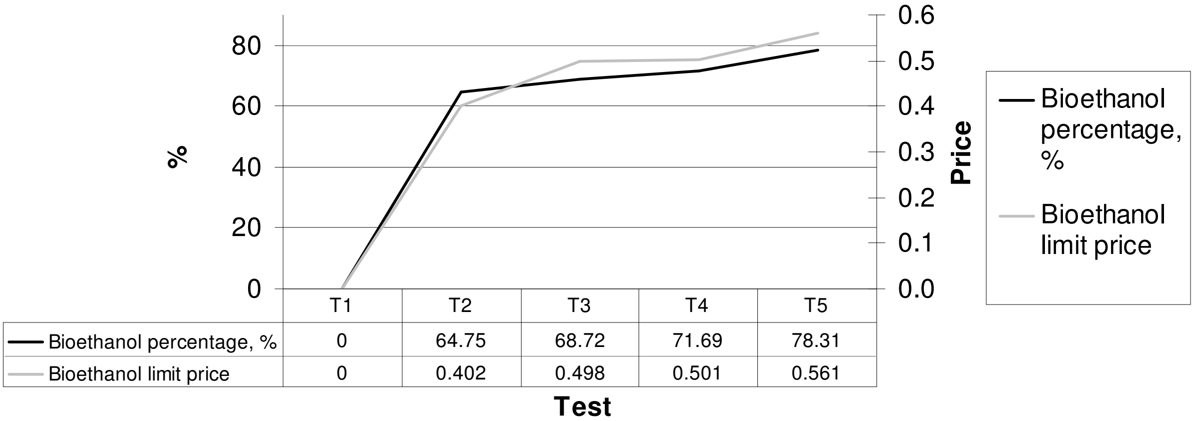


Fig. 3. **Formation of limit price of bioethanol with different ethanol content depending on the cost price of diesel fuel**

Based on the analysis of the results obtained by using internal combustion engine D-120, the maximum limit price when using 60 % bioethanol must be 60 % lower than that of regular fuel (40 %), in order to remain competitive. Meanwhile, when using 90 % bioethanol, the limit price may increase up to 56 % of the regular fuel price.

For better and condense overview the formation of the maximum bioethanol limit price and the proportion of bioethanol in fuel depending on the ethanol content are presented in Figure 4.



	T1	T2	T3	T4	T5
Bioethanol percentage, %	0	64.75	68.72	71.69	78.31
Bioethanol limit price	0	0.402	0.498	0.501	0.561

Fig. 4. **Bioethanol limit price and proportion in fuel depending on ethanol content**

Conclusions

1. If the specific cost of fuel consumption is the same both for regular fuel and bioethanol fuel, then the maximum allowed limit price of bioethanol production when using 60 % bioethanol in the fuel is 28.5 % lower than the price of bioethanol with higher concentration (90 %). In order to choose which bioethanol concentration is better suited for using as motor fuel, one has to find the bioethanol production cost curve based on the ethanol content.
2. However, quantitatively we can use less 60 % bioethanol than 90 % bioethanol in total fuel amount (Figure 4). Thus, using bioethanol with lower content sets certain limits to increasing the proportion of bioethanol fuel in transportation.
3. The specific fuel consumption is on average 36% higher when using ethanol fuels than when using regular fuel. However, when using bioethanol, the total fuel amount in the tests (T2, T3, T4, T5) is relatively similar irrespective of the ethanol content (largest difference 6.6 %).
4. When selecting or developing the production technologies of bioethanol fuel it is possible to employ the calculation model for determining the bioethanol limit price (Figure 3) based on the ethanol content.
5. Further research will comprise preparation of a model describing the limit price of using bioethanol and the relation between the formation of the production price depending on the ethanol content.

References

1. Bremers G., Birzietis G., Blija A., Danilevics A.Skele A. Scheme of technology for congruent dehydration of bioethanol in semi-dry way. Engineering for Rural Development,Latvija, 2011, pp. 244-247.
2. European Union: „Directive 2009/28/EC/ of the European Parliament and the Councilof 23April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending Subsequently Repealing Directives 2001/77/EC and 2003/30/EC.
3. Persitski H. Kattetuluarvestyusedtaime- jaloomakasvatuses. JänedaÕppe- jaNõuandekeskus OÜ, 2006, pp. 13-35.
4. Reintam A. Optimaalnepõllutöömasinalaius..EestiPõllumajanduseAkadeemiateadusliketööde kogumik,1982, pp. 13-27.
5. Demirbas A. Biofuels,. Trabzon, 2009, pp. 96-99.
6. Olt J., Mikita V., Ilves R.., Küüt A. Ethanol as an Additive Fuel for Diesel Engines. Engineering for Rural Development, Latvija, 2011, pp. 248-253.