IMPACT OF BIOETHANOL FUEL ON OUTPUT PARAMETERS OF TWO-STROKE RECIPROCATING ENGINE

Arne Kuut, Risto Ilves, Andrey Vlasov, Kaarel Soots, Juri Olt
Estonian University of Life Sciences
arne.kyyt@emu.ee

Abstract. This is a preliminary study of a more extensive research on the possibilities of using second generation bioethanol as a fuel. The main intention is to research, develop and implement the possibilities of using bioethanol fuel in agriculture and forest management. In the framework of this research, bioethanol is used as one of the main components in a fuel mixture for a small volume two-stroke internal combustion engine. The research methodology used was mainly based on testing. The article analyses the results achieved in testing the engine. The aim of the study was to assess the effect of bioethanol on the output and economy parameters of the engine and on the composition of exhaust gases. The results of the tests and the discussion are presented in comparison with regular fuel. As a result of the study, it can be said that using bioethanol and two-stroke engine oil as a fuel mixture was not accompanied by a quick wear of the elements of the engine, but by corrosion. The analysis of the harmful substances contained in the exhaust emissions revealed a significant increase in nitric oxides; yet, no significant reduction in the amount of carbon monoxide. From the perspective of economy, the fuel system of two-stroke engines must be reconstructed in order to achieve better results.

Keywords: two-stroke reciprocating engine, oil and bioethanol fuel mixture, lubrication, engine output parameters.

Introduction

Second generation bioethanol is one of the most suitable renewable fuels for internal combustion engines. Organic ligno-cellulosic raw materials, such as wood residues, agricultural residues, straw, etc. are used for the production of second generation bioethanol. In terms of domain, the common denominator of organic raw materials is agro-biomass [1]. The advantage of producing second generation bioethanol is the fact that its raw material does not compete with the production of foodstuff [2]. A problem, however, is the low production capacity of bioethanol in Estonian conditions at the moment [3] and its physical-chemical properties that hinder usage compared to regular fuels. One possibility for developing bioethanol as a motor fuel is using additional fuels. The usage of additional fuels requires a dual system fuel apparatus or producing air-fuel mixture as another possibility. The dual system fuel apparatus enables using bioethanol without additives. For this purpose, a separate additional bioethanol fuel system [4] has to be added to the engine that requires additional expenses compared to using mixtures. The use of bioethanol fuel mixtures has been studied more widely. Bioethanol-diesel-biodiesel mixtures [5], bioethanol-petrol mixtures [6; 7] and bioethanol-diesel mixtures[8] have been studied.The main problem in producing bioethanol is the production of anhydrous ethanol and mixtures. Development of anhydrous technologies has been researched at the Latvian University of Agriculture [9]. In the production of fuel mixtures, the main problem is the non-mixing of ethanol, oil and regular fuels. Problems of mixing arise from the polarity of the substances. A primary mixing method that has shown positive results has been developed at the engine laboratory of the Estonian University of Life Sciences. One possibility for using bioethanol and oil mixture is insmall cubature two-stroke engines. This is reasonable in conditions where the production volumes of bioethanol are not that big. Generally, machines with two-stroke and small cubature engines are operatedinthe vicinity of people, where the harmful substances of exhaust gases are particularly important. Using bioethanol in two-stroke engines compared to petrol provides the possibility for reducing the harmful substances found in exhaust gases [10].At the same time, the impact of bioethanol on the working details of the engine is a problem. A two-stroke engine needs fuel with good lubrication properties in order to ensure the proper functioning of the engine stroke group. The third but no less significant problem comprises of the economy indicators, i.e., fuel consumption. To solve the problems mentioned, a test-based research method was used. The tasks comprised producing a suitable bioethanol fuel mixture and implementing engine tests.

The aim of this article is to provide an overview of the impact of bioethanol and oil mixture on the output parameters of a two-stroke engine as well as on exhaust gas emissions. Additionally, the impact of bioethanol fuel on the working details of the engine was evaluated.

Materials and methods

The tests were conducted using two two-stroke engine generators NPEGG780-2 (Table 1, Fig. 1); the fuel used was a mixture of a regular fuel (E95) and a combination of bioethanol-oil (Table 2). The oil in the production of both fuel mixtures was two-stroke motor oil Addinol *Super Synth 2T MZ 408*. The generators were chosen to ensure as constant test conditions as possible. In comparative tests of engines, it is important that the devices compared would work in as similar working conditions as possible. The main working conditions that have to be strictly observedare load and environmental conditions. When using generators, similar working conditions can be much more easily guaranteed than compared to, for example, chainsaws, in order to get more precise measurement results. The technical data on the generators are indicated in Table 1 and the physical indicators of the test fuels in Table 2.

