BIO-ETHANOL USED IN ENGINES AND IN THE FUEL CELLS

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Abstract. Bio-ethanol produced from the wooden biomass is an appropriate alternative fuel for Spark Ignition Engines in order to increase engines efficiency and to drop the gas emissions levels; bio-ethanol proves to be also an efficient primary agent in alcohol based fuel cells.

Key words: Bio-ethanol, wooden biomass, engine efficiency, low emissions, fuel cell

1. Introduction

One of the main alternative fuels used in spark ignition engines fueling is ethanol (C_2H_5OH). It is a clear and transparent liquid, very less toxic and with little impact on the environment. Due to its relative good miscibility with gasoline and to its high octane number ethanol can form efficient mixtures with gasoline, such as E10 (90% gasoline and 10% ethanol, mass fractions). Following the first worldwide oil crisis, ethanol was in fact the very first alternative fuel used in the years '70 by Brazil at FIAT 124 car engine [1]. EU Directive no.2003/30/EC requires that all member states should provide a minimum proportion of bio-fuels to replace the classic fuels. The reference value of the replaced energetically content should have been taken at 2% of all the engines gasoline type fuels and diesel fuels by the end of 2005 and 5.75% by the end of 2010 [2].

The first aspect of the proposed paper reefers to the possibilities of bio-ethanol production based on the opportunities given by wooden biomass obtained itself by harvesting rapid-cycle development cultures. Therefore, starting from poplar trees with only two years cycle, the resulting biomass is hydrolyzed into sugar compounds which follow a fermentation process and lead to ethanol. The tested ethanol samples prove the requested fuel properties in order to be used in engines fueling [3] [4].

The second objective of this paper consists in highlighting the benefits of using gasoline-ethanol mixtures in spark ignition engines in terms of limiting the classic fuel consumption as the levels of the exhaust emissions. Optimizing the combustion inside the cylinder of spark ignition engines is connected to the optimization of the air-fuel mixture formation. Due to its higher values of the octane number, ethanol confers better auto-ignition resistance in mixtures with gasoline. The increase of the indicated efficiency is given by the decrease of the on-cycle combustion duration because of higher values of flame propagation velocities in air-ethanol vapors mixtures. This aspect leads to the conclusion that the leaning limit of the dual air-fuel mixtures could be increased from normally 1.12…1.18, when only gasoline is used, up to 1.4 by adding ethanol [5].

The third element of the paper is to describe the perspectives of using the above mentioned fuel as primary agent in alcohols based fuel cells instead of using hydrogen as main stored fuel. This represents a better way of electrical energy production, based on exclusive regenerative sources. The ethanol used in this way decreases air pollution and ensures a 40 up to 50% higher efficiency in energy conversion [6].

2. Bio-Ethanol Produced from Wooden Biomass

Unlike the main industrial process of ethanol obtaining by chemical reaction between the ethylene and water steams, ethanol could be also obtained by sugar compounds fermentation. These sugar elements are themselves obtained from the wooden biomass, which contains a complex mixture of carbon-hydrate polymers, better known as cellulose, hemicelluloses and lignin. Using enzymes or acids, these polymers lead to sucrose, glucoses and fructose, further leading to ethanol by fermentation. There are three methods to extract sugar compounds from biomass: hydrolysis with concentrated acids, hydrolysis with diluted acids and enzymatic hydrolysis. The first two methods are well known and industrially used, but with a considerable impact on the environment due to the high toxicity of the intermediate products. This aspect is minimized by applying the last method, but this procedure is still expensive and it is at its very beginning to be developed. The reactions through which finally ethanol could be obtained by enzymatic fermentation of the sugar compounds are described as following [3] [4]:

$$\mathbf{C_{12}H_{22}O_{11}}\ \text{(sucrose)} + \mathbf{H_2O} \rightarrow \mathbf{C_6H_{12}O_6}\ \text{(fructose)} + \mathbf{C_6H_{12}O_6}\ \text{(glucose)}$$

$$\mathbf{C_6H_{12}O_6}\ \text{(fructose/glucose)} \rightarrow \mathbf{2C_2H_5OH}\ \text{(ethanol)} + \mathbf{2CO_2} \uparrow$$

