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AN EXPERIMENTAL STUDY ON PERFORMANCE AND EMISSION CHARACTERISTICS OF A BIOETHANOL FUELED S.I. ENGINE

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Bioethanol is a viable alternative fuel for spark ignition engines due to its good burning properties and due to its unlimited manufacturing resources. In this paper bioethanol mixed with gasoline in various proportions was used as fuel in order to improve energetically performance and reduce of the pollutant emissions. The experimental results showed an increase in effective engine power with 16% using E85 fuel, a reduction in specific fuel consumption in CO and HC with 12%, 48% and 34%, but an increase in NO_x emissions. By using leaner mixtures one can achieve a considerable reduction of NO_x emission level.

Keywords: alternative fuels, bioethanol, SI engine, combustion, emissions.

1. Introduction

The use of alternative fuels represents an effective solution to reduce the main pollutant emissions and specific fuel consumption, and increase the engine power. One of the most promising alternative fuels is bioethanol. Being produced from biomass, bioethanol is a renewable source of energy and since its characteristics are fairly similar to the gasoline ones, the conversion of power units from one fuel to another looks quite promising in terms of efforts and costs [1-3].

Several studies have been conducted on the usage of ethanol and ethanol–gasoline blends as fuel in the SI engines.

For example, Topgul et al. [4] investigated the effects of ethanol-unleaded gasoline blends (E0, E10, E20, E40, E60) and ignition timing on engine performance and emissions. The experimental results showed that the brake torque slightly increased, and CO and HC emissions decreased when ethanol blend was used. It was also found that blends with ethanol allowed the compression ratio to increase without any knock [5].

Magnusson et al. [6] investigated the regular HC, CO and NO_x emissions of a two-stroke chain saw engine using ethanol, gasoline and ethanol-blends as

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fuel. The emissions of CO, HC and NO_x were reduced when the ethanol content was increased. But HC increased when using E85 and E100. When using ethanol and ethanol-gasoline blends instead of gasoline, the engine power did not vary significantly [5].

Yücesu et al. [7] studied mixtures of E0, E10, E20, E40 and E60 in a four-stroke one-cylinder engine tested on a dynamometer. The average reductions of HC and CO emissions for E40 and E60 mixtures were 11 % and 19.8 % correspondingly. They also examined the effect of increasing the compression ratio from 8:1 to 11:1 with the E60 mixture and measured a reduction on the specific consumption by 14.5 % and 17 % at 3500 RPM and 5000 RPM correspondingly [8].

El-Emam and Desoky [9] investigated the combustion of alternative fuels theoretically and experimentally in SI engines. The results showed that there was an increase in engine thermal efficiency and decrease in NO_x and CO emissions when ethanol and methanol fuels were used [5].

Charalampos et al. [10] investigated the behavior of a small four-stroke engine when mixtures of gasoline-ethanol and gasoline-methanol were used as fuel. In the engine tests, 11 test blends ranging from 0% to 100% ethanol with an increment of 10% were used CO emissions were decreased as ethanol content in fuel increased, but HC emissions significantly increased when using E90 and E100 fuel [5].

2. Comparison on fuel properties

Octane number of ethanol is higher compared to gasoline, so higher compression ratios can be utilized due to higher auto-ignition resistance; using higher compression ratios leads to better efficiency and power per liter performances.

Ethanol contains oxygen in its composition (Table 1), this fact has a direct effect on emissions.

Ethanol flammability range is much wider for air-ethanol mixtures comparative to gasoline (0,3...1,56 versus 0,4...1,4) providing engine run stability in the area of lean mixtures [11].

The heat of vaporization of ethanol is approximately three times higher than that of gasoline and requires more energy to vaporize the fuel. This property can contribute to the increase of engine power and efficiency because of the resulting higher density of the mixture.

