BIO-ETHANOL – A VIABLE ALTERNATIVE FUEL FOR S.I. ENGINE

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Abstract. The experimental investigation has the goal of determination of the influences on a single cylinder engine performances, mechanical running and pollution level for gasoline-bio-ethanol blends fuelling. The reference is establish for gasoline fuelling, E 0 and two other types of fuel were used E20 and E85. By its physical and chemical properties bio-ethanol influences the combustion process and finally the engine running, performance and pollutant emissions. It's shows that the increase of bio-ethanol content in gasoline blends leads to the reduction of combustion duration due to a faster burning assured by bio-ethanol high flame velocity and increase in terms of power. Also, the maximum pressure values reached for E20 and E85 are significantly bigger comparative to E0 and the engine efficiency defined by BSFC is improved. On the aspects of chemical structure and combustion improvement, the pollutant emission, as CO and un-burn HC, are decreased for E20 and E85. Only the NO_x emissions increase for E20 and E85 comparative to gasoline fuelling, E0, in similar percents with possibilities of decreasing by exhaust gases recirculation and catalytic converter use. All these parameters variation at E20 and E85 fuelling is presented for a wide area of air-fuel ratios from λ =0.85 till λ =1.3. Finally, the main conclusions of the study were formulated as a definition of the dosage values at which the efficiency and pollution level are improved.
Keywords: gasoline-bio-ethanol blends, flame velocity, maximum pressure, efficiency, pollutant emissions.

1. INTRODUCTION

For many years the use of alternative fuels has an important and special place in the area of internal combustion development. The family of alternative fuels on classic petroleum ones is defined by many types and the alcohols represent a significant percent due to the following aspects as: adequate properties for internal combustion engines use; good conditions of producing process from agriculture products or green mass [9]; for the next decades the liquid fuels shall continue to have an important share in transportation activities so the storage and transportation can be realised in safe conditions using the existing infrastructure for classic fuel distribution.

As alcohol, ethanol offers significant opportunities in order to decrease the exhaust emissions levels and to reduce the consumption of the classic petroleum products. Ethanol could becomes a cheap alternative fuel knowing that many countries are developing new technologies based on the process of the green mass in order to obtain bio-ethanol. If is obtaining from agricultural products represent a low cost and ecological process.

That why bio-ethanol can win the cost price - pollution competition if is used as a single fuel or in addition with gasoline in the spark ignition engine.

In different countries the gasoline is more expensive and rare and so ethanol becomes the most important fuel for engines and automotives. Also, from another point of view the N.E.V.C (National Ethanol Vehicle Coalition) responds to a recent health report about the potential health and pollution risks of E85, [10]. The report informs about the issues of possible cancer and ozone-related health consequences of a large-scale conversion from gasoline to ethanol, comparing the effects of gasoline vehicle emissions with those from bio-ethanol fuel. The NEVC argues that the report's negative conclusions are unrealistic and will continue to support the use of E85 as a fuel source, along with all other alternatives fuel like bio-diesel, LPG, compressed natural gas, electricity, hydrogen and other yet-to-be defined fuels, [10]. So another important aspect is the mentality of the automotive users to buy or use ethanol in order to reduce the pollutant emission or to improve engine performances. For example, half of all vehicles manufactured today in the U.S.A are flex fuel ready, so the engines of these cars can operate with gasoline or with bio-ethanol. These kind of automotive, defined FFVs (Flex Fuel Vehicles) are specially designed to run on regular unleaded or any bio-ethanol fuel blends up to 85 percent. Special on-board diagnostics systems are capable to read the fuel blend, enabling drivers to fuel with E10, E15, E20, E30, E40, E50 or any bio-ethanol blend up to E85, [10].

Therefore, any part of the engine which comes in contact with the fuel has been upgraded to tolerate the ethylic alcohol [10, 21, 22, 27]. Generally, these parts include an upgraded fuel system with grain alcohol compatible parts. Nowadays, automotive manufactures as Chrysler Corporation, Ford Motor Company, General Motors, Nissan, Saab and Toyota offer flexible fuel engines as standard equipment in many vehicles without additional cost to consumers and haves the same factory warranties as gasoline regular automotives, [10].