The ethanol obtained by applying the fermentation reactions contains also a significant water amount. The water is supposed to be eliminated by a process of fractioned distillation. Due to the fact that at normal atmospheric pressure ethanol has a lower vaporization temperature (78.5°C) than water (100°C), it means that it could be vaporized before water and subsequently condensed and separated from water. In Table no.1 there are shown the main physical properties of bio-ethanol comparing to those of gasoline [7].

Table 1 Properties of bio-ethanol and gasoline

Property [unit]	**Bio-Ethanol**	**Gasoline**
Molar weight [kg/kmole]	46.1	98
Carbon [% mass]	52.2	85
Hydrogen [% mass]	13.1	14
Oxygen [% mass]	34.7	1
Water [% mass]	< 6.2	-
Density at p_0 and T_0 [kg/m^3_N]	0.794	0.735…0.760
Vaporization temperature at p_0=1 bar [°C]	78.3	30…190
Caloric heat [kJ/kg]	26700	43500
Octane Number [-]	108	95 (unleaded)
Vaporization specific heat [kJ/kg]	923	290…380
Viscosity [Ns/m^2]*1000	1.2	0.42
Reid vapors pressure [daN/cm^2]	0.14	0.6…0.9

3. Simulation and tests when using gasoline-ethanol mixtures in SI Engines

A computer model has been proposed in order to describe the development of the combustion and its heat release inside the engine when gasoline-ethanol mixtures are fueling a Dacia-Renault commercial four-cylinder SI engine. Certain usual hypotheses have been considered when writing the equations of the mathematical model [5] [7]:

- Ethanol-gasoline mixtures are considered homogenous blends, taken as new types of fuels with modified values for the Carbone, Hydrogen and Oxygen mass participations (with respect to x_{eth} – the ethanol substitution rate for gasoline);
- The combustion model is a zero-dimensional one, with no influence of the combustion geometry volume. The motor fluid is divided in burned and unburned zones under the same thermal state conditions;
- The air-fuel mixture is preformed and homogenous before combustion starts. The delay between the spark ignition point on cycle and the flame kernel occurrence is neglected;
- The combustion model operates with the well-known Wiebe formalization equations [9] of the in-cylinder heat release. Thus, a fraction of fresh unburned fluid leads to an equal heat release fraction reported to the whole quantity of the on-cycle released heat;
- Equations taken into consideration are: energy conservation, mass conservation and thermal state.

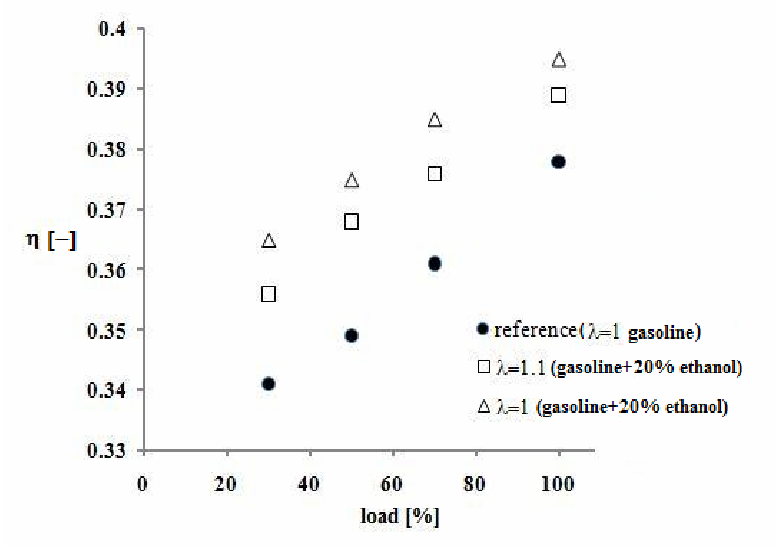

Fig. 1 – Indicated efficiency vs. engine load at maximum speed and 20% ethanol mass substitution rate.