Table 1

Manufacturer's data of the generator

Property name	Manufacturer's engine data
Model	LTE145
Type	2-stroke, ventilated, one-cylinder
Piston stroke	40 mm
Cylinder capacity	63 cm³
Maximum engine power	2 hp (1.5 kW) 3000 rpm
Fuel	Unleaded petrol
Fuel to oil ratio of the fuel	1/50
Ignition system	C.D.I
Spark plug type	F6RTC

Table 2

Tested fuel properties and lubrication properties

Fuel	Density*, $kg \cdot m^{-3}$	Viscosity (KV)**, $mm^2 \cdot s^{-1}$	Force of friction***, N
Ethanol	0.8096	1.653	19.94
Ethanol+oil	0.8297	1.746	11.06
Gasoline+oil	0.7672	0.660	15.01
Gasoline	0.7593	0.584	20.61

* Measured at 15 ºC

** Testing method ASTM D445

*** Measured using test stand GUNT TM 260.03

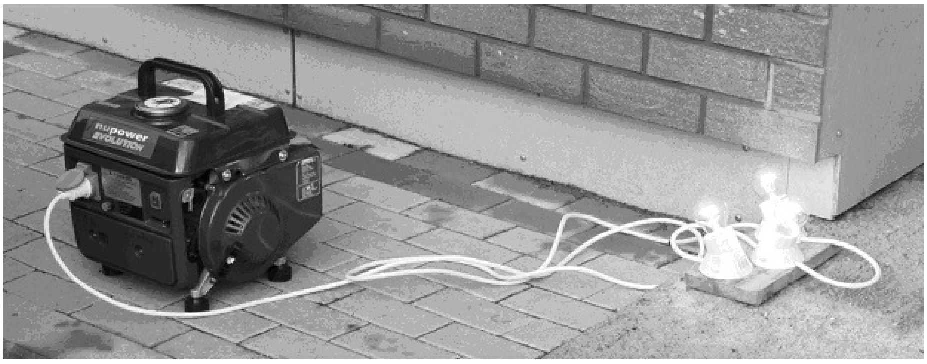

Fig. 1. **Test apparatus**

The engine tests were carried out in two parts as Test 1 and Test 2. During the experiments of Test 1 the generator carburettor, working with bioethanol, was adjusted so that the engine operation would be in balance. The need of adjustment is caused by the lower calorific value of ethanol and larger oxygen content. To load the generators, consumers with the capacity of P = 200 W for one test device were used. The total duration of the tests was 300 hrs, in Test 1, t_1 = 200 hrs and in Test 2, t_2 = 100 hrs. Test 1 was performed with the original adjustment of the generator fuel system. In conducting Test 1, problems occurred in the use of bioethanol-oil mixture and due to this, the test conditions were chosen to be changed in Test 2. The problem caused weaknesses in the fuel system, as a result of which there was a need to reconstruct the carburettor of the bioethanol generator (generator II). During the reconstruction, the diameter of the port of the carburettor nozzle d_2 was increased, taking the fuel need B_{f2} as a basis. The diameter of the nozzle port d_2 of the generator working with bioethanol fuel was found from the following relation:

$$d_2 = \frac{B_{f2} \cdot d_1}{B_{f1}}, \tag{1}$$

where B_{f1} – amount of the measured gasoline-oil in case of non-modified nozzle $g \cdot h^{-1}$ (Test 1);
B_{f2} – necessary theoretical bioethanol fuel amount $g \cdot h^{-1}$;
d_1 – diameter of the non-modified nozzle port in mm;
d_2 – diameter of the modified nozzle port in mm.

The calculations of the necessary amount of fuel in using bioethanol on the given test conditions were based on special combustion heat for petrol Q = 43.5 $MJ \cdot kg^{-1}$, but for ethanol Q = 26.8 $MJ \cdot kg^{-1}$ [13]. The results indicate the diameter of the nozzle port as d_2 = 1.16 mm. The literature sources suggest increasing the diameter of the nozzle port by at least 1.5 times [14]. Considering the low engine efficiency in bioethanol use and problems related to lubrication, it was decided to increase the initial nozzle port in order to ensure lambda value of 0.9. The initial diameter of the port d_1 = 0.71 mm was increased to the diameter of d_2 = 1.37 mm (Fig. 2).