Table 1

Physical and chemical properties of gasoline and ethanol [12][15]

Properties	Gasoline	Ethanol
Density at 15°C [kg/m^3]	735..760	785

Boiling temperature (at 1.013 bar) [°C]	30..190	78
In flammability limits: $\lambda_s..\lambda_i$	0,4..1,4	0,3..1,56
Reid pressure [daN/cm^2]	0.8..0.9	0.14
Auto-ignition temperature [°C]	257..327	420
Lower heating value [kJ/kg]	43500	26900
Heat of vaporization [kJ/kg]	290..380	840
Octane number MON/RON	90/98	89/107
Composition : C/H/O [% mass]	85/15/0	52/13/35
Dynamic viscosity at 0°C [mPa s]	0.72..0.74	0.796
Stoichiometric burning air [kg/kg]	14.5	9

Spark timing is important because of ignition delay issues. Ethanol has a slightly higher flame speed in laminar combustion compared to gasoline. However, it has a much longer delay between application of the spark and a fully-formed flame (the "ignition delay"). This means that the spark timing may need to be advanced [13].

The enthalpy of evaporation of ethanol is 842-930 kJ/kg that is higher than the value of 330-440 kJ/kg for gasoline. This property can contribute to the increase of engine power and efficiency due to the greater cooling effect, resulting an improvement of the cylinder filling, but it can cause ignition problems at low temperatures [14]. The ethanol lower heating value is smaller than of gasoline, but this difference is compensated with the difference between the stoichiometric burning air (table 1). Thus, the chemical energy of the mixture mass unity is practically the same (2975kJ/kg for ethanol, 2925 kJ/kg for gasoline at stoichiometric dosage) [16].

3. Experimental investigations

Experimental investigations were performed on an experimental single cylinder engine derived from an 810-99 serial automotive engine, showing the technical characteristics of Table 2:

Table 2

Test engine specifications

Cylinders	1
Bore [mm]	73

Stroke [mm]	77
Displacement [liter]	0.322
Compression ratio [-]	8.5
Conrod length [mm]	124
Fuelling system	carburettor

The engine was coupled with a hydraulic dynamometer and was equipped with the suitable devices for tuning and operating parameters monitoring in order to measure performance and emissions level of the engine fueled with two different gasoline-ethanol blends: E20 and E85. Measurement and analysis of combustion data was made with a Kistler pressure transducer together with a Kubler incremental encoder and an AVL data acquisition system. For measurement the exhaust gas emissions an AVL Dicom 4000 gas analyzer was used. Oil temperature from oiling system and cooling liquid temperature were maintained at 85°C. All instrumentations were calibrated prior to engine testing.

Because of the ethanol heat of vaporization higher value, the engine was equipped with an electrical resistance and rheostat device assuring a controlled preheat of inlet air. [11]

The experimental investigations were carried at engine speed 3000 rpm (±50 rpm), full load and different dosage values for three fuels: gasoline, E20 (80% gasoline blend with 20% ethanol) and E85 (15% gasoline blend with 85% ethanol). Spark ignition timing was adjusted for each operating regime at optimum value. In case of ethanol fueling the optimum spark ignition timing is smaller comparative to gasoline S.I. engine due to a much higher burning rate of the ethanol.

The main properties of the three fuels tested are shown in Table 3:

Table 3

Properties of the tested fuels

Properties	Gasoline	E20	E85
Chemical composition C/H/O [%]	85,4/14,2/0,4	78/14/8	57/13/30
Lower heating value [kJ/kg]	43500	40160	29305
Stoichiometric A/F ratio	14.5	13.4	9.8
Density at 15°C [kg/m^3]	760	766	787

4. Results

As shown in Figure 1, increasing the bioethanol content in the mixture led to increased peak cylinder pressure for the same excess air-fuel ratio, reaching values up to 37.5 bar for E20 and up to 50 bar for E85 (average values of 150 consecutive cycles). This fact is due to combustion improvement and cycle burning release heat and heat release rate increasing.

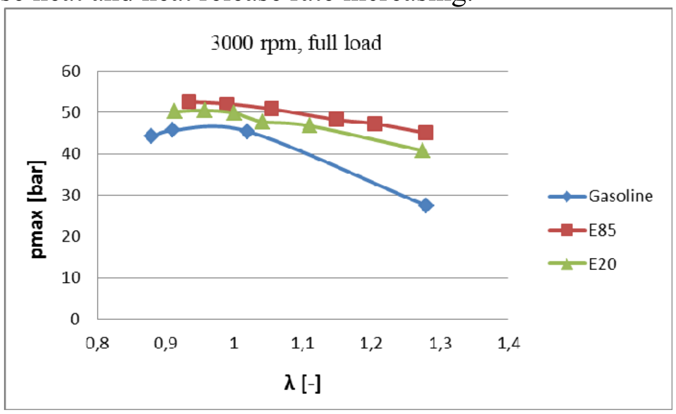

Fig. 1. Variation of peak cylinder pressure versus excess air-fuel ratio.