By applying this model to analyze the combustion process and to plot the pressure diagram vs. the crankshaft rotation angle, following engine operating parameters were used: maximum speed (5000 rpm), various load coefficients (30, 50, 70 and 100%), stoichiometric air-fuel ratios for air-gasoline only mixtures (the reference) and ethanol (20%)-gasoline-air fuel mixtures; another value of 1.1 was chosen for the air-fuel ratio of the ethanol (20%)-gasoline mixture [7]. Figure no.1 shows the results of the simulation concerning the values of the indicated efficiency vs. the engine load when only gasoline (reference case) and 20% ethanol-gasoline fuels mixture are used at different air-fuel ratios used. The highest efficiency values are obtained when using ethanol at stoichiometric dosage value which is conclusive regarding the fact that combustion process in SI engines is well centered on the top dead center point at optimum spark advance value (about 25 degrees of crankshaft rotation angle).

Preliminary tests have been conducted on a single-cylinder CFR (Committee for Fuels Researches) engine in order to approximate the velocity of the flame propagation through gasoline-air and ethanol-air fuel mixtures. Measurements were taken at constant engine speed of 900 rpm, full load and a compression ratio set on 7.25. The results are shown in Figure no.2, in which the ratio between the ethanol-air flame velocity and the gasoline-air flame velocity is plotted versus various relative air-fuel ratios (within the range 0.8…1.2). Flame propagation velocity could be measured by measuring the time of flame propagation between two ionization plugs mounted inside the cylinder at certain distance one from another.

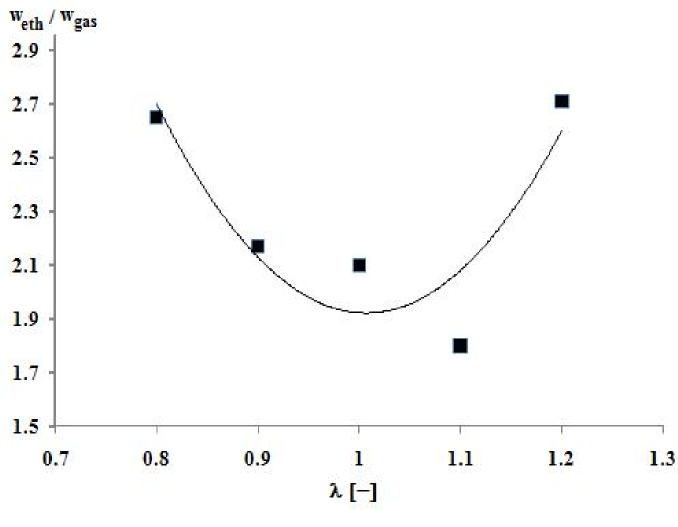

Fig. 2 – ethanol-air and gasoline-air flame velocities ratio vs. relative air-fuel ratio on CFR engine at 900 rpm speed and 7.25 compression ratio

The trend of the obtained curve could be explained by the particularities of both combustion types. At rich air-fuel mixtures, the flame velocity of gasoline-air mixtures is low due to the lack of oxygen; on the contrary, ethanol molecule contains a high oxygen amount, favoring the reactants diffusion and the flame propagation. At lean air-fuel mixtures the flame velocity through gasoline-air mixtures gets also down because of the lack of the mixtures flammability. This results lead to the conclusion that using dual gasoline-ethanol mixtures as SI fueling agent it is doable to increase the flame propagation velocity inside the cylinder in order to decrease the global combustion duration and subsequently to increase the engine thermal efficiency. Further tests will be planned on SI four-cylinder engine with emissions measurements to study the influence of the combined combustion types on the main exhaust emissions levels.

