

MIXTURES OF BIOETHANOL AND GASOLINE AS A FUEL FOR SI ENGINES

by

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The importance of alternative fuels, especially bioethanol and biodiesel, rises due to the limited oil sources, secure supply, prices changes, and environment pollution. Bioethanol is an alternative fuel which will be important in future, as a fuel produced from different crops and lignocelluloses materials. The quality of bioethanol has significant influence on the characteristics of mixtures with gasoline and engine performance.

The investigations were performed with the bioethanol obtained as by-product from sugar industry, which is not denaturated and produced according the requests prescribed by standards for ethanol used in mixtures with gasoline. Main target was to examine the possibility of utilisation of bioethanol obtained as by-product and without additional technologies for purification and additional costs. The results of standard and non-standard investigations and engine tests of bioethanol and gasoline mixtures are presented.

Key words: *bioethanol, gasoline, mixture, SI engine*

Introduction

Transport completely depends on oil supply and it is the source of important part of greenhouse gas emission. All predictions for the future have shown that the transport will increase and that it is important to find the solutions for secure fuel supply and the possibilities for pollution reduction [1, 2]. One of the solutions for these problems is utilisation of alternative fuels which were examined as possible fuel for SI engines at the beginning of the 20th century. The first attempts of ethanol use were made by H. Ford while R. Diesel predicted the use of vegetable oils. The importance of investigations of alternative fuels for SI engines rises with oil crises and with the knowledge about importance of pollution reduction.

Directive 2003/30/EC sets up guidelines for adopting biofuels in all transport fuels in the EU [3]. European Community program predicted the increase of biofuels utilisation from 2% in 2005 to 5.75% in 2010, with the final goal to meet 20% in 2020 [4]. The main objectives of the Directive are to reduce emissions of carbon dioxide from transport across Europe, and to reduce the EU future reliance on external energy sources (fossil oil). Both reasons suggest the necessity of introducing bioethanol and biodiesel as engine fuels [5].

The reason for the trend of increased use of bioethanol is, among others, a positive net energy balance, meaning that the energy contained in a ton of bioethanol is higher than the energy needed to produce it. Bioethanol could be produced from different crops, such as sugar

beet, sugar cane, corn, wheat, *etc.* The conventional technologies (fermentation process) are used for bioethanol production from these crops (first generation of bioethanol). Further, it is expected that the second generation of bioethanol will be produced from lignocelluloses materials using more advanced technologies – hydrolysis and fermentation [6]. Numerous investigations have been made related to the production technologies, bioethanol quality and possibilities of utilisation as a fuel for SI engines [7].

In the primary phase, bioethanol could be used in mixtures with gasoline. The problems of bioethanol use in mixture with gasoline are increased vapour pressure, corrosion, mixture stability (phase separation in cold conditions), and poor lubricity. The content of bioethanol in mixture with gasoline could vary depending on the quality (denatured or non-denatured). The mixtures of gasoline with up to 15% of bioethanol could be used, because majority of the vehicles can operate without significant changes of engine and fuel supply system. The increase of percentage of bioethanol in gasoline would inevitably lead to adjustment of engine and fuel supply system. In USA, content of up to 10% v/v of bioethanol in a mixture with gasoline is in use (Gasohol E10), in Brazil 20-25% v/v and in European Community content of bioethanol as an oxygenate, as well as an octane buster, was restricted depending on maximum permitted oxygenate content (2.7% m/m) in gasoline. The maximum content of ethanol in gasoline according EN 228 is 5% v/v. However, the major part of ethanol produced for transport is used in the form of ETBE and added in gasoline.

The actual investigations are oriented to the examination of the possibility to increase the bioethanol content and the effects on hot and cold weather driveability of modern vehicles [8], emission from vehicles [9], and demands for bioethanol quality [10, 11].

In this paper, the results of standard and non-standard investigations and engine tests of bioethanol and gasoline mixtures are presented. For all tests, the bioethanol of non-standard quality is used with the intention to determine the possibility of its utilization in mixture with gasoline.