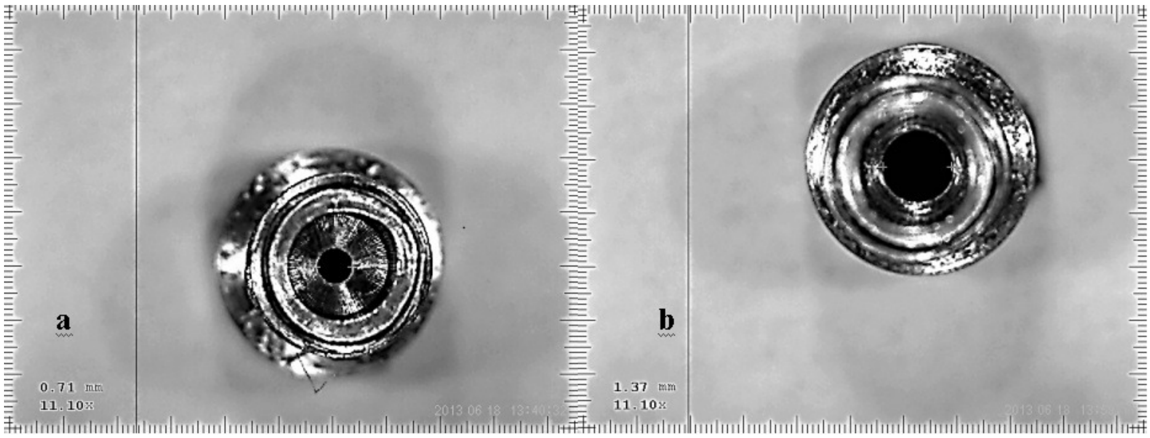

Fig. 2. **Non-modified nozzle port (a) and modified nozzle port (b) of the generator II**

Measurements were conducted at the beginning and end of the test. By using comparative analysisafter receiving the test results,the fuel consumption B_f was evaluated and analysed, as well as the content of exhaust gases depending on the type of fuel and the regulation of the test device fuel system.

The share of the compounds found in exhaust gases was measured with the device BEA-350 and has been presented as comparative analysis. Following from the test conditions, the measurement results of the generators can be compared. The measurement results of Test 1 and Test 2 are not directly comparable due to different environmental conditions. The tests were conducted during different seasons, and thus, the environmental parameters differed, for example, temperature during the tests: Test 1 T_1 = 12.5 ºC and Test 2 T_2 = 26.0 ºC.

Additionally, the wear of the working details was determined [15] and the influence of corrosion was evaluated, which is, however, not elaborated further in this article. A summary of the results received during the test have been presented as well as main problems encountered that could start influencing the functioning of the engine in a long-term perspective.

Results and discussion

In evaluating the output parameters, fuel consumptionB_{fet}in Test 1ethanol generatorincreased 134.6 % (Fig. 3),compared to the fuel consumption of a petrol generator B_{fd}. Normal increase in fuel consumption when using ethanol is 60-70 % based on the fuel calorific value. The problem was the too small a port of the fuel trim nozzle of the generator working with ethanol, and as a result the fuel mixture was insufficiently trimmed (Fig. 2-a). To solve the problem in Test 1, the ongoing stream of air into the engine was limited by partly closing the air valve of the carburettor. This solution ensured stabile functioning of the engine on the previously mentioned load, but caused the formation of a rich air-fuel mixture. The small port of the carburettor nozzle caused an additional problem, where oil gathered to the bottom of the float-chamber, spoiling the work of the fuel system and causing the engine to switch off. The problematic sedimentation of the oil onto the bottom of the float-chamber, when using bioethanol fuel mixture, was partly caused by the non-mixing of substances. In Test 2, with a modified carburettor, oil did not sediment out and the engine continued stable operation. Based on this result, it can be said that in an engine with a modified carburettor, the fuel mixture of oil and bioethanol can be used. The fuel consumption B_{fet} uponusing bioethanol fuel mixture in Test 2 decreased by 19 %, compared to Test 1, which is a rather positive result (Fig. 3). As a result of modification, the specific consumption of bioethanol fuel b_{fet} decreased by 275 $g\cdot(kW\cdot h)^{-1}$.As a result of the fuel consumption analysis, it can be observed that in using bioethanol in the generator when the output parameters are to be improved, the reconstruction and adjustment of the fuel apparatus has to be implemented.