2. BIO-ETHANOL PROPERTIES OVERVIEW

The physical and chemical properties of the bio-ethanol directly influence the combustion process, the performances and the efficiency of the engine.

Bio-ethanol is a colourless liquid, with specific scent. In storage and manipulation conditions, bio-ethanol is a stable product if it's storage in sealed tanks at room temperature, otherwise appears the risk of water vapours absorption from the air. Also, from physically and chemically stability point of view, bio-ethanol does not suffer accidental poly-merization.

Bio-ethanol contains acetic acid and therefore it corrodes aluminum alloys. It also absorbs the lead in alloys and finally the surfaces become porous; same phenomena appear on zinc alloys (Al and Zn) [1, 2, 3, 21, 22]. In order to avoid this issue it is recommendable a nickel cladding for all those surfaces. Same phenomena may appear on plastic parts of carburetors or injection systems as the carburetor bowl, fuel pump and injector inside parts, filters or any plastic – rubber gaskets. It is recommendable to be manufactured of nylon or raylon. Thus, different part of the classic fuelling systems, carburetor or injection systems, must be replacement or protected for ethanol use [1, 21, 22].

Bio-ethanol has a low volatility expressed by a low value of the superficial tension at ambient temperature and also by a low value of the Reid vapours pressure. Thus, because the vapours pressure of the bio-ethanol (at 0ºC) is almost 4 times lower comparative to gasoline, the vaporization of bio-ethanol at temperatures below 10ºC becomes difficult. Different research's show that this situation could be improved if very volatile additives would be used, such as iso-pentane or dimethyl ether (DME), or by a special intake air heating device use, especially in situations when higher bio-ethanol percentage in blend with gasoline or and pure bio-ethanol is used [1, 2, 3]. Other physical properties of bio-ethanol are: firing point –13 ^{o}C, autoignition point –363 oC, lower explosive limit (volume percent in air at 760 mm Hg and 20 ^{o}C) –3,3 %, higher explosive limit - 19 %, [1, 3].

Using bio-ethanol in spark ignition engine with higher values of the compression ratio becomes possible due to its higher octane number with a research octane number value up till 106. Also the higher combustion rate of bio-ethanol is directly related with the engine efficiency improvement.

If bio-ethanol is use as single fuel another important issue is related to the lower value of the caloric power registered for bio-ethanol compara-tive to gasoline. As any other alcohol, the bio-ethanol has a low caloric power comparative to gasoline (26800 kJ/kg and 43850 kJ/kg for gasoline). This deficiency leads to the necessity of increasing the ethanol consumption and also of the storage capacity on board of the vehicle; this last issue require larger fuel tanks in case of bio-ethanol use as single fuel.

Table 1. **Physical and chemical properties of bio-ethanol [1, 2, 3]**

The fuel properties	Gasoline	Bio-ethanol
Density at 15 ^{o}C [kg/m^3]	735…760	792
Boiling point (at 1.013 bar) [^{o}C]	30…190	78
Specific heat (at 20 ^{o}C, 1.013 bar) [kJ/kgK]	2.01	2.369
Dynamic viscosity at 0 ^{o}C [mPa s]	0.42	1.20
Heat of combustion [kJ/kg]	43500	26800
Theoretical combustion air quantity [kg/kg]	14.9	9
Heat of vaporization [kJ/kg]	290…380	904
Autoignition temperature [^{o}C]	257…327	420
Octane number, MON/RON	90/98	87/106
Flame temperature (λ =1) [^{o}C]	2290	1930
Ignitability range (20^{o}C, 1.013 bar): Φs….Φi	0.4…1.4	0.3…1.56
Composition: c/h/o [%mass]	85/15/0	52/13/35
Flame velocity (λ =1, at 20 ^{o}C, 1.013 bar) [m/s]	0.41	0.56
Ignitability point [^{o}C]	<20	12.5
Reid vapour pressure [daN/cm^2]	0.8….0.9	0.14
Temperature reduce at vaporization (λ =1) [^{o}C]	28	96.5
Heat of combustion for stoichiometric mixture [kJ/kg]	2990	2975
Temperature decrease when vapo-rizing a theoretical mixture [ºC]	28…31	96.5
Molecular weight [kg/kmol]	98	46.070
Melting point at 1.013 bar [ºC]	< –30	–114.6