4. Bio-Ethanol as primary agent in alcohol fuel cells

Fuel cells which use ethanol as primary agent are among Proton-Exchange Fuel Cells (PEFC). Like fuel cells based on methanol operation, ethanol fuel cells are Direct Alcohol Fuel Cells (DAFC). DEFC (Direct Ethanol Fuel Cell) is more likely to be used than methanol fuel cells due to the high toxicity of methanol. Ethanol is an attractive alternative to methanol also because it comes with a supply chain that's already in place. Ethanol also remains the easier fuel to work with for widespread use by consumers. Figure no.3 presents the basic scheme of a DEFC operation [6].

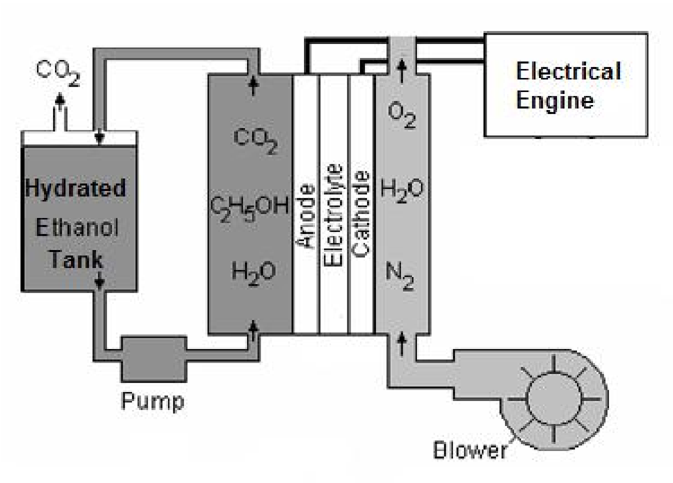

Fig. 3 – Scheme of a DEFC operation

The use of ethanol would also overcome both the storage and infrastructure challenge of hydrogen for fuel cell applications. Comparing to the fuel cells using hydrogen as primary fuel, DEFC has its benefits concerning the lack of the hydrogen storage necessity. Platinum-based catalysts are expensive, so practical exploitation of ethanol as fuel for a PEM (Proton Exchange Membrane) fuel cells requires a new catalyst. New micro-structured electro-catalysts have been developed, which are based on non-noble metals, preferentially mixtures of Fe, Co, Ni at the anode, and Ni, Fe or Co alone at the cathode. A polymer acts exactly like an electrolyte. The electric charge is carried by the hydrogen ions - protons. The hydrated liquid ethanol is oxidized at the anode, finally generating CO_2, hydrogen ions and electrons. Hydrogen ions travel through the electrolyte. They react at the cathode with oxygen from the air and the electrons from the external circuit forming water.

These types of fuel cells develop up to 40 kW, enough to supply an electric car engine when using it under urban operating regimes. Operating temperatures are below those characterizing a hydrogen fuel cell, but the voltage of the supplying electric energy remains dangerous high, approximately at 500 V; thus, the assembly forming the electric unit has to be very well isolated [8].

5. Conclusions

Bio-ethanol could represent a valuable alternative fuel for replacing classic fossil fuels fueling the internal combustion engines. Wooden biomass could easily be produced exploiting rapid cycle trees cultures.

Ethanol is less toxic than other alcohol products, has a good miscibility in mixtures with gasoline, as an alternative to fuel SI engines.

The paper presents some theoretical and experimental results of using ethanol-gasoline fueling mixtures in SI engines. Further experiments have to be carried out in order to obtain data concerning the levels of the main exhaust gas emissions connected to ethanol combustion. These will have to prove that bio-ethanol, used as a fuel, contributes to the decrease of the classic fuels consumptions as well as to the decrease of the emissions levels. Many other studies have already proved that bio-ethanol is a better agent for the fuel cells, replacing hydrogen in future fuel cells design.

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