Experiments

The experiments were carried out with the bioethanol produced in the sugar industry and with the unleaded gasoline produced in domestic refineries. The bioethanol obtained from sugar industry has not been additionally treated and denaturised. The quality of bioethanol was non-standard related to the requirements defined in the standards for ethanol used for blending with gasoline for automotive SI engine (ASTM D 4806-03, ASTM D 5798-99, and prEN 15376:2007). The characteristics of used bioethanol and gasoline are given in tabs. 1 and 2. Three different mixtures were investigated: gasoline mixtures with 1, 3, and 5% v/v bioethanol.

The experimental program included determination of:

- physical and chemical characteristics of bioethanol and gasoline mixtures,
- phase separation of bioethanol and gasoline mixtures,
- aggressiveness of gasoline and bioethanol and gasoline mixtures on the fuel supply system,
- engine performances on test bench, and
- exhaust gas analysis.

The physical and chemical characteristics of bioethanol and gasoline mixtures were determined according to the standard test methods used for pure gasoline (EN 228).

From the practical and technical point of view, it is extremely important that in all climate conditions bioethanol and gasoline mixture remain homogeneous. The bioethanol and gasoline mixtures exhibit separation in two phases – upper (gasoline) and lower (bioethanol), especially in the case of high water and impurities content in bioethanol and with decrease of

Table 1. Bioethanol characteristics

Characteristic	Value
Ethanol content [% v/v]	96,3
Density [kgm^{-3}]	788
High heating value [kJkg^{-1}]	26.700
Taste and smell	specific
Visual appearance	clear and colourless
Barbet test 18 °C [min.]	34
Acid content, calculated as acetic acid (mg/l a. A.)	6.22
Ester content, calculated as ethyl acetate (mg/l a. A.)	18.26
Aldehydes content, calculated as acetaldehyde (% v/v a. A.)	0
Fusel oil content, calculated as isoamyl alcohol (% v/v a. A.)	0

Table 2. Analysis of unleaded gasoline

Characteristic	Unleaded gasoline	Standard EN 228
Density at 15 °C [kgm^{-3}]	758	720-775
Copper strip corrosion (3 hours at 50 °C)	1a	1
Research octane number	95.5	min. 95
Reid pressure [kPa]	52	45-60* 50-80**
Distillation:		
% v/v distilled up to 70 °C, E70	24.8	20-48*, 22-50**
% v/v distilled up to 100 °C, E100	54.0	46-71
% v/v distilled up to 150 °C, E150	79.5	min. 75
Final boiling point (FBP) [°C]	195	max. 210
Distillation residue (% v/v), max.	1	max. 2

* for period May 1 to September 30

** for period October 1 to April 30

ambient temperature. Phase separation of gasoline-ethanol mixtures, as a non-standard investigation included:

- determination of temperature at which the sample of bioethanol and gasoline mixture divides in two layers – phase separation temperature, and
- selection of appropriate stabilizer to diminish this phenomenon, resulting in decrease of phase separation temperature (if needed).

Determination of phase separation temperature of bioethanol and gasoline mixture was performed according to the ISO 3015:1997. Phase separation temperature is defined as the temperature during cooling, at which the separation of two phases in the sample occurs. In some

cases, when the bioethanol and gasoline mixture was separated at the room temperature, the sample was heated to make it homogeneous, and afterwards it was cooled to determine phase separation temperature. The heating was carried out up to temperature of 35 °C, to avoid evaporation of light gasoline components.

Based on experiences from earlier investigations of ethanol-gasoline mixtures [12, 13], three stabilizers were used:

- stabilizer A – isopropyl alcohol (IPA)
- stabilizer B – n-butyl alcohol, and
- stabilizer C – tertiary butyl alcohol.

A basic criterion for determination of optimum stabilizer concentration was to achieve homogeneous mixture (without the phase separation) with smallest concentration of stabilizer. For proposed mixtures, the standard fuel tests were performed with the intention to determine the influence of bioethanol and stabilizer on the most important characteristics.