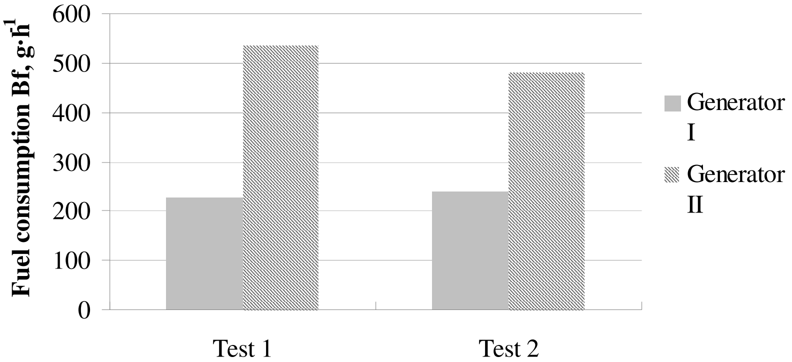

Fig. 3. **Comparison of fuel consumption**

When studying the impact of the lubrication properties and corrosion of the bioethanol fuel mixture, the studied wear details were cylinder surfaces, piston rings, piston finger, the opening of the connecting-rod neck and crankshaft bearings. Micrometric measurements were performed on the wear details three times. Initial measurements were taken before the tests began, second measurement took place between Test 1 and Test 2, and the third measurement at the end of the tests. Geometric parameters of the wear details were measured as well as surface roughness. As a result, the diameter of the generator cylinder working with regular fuel mixture had decreased by 6 μm, while the diameter of the engine cylinder working with bioethanol fuel mixture increased somewhat (7 μm). This was caused by thermal expansion during the engine working process. Similar results occurred also while evaluating the dimensions of piston rings, where there was a somewhat larger wear in using a bioethanol fuel mixture. However, engine compression increased equally by 100 kPa. When evaluating the working surfaces of the details, it can be said that upon using a regular fuel mixture, fuel residues sedimented. On the other hand, the difference in the change of cylinder and piston dimensions is caused by the difference in the fuel combustion temperatures. Studying the sedimentation of the fuel residues onto the piston surface, a better result was achieved by using a bioethanol fuel mixture, which could be also seen on Fig. 4 after 200 hours of tests. As a result of Test 2,after 300 working hours, the formation of corrosion is perceivable on the details that are in contact with bioethanol of generator II (Fig. 5). The reason is the one month suspension period of the generator after the engine tests and before the micrometric measurements that is characteristic to the regular use of the device. As a result of the influence of corrosion, anti-corrosive additives are planned to be studied and developed later, based on renewable raw materials.

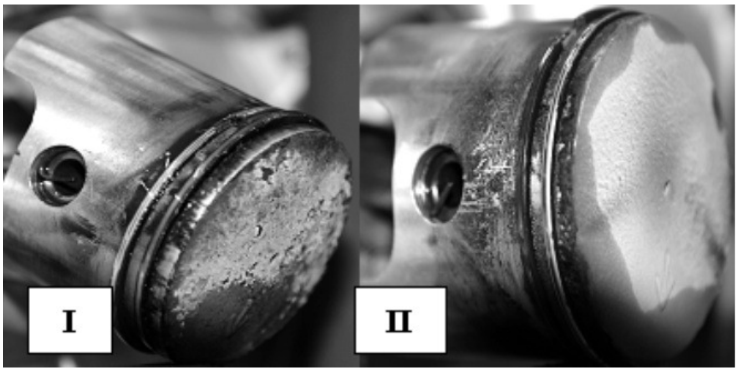

Fig. 4. **Comparison of residues on the piston with the tested generators I and II**

