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The impact of bioethanol on two-stroke engine work details and exhaust emission

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Abstract. This research is important for expanding the possibilities for using bioethanol as a fuel for internal combustion engines. Small displacement two-stroke engines are widely used as power sources for manual power units. By using bioethanol as a fuel for two-stroke engines, we significantly decrease the risk to human health. The main problems entailed with using bioethanol include achieving the required lubrication properties, more precisely, the poor mixing or immiscibility of ethanol and oil. In the course of the research, a breakthrough was achieved in solving the problem in order to produce a fuel mixture for two-stroke internal combustion engines.
Results covered include the effect of the fuel mixture on the functioning surfaces of an engine, but also the composition of the exhaust emissions. The aim of the investigation is to examine the effect of bioethanol fuel on the details and fuel system of a two-stroke engine. Test fuels are gasoline E 95 and bioethanol (96.3%), mixed by two-stroke engine oil. The mixture of bioethanol and oil shows the best results in the test of the friction force. That means wearing is not problematic but the problem is corrosion and CO emission.

Key words: two stroke engine, tribotechnology, bioethanol fuel blends, wearing.

INTRODUCTION

The use of bioethanol as an engine fuel is an increasing trend (IEA 2008), especially when it is manufactured based on lignocellulosic raw material. An advantage of bioethanol compared to engine fuel is the reduced concentration of hazardous components in the exhaust gases. This advantage makes it especially beneficial to use bioethanol in two-stroke engines, power saws, trimmers etc. In the case of the aforementioned equipment, the exhaust gases emitted from the engine often get into the respiratory tract of people working close to it. Such hazardous components as NO_X, CO and HC in the exhaust gases of an engine may cause headaches, irritate the mucous membranes of the eyes and throat, and cause cancer (Wargo et al., 2006). The use of bioethanol as fuel for a two-stroke engine is hampered by the fact that bioethanol does not dissolve in oils. As far as is known, a two-stroke engine requires fuel with good lubrication properties to ensure problem-free operation of the piston assembly of the engine. The reasons for that are the technical peculiarities of using bioethanol as a fuel in piston engines (Pulkrabek & Willard, 1997; Demirbas, 2009; Schwarze et al., 2010; Vesela, 2014). The majority of tests have been carried out with four-stroke engines and engines with a bigger cubature (approx. 300 HP) (Hilbert, 2011) as well as tests with fuel apparatuses (Olt et al., 2011). Moreover, the impact on the sub-systems of a two-stroke engine resulting from bioethanol fuel not conforming to the standard is not known.

This research is a preliminary study to working out biofuel for two-stroke engines. The fuel which has been used in this experimental research is bioethanol with little water content (E100) and oil blend, which has not been widely studied in the world. The effects of different blends of gasoline and bioethanol on the exhaust gas emissions of a two-stroke engine have been studied worldwide (Tung & Gao, 2003; Ghazikhani et al., 2013). What is more, the effect of ethanol on the exhaust gas of an engine has been researched (Magnusson & Nilsson, 2011). However, the use of bioethanol and oil blends as the fuel in a two-stroke engine has not been widely studied.

The use of bioethanol as a two-stroke engine fuel generally decreases CO, HC and NOx emissions (Ghazikhani et al. (2013; 2014). Studies on the wearing of engine details have indicated that different engine details (valves, bearing shells) tend to break when E85 fuel is used in a two-stroke engine. In that particular study, lubrication component was not used in the fuel. (Hilbert, 2011)

The purpose of this paper is to conduct practical research and explore the tribotechnical system of a two-stroke engine using a bioethanol fuel mixture (ethanol 96.3% vol). The surface wear of the workpieces has been the main focus in researching tribotechnical systems. In addition, an overview of exhaust emissions has been added. A more thorough overview of exhaust emissions is published by Küüt et al. (2014).

MATERIALS AND METHODS

Aims of the preliminary study discussed in the article are to examine the effect of bioethanol fuel on the details and fuel system of a two-stroke internal combustion engine, in order to assess the reliability of the engine. In the field of using biofuels as motor fuel, the author is more specifically interested in the use of bioethanol, not biomethanol (Govindarajan, 2008). When using bioethanol as a fuel for a two-stroke engine, preparing the mixture is an issue. The problem in preparing the mixture is the bad solubility of ethanol and oil. The reason for non-solubility is the polarity of the substances. In addition to examining the effect of bioethanol, the behaviour of the fuel mixture produced by a novel production method was observed as well in the course of this research. The new method for producing the fuel mixture is full of potential, if we wish to use fuel mixtures produced of renewable and domestic raw material, such as a fuel mixture produced on the basis of bioethanol and oil.