Testing of the influence of bioethanol and gasoline mixtures on the fuel supply system was made by static method. The representative parts of fuel supply system were submerged in the gasoline and bioethanol and gasoline mixture with highest percent of ethanol (5% v/v, as the worst case) for 720 hours. The mass of each single part was measured before and after the test. Every part was photographed before and after the test to check out possible deformations or corrosion effects.

Tests, both on engine and vehicle, were carried out in parallel, with the primary gasoline sample and with the mixtures of bioethanol and gasoline in concentrations 1, 3, and 5% v/v of bioethanol (respectively fuels E1, E3, and E5). According to the previous results of phase separation, the mixtures E3 and E5 were prepared with the addition of stabilizer C in the amount of 1% v/v. The investigations of engine performances were carried out on test bench Schenk W130 and installation on 1.3 litre engine with system for ignition and fuel supply BOSCH M.4.6 (fig. 1). Test engine characteristics are given in tab. 3.

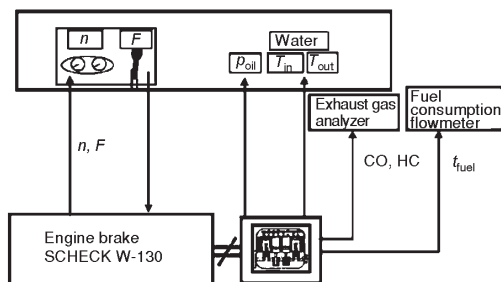


Figure 1. Schematic display of measuring and test installation

Table 3. Test engine characteristics

Engine type	Engine 128A6.064
Number of cylinders	4 in line
Piston diameter	86.4 mm
Stroke	55.8 mm
Compression ratio	9.1
Maximum power	46.5 kW
Engine speed at full power	5800 rpm
Ignition	non-contact

The investigations comprised the following tests:

- flat road load characteristics (power, torque, and specific fuel consumption) according to St. 7.A6400,
- flat road load characteristics according to St. A.642, and
- exhaust gases emissions at full power curve (CO and HC).

Test engine was equipped with standard engine equipment (intake and exhaust system, filters of air, fuel, and oil, *etc.*). For engine cooling during investigation, installed cooling system was used, which was located on test bench for engine investigation. Oil temperature in en-

engine crankcase was regulated by additional oil cooling system. Engine running in was performed on test bench in the period of 6 hours per cycle (according to St.7.A6000). Before all investigations, reading was performed on engine, as well as control of main parameters of engine operation (engine speed at idle travel, λ value, throttle position, *etc.*) by special diagnostics device BOSCH VS 23.

Special additional tank was used for test engine supply with fuels. Mixers, installed in the tank, provided homogenous mixture of main fuel and bioethanol. The fuel preparation procedure for each test included two phases: mixing and rinsing the fuel supply system. After each one of the tests, the fuel supply system was discharged, rinsed, and filled with new fuel for the next test.

Results

For investigated bioethanol and gasoline mixtures, phase separation starts immediately after mixing at the room temperature and becomes more and more expressed during the time. Phase separation was not typical: instead of two homogeneous layers, the bioethanol was separated in the form of drops settled at the bottom of the test tube (fig. 2). Because of the phase separation at the room temperature for mixtures with 3 and 5% v/v of bioethanol, the stabilizers were used. Based on previous tests, phase separation temperature for mixtures with stabilizers A and B were higher than 0 °C, so the stabilizer C was found to be the most effective and it was used for all further tests [12.]. Phase separation temperature results are presented in tab. 4.

The results of standard tests for bioethanol and gasoline mixtures with stabilizer are given in tab. 5. Distillation curves are presented on fig. 3. All characteristic listed in tab. 5 are within limits defined by standard EN 228.

The results of the bioethanol influence on fuel supply system are presented in tab. 6, as a relative mass change in predetermined time. The test results of aggressive effect of bioethanol and gasoline mixtures on fuel supply system parts have shown no difference between gasoline and bioethanol and gasoline mixtures.