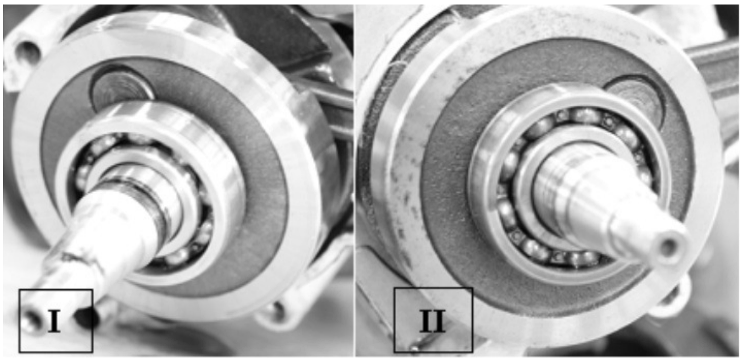

Fig. 5. **Comparison of corrosion with the tested generators I and II**

In analysing carbon monoxide (CO) components found in exhaust gases (Fig. 6), Test 1 indicates a 87 % growth in bioethanol use, compared to regular fuel. However, studying the results of Test 2 indicate a decrease of CO components over ten times in comparison of bioethanol and regular fuel. This was caused by using a better quality air fuel mixture and thus a more efficient combustion process. The noteworthy increase of CO components with regular fuels in the second test was related to the sedimentation of oil combustion residues, which spoiled the combustion process. This was also confirmed by the increase in HC residue, and this problem needs certainly further additional study.

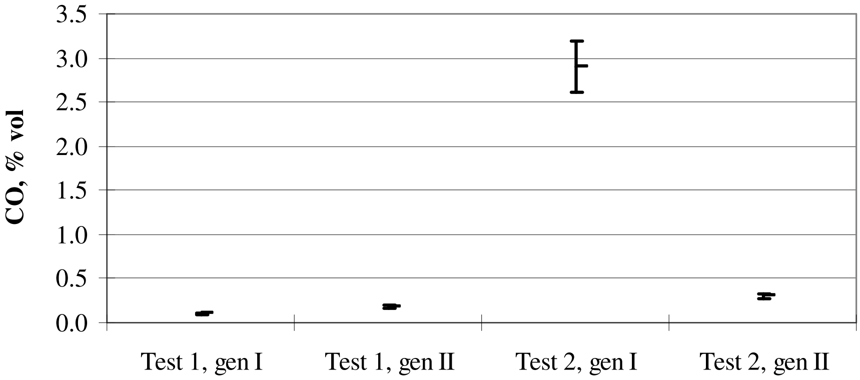

Fig. 6. **Comparison of the amounts of CO contained in exhaust gases**

The change of CO share correlates to the amounts of carbon dioxide (CO_2) in exhaust gases (Fig. 7). The results of Test 1 show a 6.3 % lower CO_2 component amount when using bioethanol, when comparing bioethanol and regular fuel. In Test 2,the CO_2indicator has increased by 12.7 % compared to regular fuel.

The better functioning of the combustion process is also characterised by the recognisable decrease of the share of hydrocarbons (HC) in the comparison of Test 1 and Test 2 (Fig. 8). Here, better results are also shown in Test 2, which indicates more complete combustion of the fuel parts also directly related to fuel consumption B_f (Fig. 3).