At the same excess air-fuel ratio λ, the effective power of the engine recorded the highest values when used E85, obtaining an increase of 11÷16% compared to standard gasoline (fig. 2a). For E20, the effective power increased by 7 to 10% depending on the excess air-fuel ratio of the engine, the maximum values being recorded for an excess air-fuel ratio λ=0.93. The higher effective power of the engine obtained at the use of gasoline-bioethanol mixtures is due to better combustion properties of bioethanol and due to shorter duration of combustion (fig. 2b). However, a disadvantage is the increase of the heat losses due to higher combustion temperatures, which leads to higher emissions level of nitrogen oxides at engine operation with gasoline-bioethanol blends.

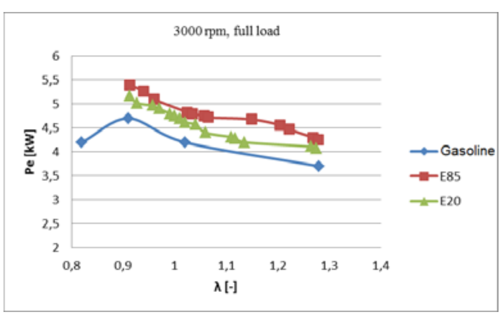

Fig. 2a. Effective power vs. excess air-fuel ratio.

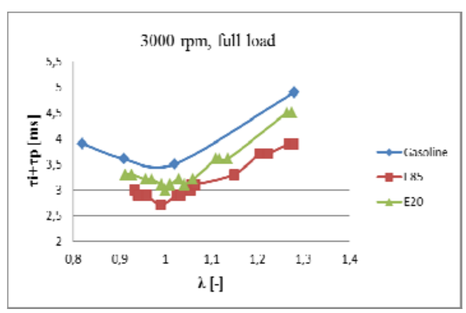

Fig. 2b. Combustion duration vs excess air-fuel ratio.

Although oxygenated fuels have a lower calorific value than gasoline, the experimental tests showed lower energetic brake specific consumption for engine fuelled with gasoline-bioethanol blends compared with gasoline. Thus, the energetic brake specific consumption of E20 and E85 was shorter than the EBSFC of gasoline, for all values of the air-fuel ratio. Thus, a reduction between 8 ÷ 12% for mixtures E20 and E85 compared to gasoline was obtained (fig. 3).

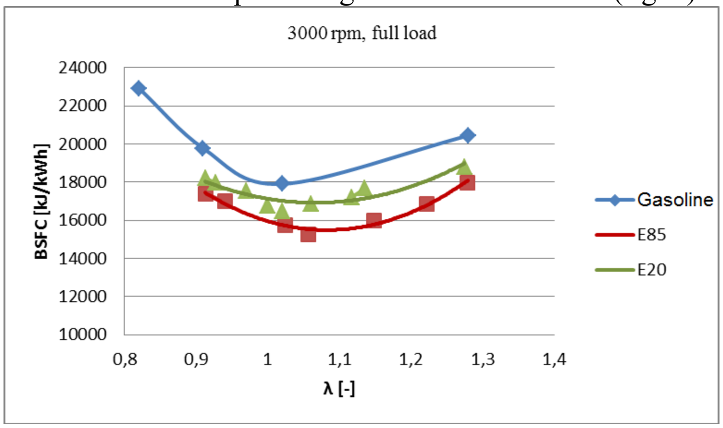

Fig. 3. Variation of energetic brake specific consumption versus excess air-fuel ratio

Fig. 4 presents the percentage concentration of carbon monoxide emissions from the exhaust gases. It can be observed that, when the engine runs with E20 and E85 , the CO emissions level is generally lower than gasoline and tend to decrease for the lean mixtures field, up to an air-fuel ratio λ=1.23, when it begin to grow slowly.