The research method used to solve the set goal was test-based. Wear testing was performed to achieve the goal in order to find problematic assembles and details. Co-functioning of the components of the tribosystem was assessed in describing the results of testing. The nature of wear and corrosion on the surfaces of the engine elements were analysed (Baširov et al., 1978). The actual working condition (load and environmental conditions) of the equipment were imitated in performing the tests.

To carry out the tests, two Evolution NPEGG780-2 power generators equipped with two-stroke engines were chosen. The parameters of the engines are given in Table 1.

Table 1. Technical data of engine of NPEGG780-2 generator

Name	Manufacturer's data
Model	LTE145
Type	2-stroke, air-cooled, one-cylinder
Piston stroke	40 mm
Cylinder displacement	63 cm^3
Maximum engine power	2 hp (1.5 kW) 3,000 rpm
Fuel	Unleaded gasoline and oil blend
Fuel to oil ratio of the fuel	1/50
Ignition system	C.D.I
Spark plug type	F6RTC

In order to imitate the actual working situation and to ensure similar working conditions in performing the engine tests (Fig. 1), it was strictly ascertained that the tested generators worked only simultaneously. The generator carburettor working on bioethanol was adjusted so that the engine would work in a balanced way. To load the generators, consumers with the capacity of P = 200W for one test device were used (engine speed n_e = 3,000 rpm). The generator load was generated by electric light bulbs.

Figure 1. Test apparatus.

To determine the required oil content in ethanol, a device GUNT TM 260.03 (Table 2; Fig. 2) for ascertaining friction force was used. This device measures the friction force of a steel pin (1) rubbing against a rotating steel disc (2). The better the lubrication properties of the liquid between the steel rod and the plate, the smaller the friction force. The friction forces of gasoline E 95, 96.3% bioethanol, and gasoline and Addinol MZ 408 two-stroke engine oil mixture and a 96.3% bioethanol and MZ 408 oil mixture were compared. As the gasoline and MZ 408 oil mixture is meant to be used as fuel for a two-stroke engine, the friction force of the bioethanol and MZ 408 mixture must be similar to or smaller than the friction force of the gasoline and oil mixture. Oil was added to the gasoline and bioethanol at a ratio of 1:50. The chapter 'Results and discussion' include the measured static and kinetic friction forces with the abovementioned fuels (Table 3). Using static and kinetic friction force for describing tribotechnical processes is justified with the nature of the work between the cylinder and the piston ring. In carrying out the test, a load of 35 N was applied to the rod.

Table 2. Specification of the test stand GUNT TM 260.03 (GUNT Hamburg)

GUNT TM 260.03	Manufacturer's data
Friction disc	Stainless steel, hardened, ground
Operating speed	Adjustable 0...0.42 m s^{-1}
Friction pin diameter	4mm
Pin material	Steel, aluminium, brass
Load	0...80N
Friction force measuring range	0...50N

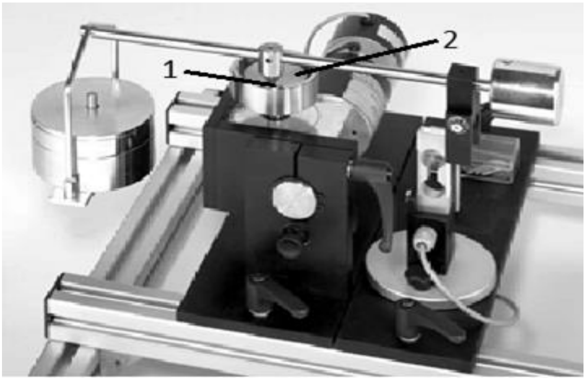


Figure 2. Pin of experimental Module TM 26003 on Disc (GUNT Hamburg).

The main issue explored in this paper is the effect of the tribotechnical processes on work surfaces. In order to describe friction and wear, elements were measured before and after an engine test. Measuring equipment MAHR MMQ-100 (Fig. 3) that enabled recording the graphic measurement results electronically was used for measuring.