Another adequate physical – chemical properties of the bio-ethanol for spark ignition engine operating conditions is it's laminar burning rate of almost 1,3…1,6 times higher comparative to gasoline which leads to the reducing the combustion duration, [1]. Also the bio-ethanol – air blend has a wider range of ignition ability comparative to gasoline (0,3 … 1,56 versus 0,4 … 1,4) which provide operating condition possibilities with much leaner air – fuel ratios.

As organic oxygenated products, alcohols feature high auto ignition endurance so they are the most adequate as SI engines fuels (RON = 100…106 for bio-ethanol). Comparative to gasoline operating conditions higher compression ratios (ε = 11…14) can be use due to its higher auto-ignition endurance. This leads to better efficiency and power per litter performances.

The higher flame velocity of ethanol is noted in the Figure 1 were for a wide range of air-fuel ratio of 0,5 to 1,3 the propagation of the flame in term of velocity increase with 175 % for λ = 0,8 and with 57 % at λ =0.9 for the power dosage area and for the stoichiometric conditions with 113 % at λ =1. Also for leaner dosage, λ = 1,3 the stable running is possible only with ethanol due to its large ignitability range.

The increase of flame velocity reduces the combustion duration with 13 % for λ = 0,8 and with 105 % for λ = 1, Figure 2. The combustion duration for ethanol at λ = 1,2 is similar with the value registered for gasoline running at λ = 0,9. The results was achieved on an octane number engine at 900 rpm, 7,25 compression ratio and 20 deg. CA spark timing as running conditions.

Bio-ethanol can be used as single fuel or in blend with gasoline in different proportions. Taken into consideration some physical chemical properties of the bio-ethanol the impact on exhaust emission becomes important. The gasoline-bio-ethanol mixtures have been studied for their effects on gas phase emissions from spark ignition engines. As the bio-ethanol is added to gasoline many of these gas-phase emissions like carbon monoxide, many hydrocarbons species as benzene, toluene and butadiene, aldehyde species or ethylene are reduced [7]. The particle mass concentration emission was reduced when the bio-ethanol is added in gasoline [7]. Even for small quantities of bio-ethanol blends with gasoline (for example E20), the concentration of the black carbon and PAHs decrease significantly. Also the quantity of sulphur decrease when the ethanol is added to the fuel. For bio-ethanol gasoline blends the molecular weigh distribution of the exhausted PAHs is significantly reduced. The addition of bio-ethanol leads to a decrease in concentration of particles larger than 10 nm, particles which significant impact on human health [7].

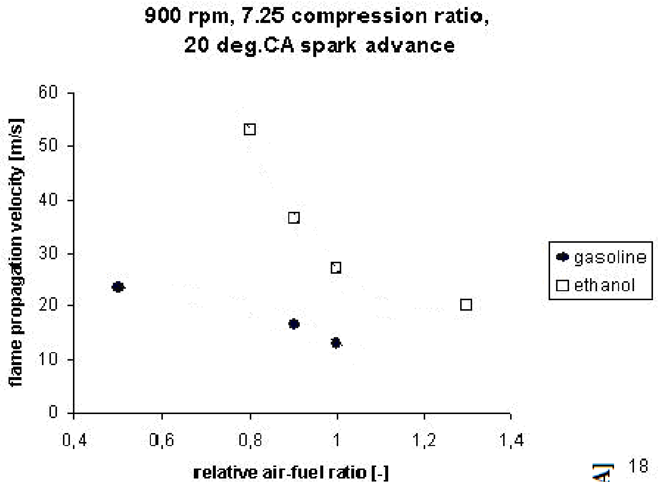

Fig. 1. Flame propagation velocity versus air-fuel ratio value for gasoline and bio-ethanol [1].