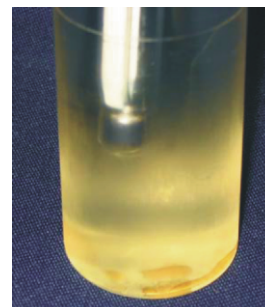


Figure 2. Characteristic appearance of phase separation

Table 4. Phase separation temperatures of gasoline-bioethanol mixtures with stabilizer C

Mixture	Fuel E1	Fuel E3	Fuel E5
Cloud point [°C]	–	–12	–2
Phase separation temperature [°C]	< –20	–26	–26

Table 5. Test results for gasoline-ethanol mixtures with stabilizer C

Characteristic	Fuel E1	Fuel E3	Fuel E5
Density at 15 °C [kgm ⁻³]	758	759	760
Copper strip corrosion (3 hours at 50 °C)	1a	1a	1a
Research octane number	95.7	96,0	96.7
Reid pressure [kPa]	48	52	49
Distillation			
% v/v distilled up to 70 °C, E70	25.5	29.2	32.3
% v/v distilled up to 100 °C, E100	51.8	52.1	50.3
% v/v distilled up to 150 °C, E150	80.0	79.4	77.1
Final boiling point (FBP) [°C]	192	190	191
Distillation residue (% v/v), max.	1	1	1

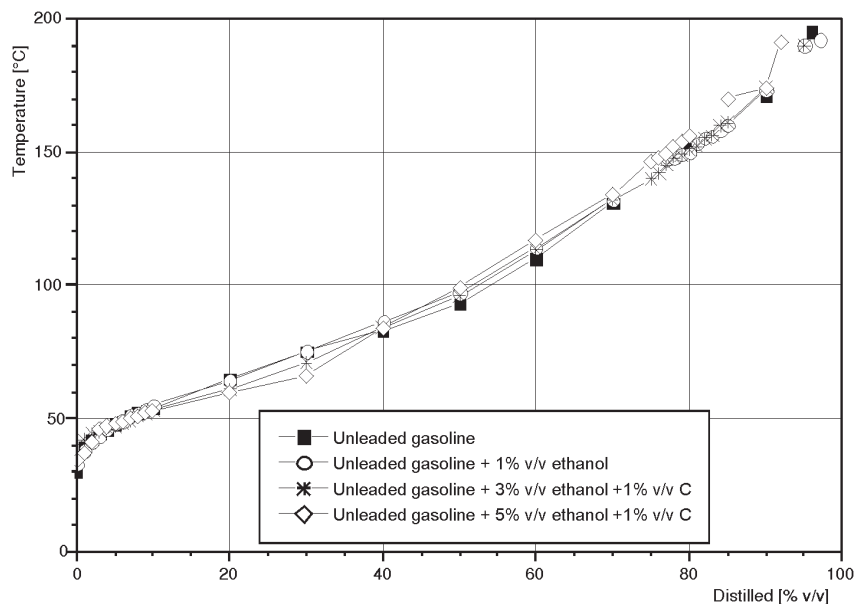


Figure 3. Distillation curves of unleaded gasoline and bioethanol and gasoline mixtures

Table 6. Mass change of parts submerged for 720 hours into the gasoline and bioethanol and gasoline mixture (5% v/v of bioethanol)

Part	Gasoline Δm [%]	Gasoline + 5% v/v bioethanol Δm [%]
Fuel reservoir	0.04	0.10
Fuel intake hose 50 mm	-6.02	-6.14
Rubber seal of fuel reservoir	-6.30	-5.10
Metal fuel pipe	-0.01	-0.22
Fuel reservoir lid	0.00	0.00
Fuel level indicator	-0.37	-1.21
Rubber hose 75 mm	-2.30	-0.09
Pipe for fuel distribution	0.06	0.07
Fuel atomizer	0.10	-0.29
Rubber seal of fuel swimmer	-7.80	-4.98

Maximum values of engine power, maximum torque, and minimal specific fuel consumption with gasoline and with gasoline mixtures with 1, 3, and 5% v/v of bioethanol are shown in tab. 7.