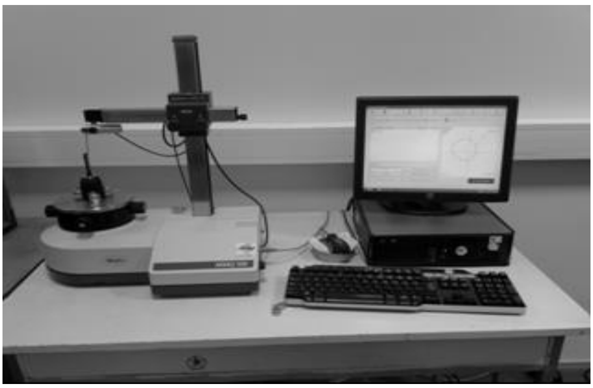


Figure 3. Measurement apparatus MAHR MMQ-100.

In order to estimate the rate of wear, the diameter of the cylinder was measured in three different positions (*I, II, II*). On the basis of the acquired results, the mean diameter was calculated. The roundness of the cylinder was also measured on two levels (*I, II)* (Fig. 4). The measurements were repeated three times for each element.

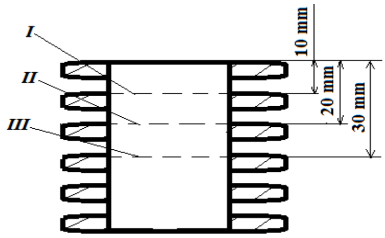


Figure 4. Measurement methods for cylinder.

The measurement points (a, b, c) for piston ring thickness are presented on Fig. 5. In order to estimate the rate of wear of the piston rings, three different measurement points were used. In determining the wear of the piston, diameter and roundness measurements were performed at two different heights (*I*, *II*).

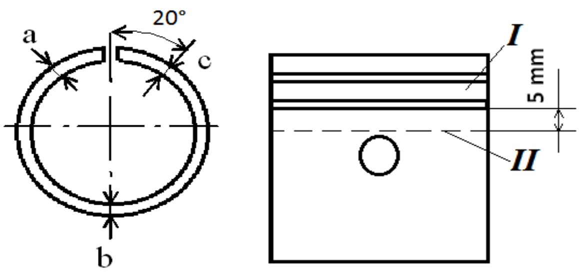


Figure 5. Measurement methods for piston rings and piston.

Roundness, diameter, and the diameter of the upper opening of the connecting rod were measured at the position of the gudgeon pin (Fig. 6).

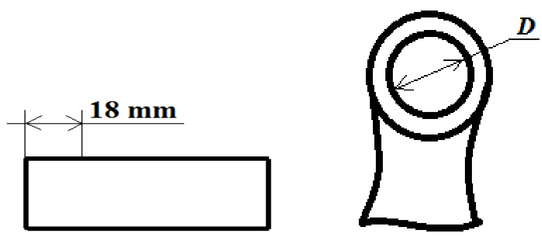


Figure 6. Measurement methods for piston pin and connection rod.

Exhaust gas emission was measured with Bosch BEA 350 exhaust gas analyser. Measured exhaust gases were CO, CO_2, HC, and NO_x. The test data was analysed in Excel 2010 program. The average results were calculated and analysed using Descriptive Statistics method.

RESULTS AND DISCUSSION

Table 3 and Figs 7, 8 show the tested fuels and the measured friction forces of the steel disc in various speed conditions. The data shows that the smallest friction force was measured about the bioethanol and oil blend. The oil content in bioethanol is 2%. The oil content was determined using test method (Standard EN ISO 3405). Comparing the kinetic friction force of bioethanol and oil mixture with the kinetic friction force of the gasoline and oil mixture, it is evident that the lubrication properties of the bioethanol and oil mixture are approx. 27% better (Fig. 8). The static friction force of the bioethanol and oil blend is 13% lower than the respective data of a gasoline blend (Fig. 7). This leads to the conclusion that the oil content in ethanol may also be less than 2%. But as it is a fuel not normally used in two-stroke engines, the oil content in the ethanol was not reduced in these tests. When comparing the friction forces of bioethanol with those of the bioethanol and oil mixtures, adding oil to the bioethanol at a ratio of 1:50 reduces the friction force by approximately 50%.

The values of the kinematic friction forces of bioethanol and gasoline are comparable (Table 3). At the same time, the static friction force of bioethanol is 20% higher than that of gasoline. As a result, it can be claimed that the quality of blending is extremely important when preparing a bioethanol fuel mixture since it directly influences the tribotechnical processes of the workpieces.