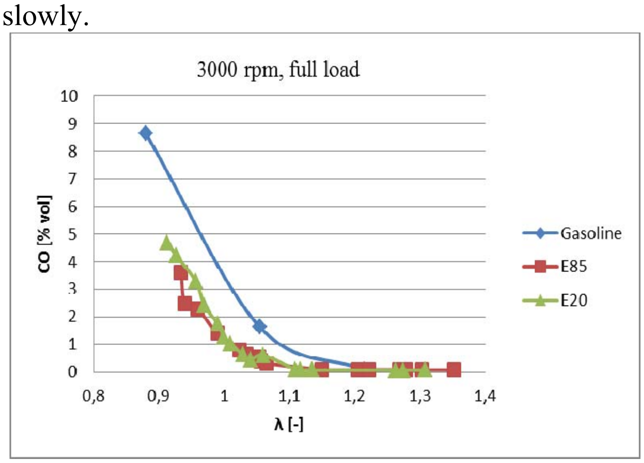

Fig. 4. Variation of CO emissions versus excess air-fuel ratio

Hydrocarbon emissions are reduced by 22% to 34% at the same dosage when the engine is fuelled with E20, respectively E85, comparative with gasoline engine (fig. 5). Reduction of carbon monoxide and hydrocarbons are mainly due to the presence of oxygen in the chemical composition of ethanol resulting an improved combustion to increase the ethanol content from the mixture.

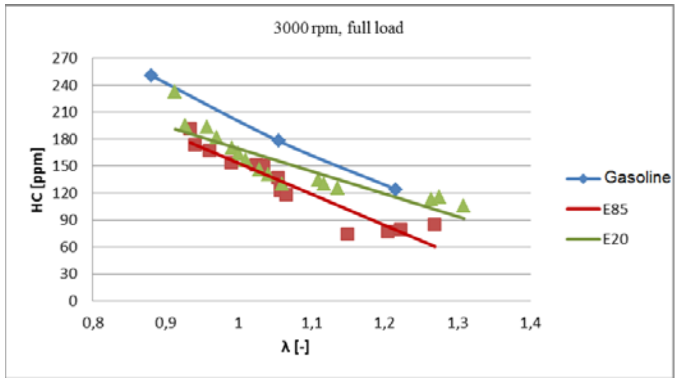

Fig. 5. Variation of HC emissions versus excess air-fuel ratio

Due to higher combustion temperature (for complete vaporization of bioethanol intake air was heated) and the presence of oxygen in the chemical composition of ethanol, emissions of nitrogen oxides for gasoline-bioethanol blends increases with increasing ethanol content from the mixture, at the same excess air-fuel ratio. In order to reduce the NO_x emissions, in case of gasoline-bioethanol blends, dosage can be leaner up to λ=1.28 without compromising the effective engine power.

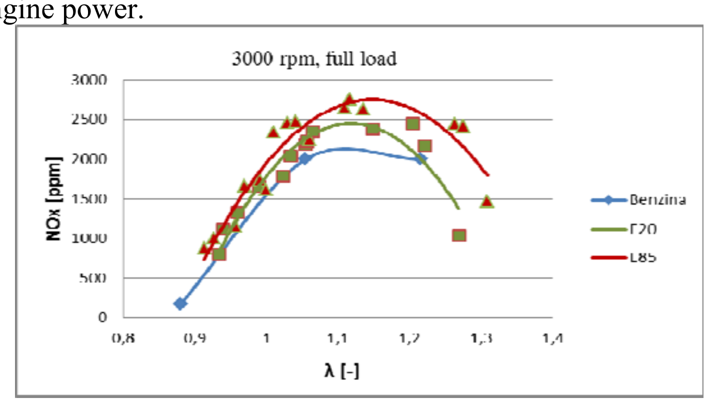

Fig. 6. Variation of NO_x emissions versus excess air-fuel ratio

5. Conclusions

At fueling the engine with gasoline-ethanol mixtures better results were obtained in terms of the energetic engine performance and the main emissions levels, comparative to gasoline. Thus, the effective power of engine increased with approximately 16% and a decrease in the brake specific fuel consumption with about 8÷12% was noticed.