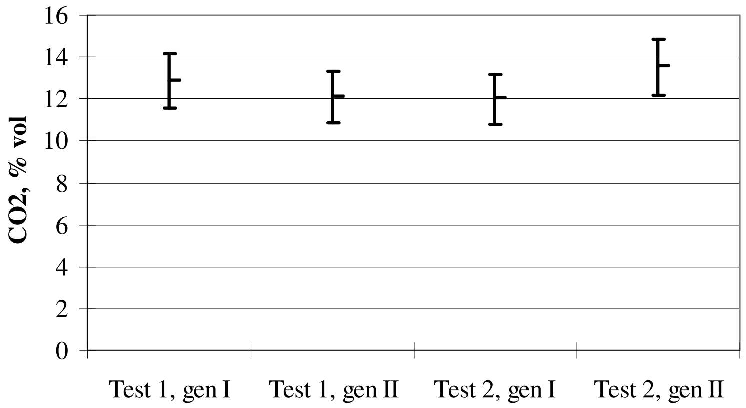

Fig. 7. **Comparison of the amounts of CO_2 contained in exhaust gases**

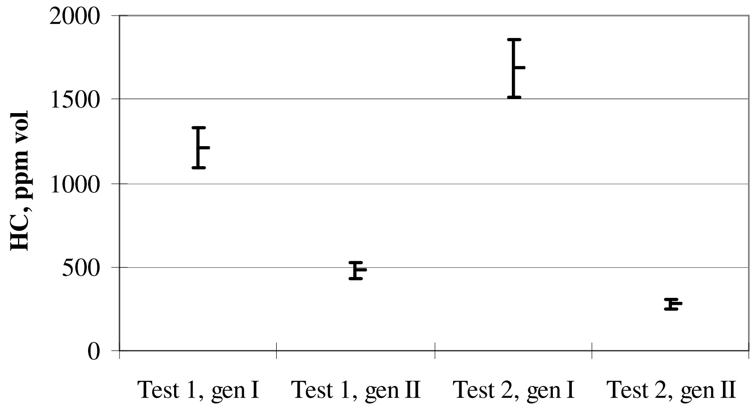

Fig. 8. **Comparison of the amounts of HC contained in exhaust gases**

Of the main components found in the exhaust gases of an internal combustion engine, the substances most harmful for human health besides CO and HC are nitrogen oxides (NOx). The large share of nitrogen oxide components contradicts with the general conditions in which the emission is lower when the temperature of the combustion chamber drops. One of the reasons for using a bioethanol fuel mixture with a higher NOx content is certainly an early ignition timing advance that was not changed in these tests. An optimum ignition timing advance ensures efficient fuel use in the engine. To ensure the decrease of NOx, theignition timing advance has to be changed into a later one. Fig. 9 indicates the share of NOx components during Test 2.

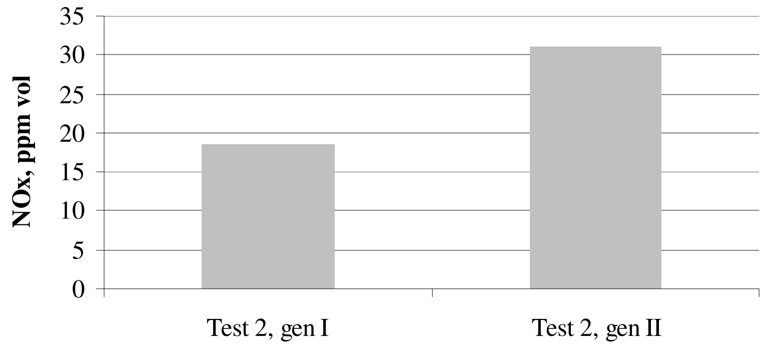

Fig. 9. **Comparison of the amounts of NOx contained in exhaust gases in Test 2**

During the use of a bioethanol fuel mixture in Test 2 compared to a regular fuel (gen I), the share of NOx components has increased 67.6 %. Based on these results, it can be claimed that the development of the use of bioethanol fuel certainly requires the modification of the construction of the fuel apparatus and the adjustment of the ignition system.

Excessive amount of oxygen (Fig. 10) in the exhaust manifold in Test 2 could cause a thermal post-reaction, increasing the share of NOx in exhaust gases. One possibility to decrease NOx exhaust gases is to drop the combustion temperature, which, in its turn, increases fuel consumption and the share of HC exhaust gases.

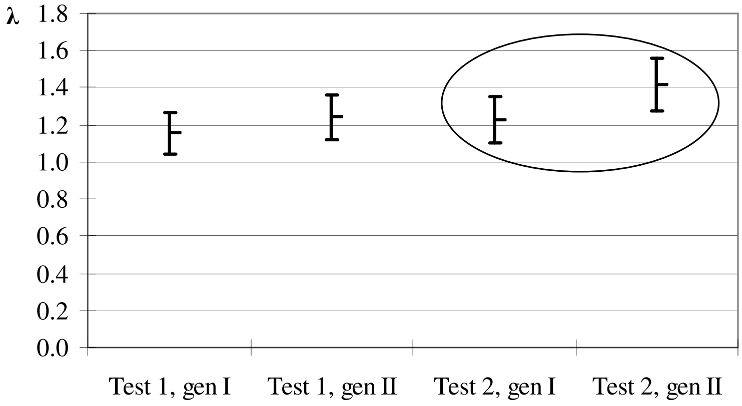

Fig. 10. **Comparison of the results of lambda in exhaust gases**

Therefore, the formation of residues of exhaust gases certainly needs further experiments and analyses. As a result of analysing the data of the engine tests, the formation of the share of NOx compounds has to be more thoroughly studied. The main cause is nitrogen dioxide (NO_2), which is a particularly toxic compound of nitrogen and oxygen in the exhaust gases of an engine.

The further research activities aim to develop a bioethanol fuel mixture based on second generation bioethanol and additives, which would be based on renewable and sustainable resources.