Table 3. Tested fuel properties and friction forces while verifying lubrication properties of fuel

Fuel	Density	Viscosity (KV)	Testing regime and performance data (N)			
	(kg m^{-3})*	(mm^2 s^{-1})**	*Start*	*20 rpm*	*50 rpm*	*70 rpm*
BE ***	0.8096	1.653	25.1	20.9	19.6	19.4
BE + oil	0.8297	1.746	13.6	11.8	10.9	10.4
Gas. + oil	0.7672	0.660	16.3	15.8	14.8	14.4
Gas.	0.7593	0.584	20	20.7	21.3	19.8

* Measured at 15°C

** Testing method for kinematic viscosity (Standard ASTM D445)

*** BE – bioethanol.

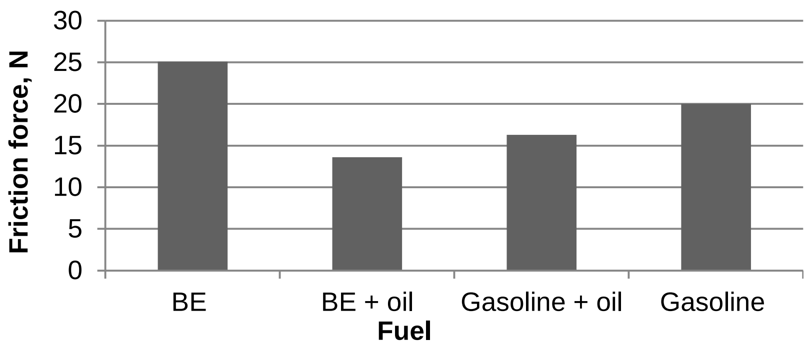


Figure 7. Static friction force of tested fuel.

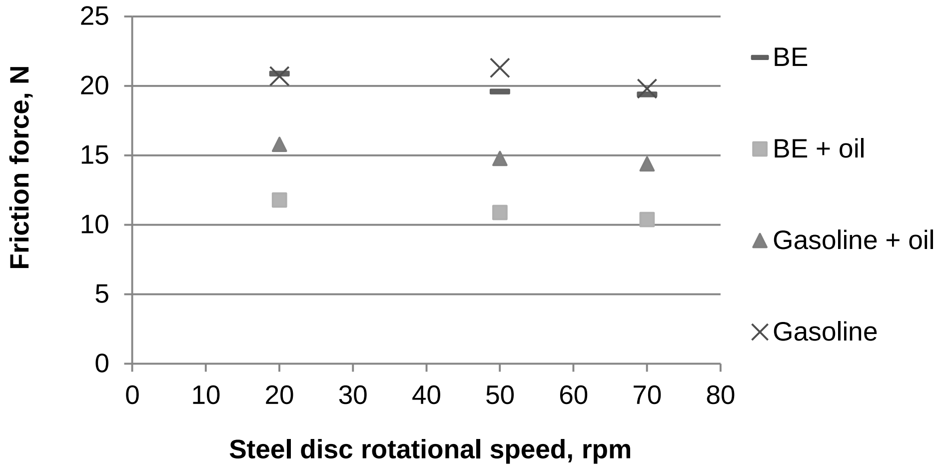


Figure 8. Kinetic friction force of tested fuel.

During the test, several problems arose in the engine of the generator working with the bioethanol and oil mixture. An overview of the problems and analysis of the measuring data is available below. The appendix includes measurement data recorded before testing and after 200 operation hours.

In the case of Generator 1 (working with the gasoline E95 and Addinol MZ 408 oil mixture) it was noted that the diameter of the cylinder had decreased. The average diameter of the cylinder had reduced by 6 µm. This was caused by thermal processes and residue accumulating between the structures of the workpieces due to the wear of the piston rings. In the case of Generator 2 (working with a 96.3% bioethanol and oil mixture) the average diameter of the cylinder had increased by 7 µm. This was caused by the running-in of the engine. The diameter of the cylinders can also be influenced by the repeated warming and cooling of the material, which is a constant process during the operation of the engine. (All engine details measurement data is presented in Table 5).

In this test the diameter of the engine piston in Generator 1 increased. In the case of Generator 2, the diameter of the piston decreased. This was influenced by the operation temperature of the engine and fuel combustion residue accumulating on the surfaces of the part. In the case of Generator 1, a lot of fuel combustion residue accumulated on the piston. In the case of Generator 2, there was less fuel combustion residue on the piston, which was also easier to clean.