Ethanol produces lower pollutants such as CO and HC, compared with standard gasoline in equivalent tests. CO emissions maintained approximately the same values, instead the HC emissions have decreased considerably. NO_x emissions increased at fueling the engine with gasoline-ethanol blends at increase the ethanol content in the mixture.

From the two used gasoline-ethanol blends, the best results of investigated parameters were obtained when using E85.

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REFERENCES

[1] *J. W. G. Turner, A. Peck, R. J. Pearson,* „Flex-Fuel Vehicle Development to Promote Synthetic Alcohols as the Basis of a Potential Negative CO2 Energy Economy", SAE Paper 2007-01-3618, 2007.

[2] *R. J. Amorim, R. Molina Valle, J. G. Coelho Baeta, J. E. Mautone Barros, R. D. Bahia de Carvallo,* „Spark Ignition Engine Performance Using Several Alcohol Concentrations in Gasoline and CNG" , SAE Paper 2005-01-4138, 2005.

[3] *J. G. Coelho Baeta, R. J. Amorim, R. Molina Valle,* „Multi-Fuel Spark Ignition Engine-Optimization Performance Analysis", SAE Paper 2005-01-4145, 2005.

[4] *T. Topgul, H. S. Yücesu, C. Cinar, A. Koca*, The effects of ethanol-unleaded gasoline blends and ignition timing on performances and exhaust emissions, Renewable Energy 31 (15), 2006.

[5] *M. Bahattin Celik*,"Experimental determination of suitable ethanol-gasoline blend rate at high compression ratio for gasoline engine", Applied Thermal Engineering, 28, 396-404, 2008.

[6] *R. Magnusson, C. Nilsson, B. Andersson,* "Emissions of aldehydes and ketones from a two-stroke engine using ethanol and ethanol-blended gasoline as fuel", Environmental Science and Technology 36 (8) (2002)1656–1664.

[7] *H. S. Yücesu, T. Topgul, C. Cinar, M. Okur,* „Effect of ethanol-gasoline blends on engine performance and exhaust emissions in different compression ratios", Applied Thermal Engineering 26: 2272–2278, 2006.

[8] *M. Gogos, D. Savvidis, J. Triandafyllis*, „Study of the Effects of Ethanol Use on a Ford Escort Fitted with an Old Technology Engine", SAE PAPER 2008-01-2608, 2008.

[9] *S. H. El-Emam, A.A. Desoky*, "A study on the combustion of alternative fuels in SI engines", International Journal of Hydrogen Energy 10 (7-8), 497-504, 1985.

[10] *A. I. Charalampos, K.N. Anastasios, S.D. Panagiotis,* "Gasoline-ethanol, methanol mixtures and a small four-stroke engine", Heat and Technology 22 (2), 69-73, 2004.

[11] *C. Pana, N. Negurescu, M. G. Popa, A. Cernat, D. Soare,* "Some Experimental Aspects of the Ethanol Use in SI Engine", Automobile, Environment and Farm Machinery, The 1th International Congress, Tehnical University of Cluj-Napoca, p. 295, 2007.

[12] *A. Radu, C. Pana, N. Negurescu, A. Cernat, E. Rusu, V. Pantile,* "Experimental Investigations of Ethanol Combustion in SI Engine", The International Congress Automotive Engineering and Environment, 2011.

[13] *A. Radu, C. Pana, N. Negurescu,* "Aspects Regarding The Use of Bioethanol in Spark Ignition Engines", ACME 2012, Iasi, 2011.

[14] *J. S. Cowart, W. E. Boruta,* „Powertrain Development of the 1996 Ford Flexible Fuel Taurus", SAE Paper 952751.

[15] *J.* Heywood John B., *"Internal Combustion Engine Fundamentals"*, 1998.

[16] B. *Grünwald, "Teoria, calculul si constructia motoarelor pentru autovehicule rutiere"*, (Theory, calculus and construction of engines for road vehicles) Editura Didactica si Pedagogica, Bucuresti, 1980. (in Romanian).