Conclusions

1. By mixing bioethanol and two-stroke engine motor oil *Addinol MZ 408*, a fuel mixture with sufficient lubrication properties has been created. The lubrication test showed that friction with bioethanol mixture was 26 % lower compared to regular fuel.
2. Considering the test results, the ratio of oil and bioethanol is recommended as 1/50, the same as the oil producer has prescribed for the use of engine petrol.
3. Minimal problems in wear have been observed in the use of the bioethanol fuel mixture, while combustion residues have sedimented in a smaller extent on the working surfaces of the engine details, compared to the use of a regular fuel mixture.
4. When using the bioethanol fuel mixture, a problem, which needs to be solved, is corrosion.
5. The share of harmful substances in exhaust gases from the modified generator when using a bioethanol fuel mixture is lower, CO 89.6 % and HC83.5 %, compared to the use of regular fuel mixture. The share of NOx-sin exhaust gases is67.6 % higher compared to a regular fuel mixture and this needs further study.
6. A two-stroke combustion engine working with a bioethanol fuel mixture needs the reconstruction of the carburettor and further regulation of the ignition system in order to achieve minimum fuel consumption and prevent the release of oil from bioethanol, as well as to ensure the prescribed exhaust gas norms.
7. In addition to adjusting the engine, the use of bioethanol as an engine fuel has to be further improved and additives need to be developed that would be based on renewable resources, such as the production of second generation bioethanol, the raw material of which does not compete with the food supply of humans.

Acknowledgement

The authors would like to especially thank Addinol Lube Oil OÜ (Estonia) for collaboration in this study.

References

1. Mikkola, H., J.; Ahokas, J. Renewable energy from agro biomass. Agronomy Research, 2011, 9(1), pp. 159-164.

2. Ritslaid, K.; Küüt, A.; Olt, J. State of the Art in Bioethanol Production. Agronomy Research, 2010, 8(1), pp. 236-254.
3. Küüt, A. Characteristics of bioethanol fuel obtained from lignocellulose biomass in internal combustion reciprocating engines with spark- and compression-ignition., Estonian University of Life Sciences, 2013, Tartu: Ecoprint, pp. 25-28.
4. Patent EE 05665 B1. Formation method of fuel-air mixture of reciprocating engine and flexible-fuel system. 2013. http://www.epa.ee/ul/doc/valjaanded/patendileht2013_03.pdf
5. Labeckas, G.; Slavinskas, S.; Mazeika, M., Laurinaitis, K. (2010). Performance and Emission Characteristics of Diesel Engine Fulled with Ethanol-Diesel-Biodiesel Blend. Engineering for Rural Development, Latvija, 2010, pp. 266-271.
6. Olt, J., Mikita, V., Sõõro, T., Küüt, A., Tamm, R., Raidla, E., Ilves, R., Ristlaid, K., Raudsepp, V., Viitkar, U. Bioetanool ottomootori kütusena. Agraarteadus : journal of agricultural science, 2009 (2), pp 26-35. (in Estonian)
7. Hilbert, D. High. Ethanol Fuel Endurance: A Study of the Effects of Running Gasoline with 15% Ethanol Concentration in Current Production Outboard Four-Stroke Engines and Conventional Two-Stroke Outboard Marine Engines. National Renewable Energy Laboratory, Colorado, 2011.
8. 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.
9. 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, Jelgava, Latvia University of Agriculture, 2011, pp. 244-247.
10. Demirbas, A.. Green energy and technology 3. Biofuels, Springer-Verlag, 2009, pp.96-99.
11. Standard ASTM D445 ASTM D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids.
12. GUNT Hamburg. Test stand GUNT TM 260.03. Available from: http://www.mutiaranata.com/product/detail/tm-260-03-experimental-module-pin-on-disc (15.11.2013)
13. Merker G. P., Schwarz C., Teichmann R. Grundlagen Verbrennungsmotoren. Praxis, ATZ, MTZ-Fachbuch, Germany, 2012, pp 20. (in Germany)
14. Taraba J. L., Turner G. M., Razov R. The use of ethanol as an unmixed fuel for internal combustion engines Energy in agriculture, Department of Agricultural Engineering University of Kentucky, Lexington, 1981, pp. 6-8.
15. Anderson P., Tamminen J., Standström C. E. Piston ring tribology. VTT Research notes 2178, Otamedia Oy, Espoo, 2002, p. 105.