Residue generated during fuel combustion (mainly soot) may get in between the piston rings and onto the sides of the piston when mixed with the fuel mixture. In the case of Generator 2, accumulation of this nature was observed to a lesser extent. Soot is a fine-fractioned by-product of incomplete combustion or the thermal decomposition of hydrocarbons. The exhaust gas analysis of the given engines (Appendix) shows that the content of unburned hydrocarbons (HC) in the exhaust gases is significantly lower (61%) for the engine working on the bioethanol and oil mixture (Fig. 9).

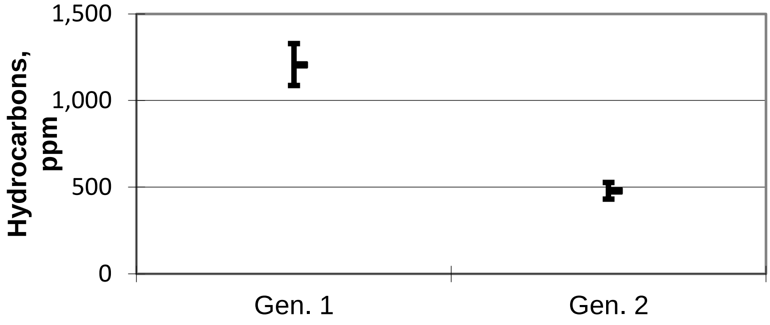


Figure 9. Comparison of the amounts of hydrocarbons.

This is caused by cleaner combustion of bioethanol due to the reduced content of substances causing the presence of hydrocarbons in fuel. As far as is known, hydrocarbons can irritate the mucous membranes of the eyes and throat, cause cancer, etc. Besides this, the quantity of soot is also greater in the combustion chamber of Generator 1. When the engines operated on a bioethanol and oil mixture, the CO emission level of the engines was 85% higher (Fig. 10) and CO_2 emission level 6% lower.

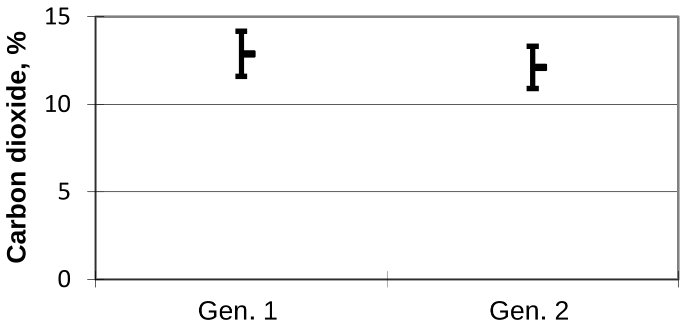
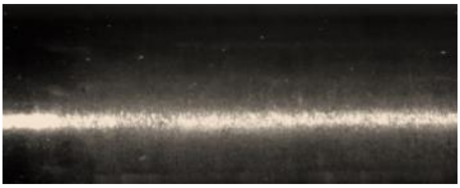
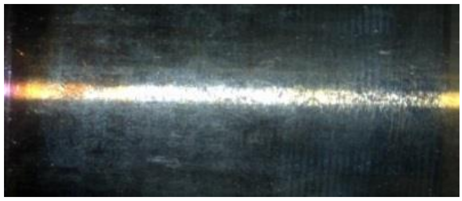


Figure 10. Comparison of the amounts of carbon dioxide.

In the case of the spark plugs, no increase in the content of combustion residue was detected. Such mixing of soot and fuel may cause the piston rings to stick or bring about engine failure when loads are bigger and temperatures higher. (All measurements of exhaust gases of the engine are presented in Table 6).

These engines were equipped with a needle roller bearing operating in the opening of the connecting rod neck. Thus the main wear surface is the area under the bearing. The diameter of the connecting rod neck of Generator 1 increased by 7 µm and the diameter of the piston pin increased by 7 µm. The reason for such an increase was the accumulation of fuel combustion residue and material from the bearing on the working surface of the piston pin. Also, thermal reactions may cause an increase in diameter. In the case of Generator 2, the diameter of the connection rod neck decreased by 5 µm and the diameter of the piston pin by 4 µm. This leads to the conclusion that these working surfaces had started wearing. When viewing the piston pin under a microscope, no differences on the working surfaces were detected. The working surface of the piston pin of Generator 2 was corroded, which can also be seen in the photo in Table 4. Corrosion was present in the deeper parts of the structure of the material, which the surfaces of the working elements of the needle roller bearing did not reach. In addition, in both engines a pin had started moving in the piston opening. Such movement is not desired. As a result, the material of the piston had stuck to the piston pin (see Table 4).