Table 7. Maximum values of power, torque, and minimal specific fuel consumption

Fuel	Power [kW] / engine speed [rpm]	Torque [Nm] / engine speed [rpm]	Specific fuel consumption [gkW ⁻¹ h ⁻¹] / engine speed [rpm]
Gasoline	53.91 / 6200	96.10 / 3600	229.04 / 2600
E1	54.01 / 6000	96.61 / 3600	243.92 / 2600
E3	53.80 / 6000	97.00 / 3600	251.51 / 3000
E5	53.73 / 6000	94.96 / 3000	253.26 / 3000

Engine full load characteristics with gasoline and with bioethanol and gasoline mixtures E1, E3, and E5 are presented on fig. 4.

Analyzing the results of investigations with gasoline and mixtures E1, E3, and E5, it can be noticed that the character of curves for power, torque, and specific engine consumption is approximately the same. The values of engine maximum power and torque with mixtures are similar compared to the values obtained for the gasoline (tab. 7). The values of engine specific fuel consumption in investigation with mixture E1, E3, and E5 are higher in the whole range of engine running (fig. 4).

There is no significant difference in results for investigations with gasoline and mixtures of bioethanol and gasoline, neither in values for volume and specific consumption, neither in the trend of the curves. This is visible in fig. 5. Smaller difference can be observed only for mixture E5, where slightly higher volume and specific fuel consumption was obtained. That is agreeable with obtained values of power and torque from the corresponding external speed engine curve.

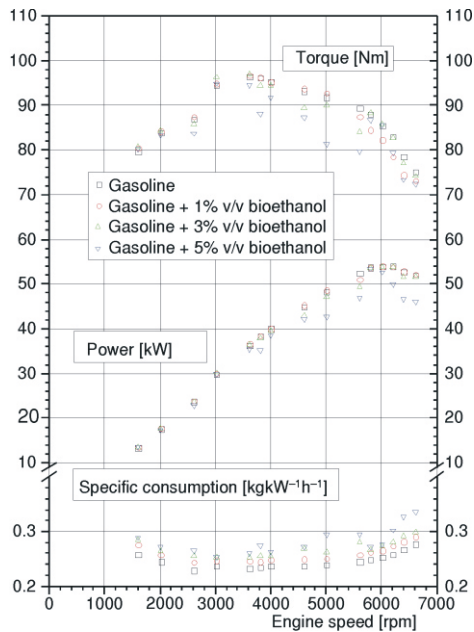


Figure 4. Engine full load characteristics with gasoline and gasoline and bioethanol mixtures

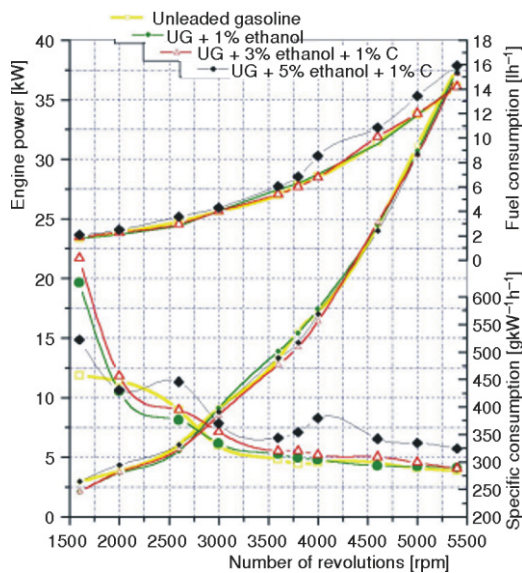


Figure 5. Engine flat road load characteristics with gasoline and with mixtures of gasoline and ethanol

Emission measurements of CO and HC content in exhaust gases at full engine load regimes are shown on figs. 6 and 7.

As shown in figs. 6 and 7, it is not possible to identify the significant changes in the CO and HC content in exhaust gases, especially for the mixtures E3 and E5.