Table 4. Working surfaces of piston pin

	
Gen. 1 piston pin, working surface below the bearing.	Gen. 2 piston pin, working surface below the bearing.
	
Gen. 1 piston pin, the end of the piston pin.	Gen. 2 piston pin, the end of the piston pin.

Based on observation and measuring data, it can be concluded that the piston pin is exposed to the greatest load and highest temperature. At the same time, supplying the piston pin and its needle roller bearing with the fuel mixture is insufficient. This may be caused by the design peculiarities of the engine.

One of the problems is the accumulation of oil at the bottom of the carburettor float chamber, which caused the fuel jet to clog (see Fig. 11).

Figure 11. Accumulated oil in carburettor float chamber.

This problem mostly occurs at low temperatures. This means that the method used for mixing does not guarantee that the oil and ethanol mixture is 100% homogenous. To improve this, fuel additives should be used to help to reduce the abovementioned problem. Another major problem is starting an engine at temperatures lower than 10°C. To achieve this easily, evaporating substances (e.g., ether) should be added to the fuel used. This would guarantee the engine starting even at lower temperatures. The emergence of these problems provides a great deal of information for the development of a bioethanol fuel for two-stroke engines.

CONCLUSIONS

Addinol MZ 408 two-stroke engine oil can be used with bioethanol in a two-stroke engine. The oil ensures that the fuel has sufficient lubrication properties and does not cause generating significant amount of soot in the engine. Based on the results of test, the recommended oil to bioethanol ratio is 1/50, the same as prescribed by the oil manufacturer when using gasoline. A major problem is the lubrication of the piston pin, although this also depends directly on the design peculiarities of the engine. In conclusion, it can be said that according to test results, it was not detected that using a bioethanol and oil mixture cause the more rapid wear of engines compared to the use of an gasoline and oil mixture. When measuring the parts of an engine working on gasoline, it was noted that some measurements had increased. The reason for this is the high temperature in the cylinder. It is well known that bioethanol absorbs more energy than regular fuel during evaporation, and, thus, the temperatures in the cylinder are lower. When the engines operated on a bioethanol and oil mixture, the CO emission level of the engines was approx. 80% higher, which means that it is important to adjust the ignition angle of the engine and to reconstruct the carburettor, which ensures the combustion of the higher quality fuel mixture in the cylinder. The abovementioned improvements also reduce fuel consumption. The concentration of other components of exhaust gases—HC and CO_2—was reduced.

The problem was the stratification of the oil in the float chamber of the carburettor, on account of which the jet opening was clogged with oil. To solve the given problem, it is necessary to lessen the amount of oil in the fuel mixture and change the construction of the carburettor in order to guarantee the effective work of the engine.

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REFERENCES

Baširov, R., Kislov, V., Pavlov, V., Popov, V. 1978. Reliability of fuel injection equipment tractor and combine diesels. *Engineering*, 184 pp. (in Russian).

Demirbas, A. 2009. *Biohydrogen: For Future Engine Fuel Demands*. In Chapter 3. Biofuels, p. 61–84, Springer Verlag. 336 p.

Ghazikhani, M., Hatami, M., Safari, B., Ganji, D.D. 2013. Experimental investigation of performance improving and emissions reducing in a two stroke SI engine by using ethanol additives. *Propulsion and Power Research*, Volume 2, Issue 4, 276–283.

Ghazikhania, M., Hatamib, M., Safaria, B., Ganji, D.D. 2014. Experimental investigation of exhaust temperature and delivery ratio effect on emissions and performance of a gasoline-ethanol two-stroke engine. In *'Case Studies in Thermal Engineering'* **2**. Iran, pp. 82–90.
Govindarajan, K. 2008. Alcohol as an Automotive Fuel.
http://www.cheresources.com/energy_future/ethanol_transportation_fuel.shtml Accessed 14.06.2014.
GUNT Hamburg. *http://www.mutiaranata.com/product/detail/tm-260-03-experimental-module-pin-on-disc* Accessed 08.12.2014.
Hilbert, D. 2011. *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.
IEA. 2008. *Energy technology perspectives to 2050*. Paris.
Küüt, A., Ilves, R., Vlasov, A., Soots, K., Olt, J. 2014. Imact of bioethanol fuel on output parameters of two-stroke reciprocating engine. International Scientific Conference *Engineering for Rural Development*, Latvia University of Agriculture, Jelgava, 288–295.
Magnusson, R., Nilsson, C. 2011. The influence of oxygenated fuels on emissions of aldehydes and ketones from a two-stroke spark ignition engine. *Fuel*, Volume 90, Issue 3, 1145–1154.
Olt, J., Mikita, V., Ilves, R., Küüt, A., Madissoo, M. 2011. Impact of ethanol on the fuel injection pump of diesel engine. 10th International Scientific Conference '*Engineering for Rural Development*', Latvia University of Agriculture, Jelgava 248–253.
Pulkrabek, Willard, W. 1997. *Engineering Fundamentals of the Internal Combustion Engine*. Upper Saddle River, NJ 07458, 411 pp.
Schwarze, H., Brouwer, L., Knoll, G., Longo, C., Kopnarski, M., Emrich, S. 2010. Effect of Ethanol Fuel E85 on Lubricant Degradation and Wear in Spark-ignition Engines, *MTZ worldwide Edition*: 2010-04.
Standard ASTM D445. *Test Method for Kinematic Viscosity of Transparent and Opaque Liquids*.
Standard EN ISO 3405. *Petroleum products - Determination of distillation characteristics at atmospheric pressure*.
Tung, S.C., Gao, H. 2003. Tribological characteristics and surface interaction between piston ring coatings and a blend of energy-conserving oils and ethanol fuels. *Wear*, Volume 255, Issues 7–12, 1276–1285.
Wargo, J., Wargo, L., Alderman, N. 2006. The Harmful Effects of Vehicle Exhaust. *Report. Environment & Human Health*, Inc. Yale University. 64 pp.
Vesela, K., Pexa, M., Marik, J. 2014. The effect of biofuels on the quality and purity of engine oil. International Scientific Conference. *Agronomy Research* **12**(2), 425–430.

APPENDIX

Table 5. Engine details measurement data

Name	Parameter	Before the test		After the test	
		Gen. 1	Gen. 2	Gen. 1	Gen. 2
Average cylinder diameter at the depth of 10, 20 and 30 mm from the upper surface of the cylinder	Diameter, mm	45.036	45.017	45.030	45.024
Average diameter of the piston	Dimension, mm	44.759	44.798	44.779	44.782
Piston pin diameter at 18 mm from the edge	Diameter, mm	9.988	10.001	9.995	9.997
Piston ring **1** (upper) measured points	Measurement a, mm	1.86	1.92	1.86	1.92
	Measurement b, mm	1.93	1.91	1.93	1.91
	Measurement c, mm	1.86	1.91	1.86	1.90
Piston ring **2** (lower) measured points	Measurement a, mm	1.90	1.93	1.90	1.90
	Measurement b, mm	1.92	1.91	1.91	1.89
	Measurement c, mm	1.90	1.91	1.89	1.89
Diameter of the upper opening of the connecting-rod	Diameter, mm	13.998	13.995	14.005	14.000
Engine compression	Compression, bar	7.00	6.75	8.0	7.75
Roundness of the working elements of the engine					
Cylinder roundness at the depths of 10 and 20 mm from the upper surface	Deviation at the depth of 10 mm, µm	6.469	5.676	6.205	5.103
	Deviation at the depth of 20 mm, µm	5.852	5.850	5.965	6.180
Piston pin roundness, 18 mm from the edge	Deviation, µm	2.616	1.091	2.5104	1.716
Piston, roundness between the rings and 5 mm below the groove of the second ring	Deviation, µm (between the rings)	12.368	15.679	38.026	19.868
	Deviation, µm (5 mm below the groove of the second ring)	48.966	39.641	47.807	58.177

Table 6. Measurements of exhaust gases of the engine

	Gen 1	Gen 2	Gen 1	Gen 2
Rotational speed of the crankshaft of the engine, rpm	3,000	3,000	3,000	3,000
	Before test		After test	
CO, %vol	0.111	0.157	0.104	0.176
HC, ppm	655	119	1172	487
Lambda	1.154	1.240	1.227	1.415
CO_2, %vol	9.17	9.31	12.96	11.64
O_2 %vol	7.80	7.24	3.18	3.88