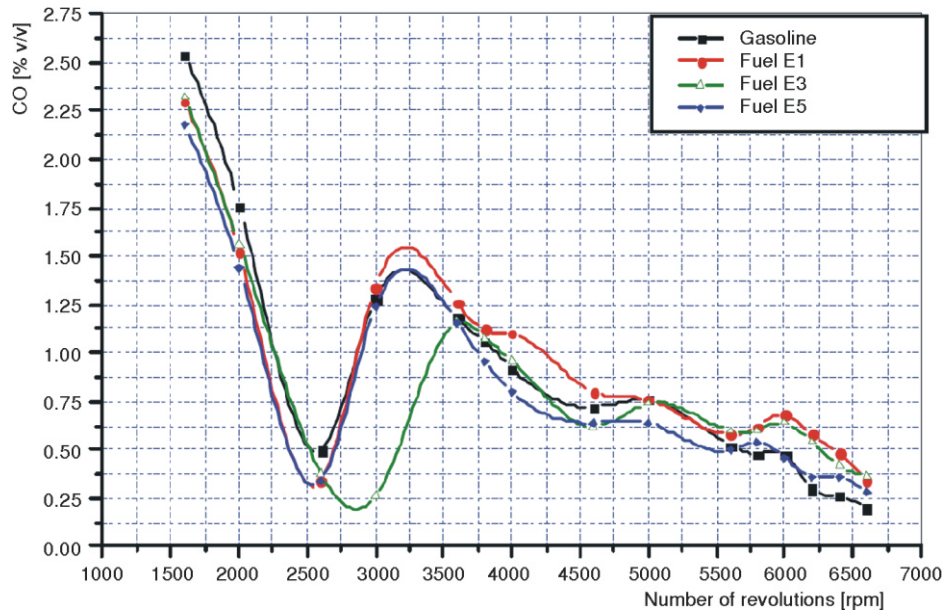


Figure 6. CO content on full power curve

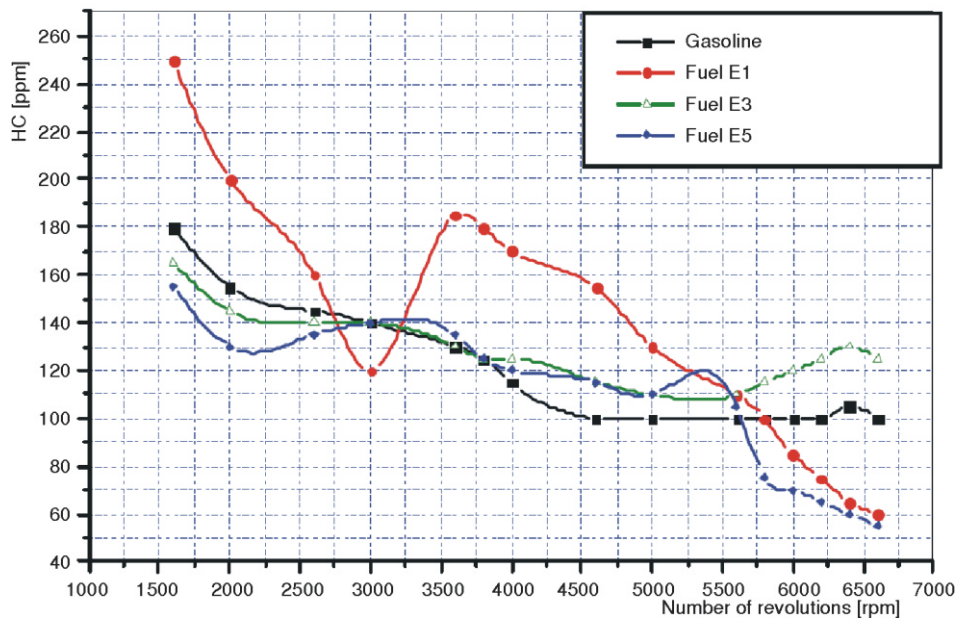


Figure 7. HC content on full power curve

Conclusions

Based on investigations performed, and results obtained for the mixtures of bioethanol (originated from sugar production process) and gasoline it can be concluded:

- judged on separation as principle criterion, mixture of gasoline with 1% v/v of bioethanol can be used in practice, without addition of stabilizer, because the mixture is homogenous up to temperature of $-20\text{ }^{\circ}\text{C}$,
- mixtures of unleaded gasoline with 3 and 5% v/v of bioethanol can not be used without addition of stabilizer, because the separation occurs at room temperature,
- tertiary butyl alcohol (TBA) is appropriate stabilizer for bioethanol and gasoline mixtures,
- addition of 1% v/v TBA to the mixtures of gasoline with 3 and 5% v/v bioethanol is necessary to secure stability of the mixtures at temperatures occurring during exploitation,
- it was observed that only mixture with 5% v/v of bioethanol has higher impact on fuel level indicator (than the impact of pure gasoline), and
- precise determination of bioethanol-gasoline mixtures impact on fuel supply system parts require that those parts are in contact with fuel for prolonged period (more than 720 hours).

Analyzing the test results it can be observed that maximum values of engine power, torque and specific fuel consumption are approximately identical for both experiments – with pure gasoline and with bioethanol-gasoline mixture.

Fuel specific consumptions are higher for bioethanol-gasoline mixtures in whole operating range of engine compared to values obtained for pure gasoline operation. Minimum values are for mixture of gasoline and 1% v/v of bioethanol, and maximum for mixture of gasoline and of 5% v/v bioethanol.

Emission tests revealed no significant influence of bioethanol addition on exhaust gases CO content for all tested mixtures. There was also no considerable change of HC emission for mixtures of gasoline with 3 and 5% v/v of bioethanol.

Nomenclature

F	– force, [N]
n	– engine speed, [rpm]
T_{in}	– temperature of inlet water, [K]
T_{out}	– temperature of outlet water, [K]
T_{oil}	– temperature of oil, [K]
t_{fuel}	– fuel spending time, [s]
p_{oil}	– pressure of oil, [Pa]

Greek letters

λ	– air-fuel mixture
Δm	– mass change, [%]

Abbreviations

ASTM	– American Society for Testing and Materials
ETBE	– ethyl tertiary butyl ether
EN	– European norm
ISO	– International Organization for Standardization
SI	– spark ignition
TBA	– tertiary butyl alcohol

References

- [1] ***, Bio Fuels for Transport – An International Perspective, IEA, April, 2004
- [2] ***, White Paper – European Transport Policy for 2010: Time to Decide, Brussels, 2001
- [3] Hansen, S., Vaals, M., Bio Fuels in the EU – Changing up Gears, Rabobank, The Netherlands, 2005
- [4] ***, Directive 2003/30/EC
- [5] Pešić, R. B., Davinić, A. L., Veinović, S. P., New Engine Method for Biodiesel Cetane Number Testing, *Thermal Science*, 12 (2008), 1, pp. 125-138

- [6] ***, Bio Fuels in the European Union – A Vision for 2030 and Beyond, Directorate – General for Research Sustainable Energy Systems, Luxembourg, 2006
- [7] ***: Alternative Fuels for IC Engines in 21st Century (in Serbian), Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2008
- [8] ***, Gasoline Volatility and Ethanol Effects on Hot and Cold Weather Driveability of Modern European Vehicles, CONCAWE, 2004
- [9] ***, European Commission Assessment of the Impact of Ethanol-Blended Petrol on Total NMVOC Emissions from Road Transport in the EU: Review of Fuel Input Parameters, Report to the European Commission DG JRC Institute for Environment and Sustainability, 2005
- [10] Avelar, H. M., Barbeira, P. S., Conductometric Determination of Total Acidity and Chloride Content in Automotive Fuel Ethanol, *Fuel*, 86 (2007), 1-2, pp. 299-302
- [11] Gao, J., Jiang, D., Huang, Z., Spray Properties of Alternative Fuels: A Comparative Analysis of Ethanol-Gasoline Blends and Gasoline, *Fuel*, 86 (2007), 10-11, pp. 1645-1650
- [12] D. Stojiljković, D. Nestorović, Investigations of Bio-Ethanol and Gasoline Mixtures as Fuel for SI Engines, *Proceedings on CD*, Conference Alternative Fuels 2008, Maribor, Slovenia, 2008
- [13] ***, Report on Investigations of Possibility for Application Mixtures of Unleaded Gasoline and bioethanol in Zastava Vehicles (in Serbian), ZA Institute for Automobiles, Kragujevac, Serbia, 2004

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