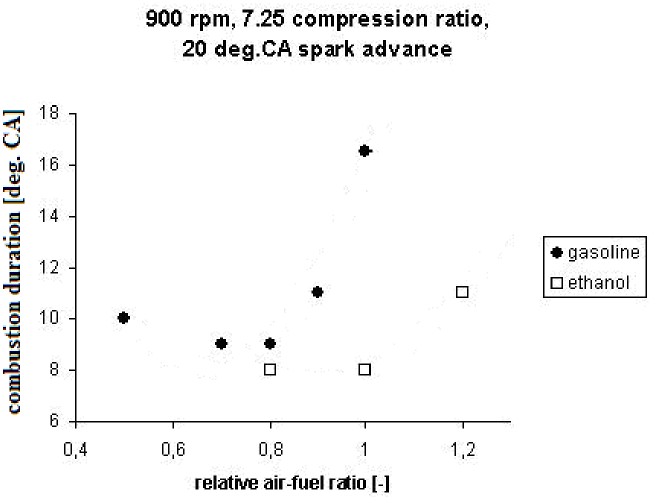

Fig. 2. Burning initial phase duration versus air-fuel ratio value for gasoline and bio-ethanol [1].

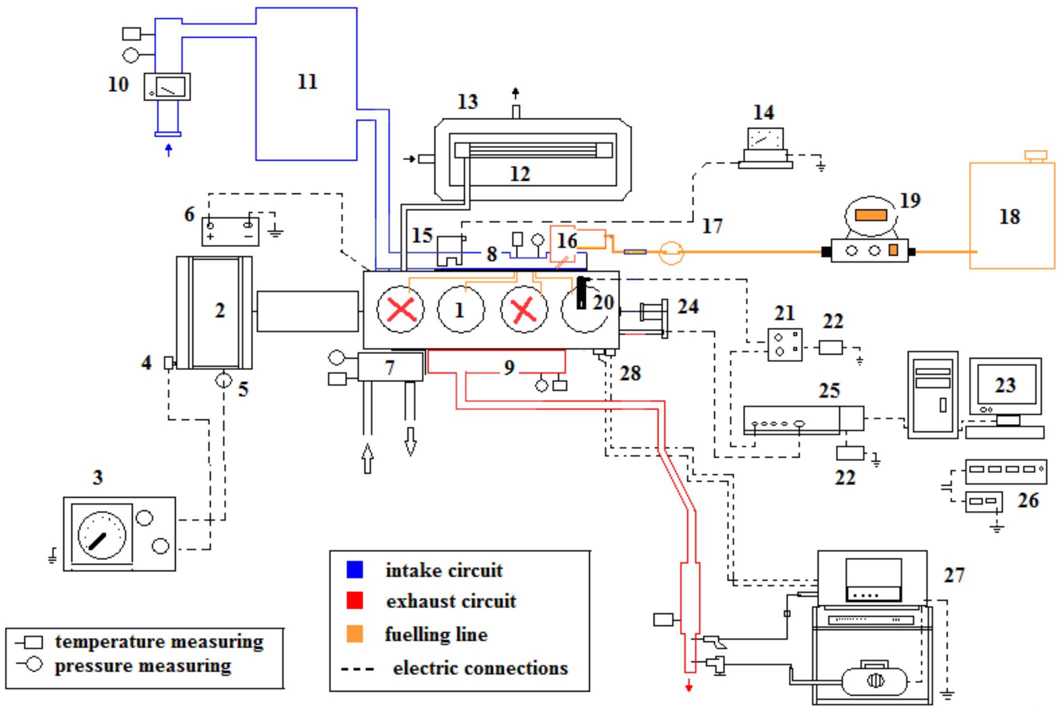

Fig. 3. Bio-ethanol single cylinder test bed:
1 – engine; *2*- hydraulic dyno; *3* – dyno controller; *4*- dyno speed sensor; *5*- dyno torque sensor; *6* – battery; *7* – oil pan cooling circuit; *8* -inlet manifold; *9* – exhaust manifold; *10* - air flowmeter; *11* – air reservoir; *12* - radiator; *13* – radiator cooling system; *14* – electric rheostat; *15* – inlet electric resistance; *16* – carburettor; *17* – fuel filter; *18* – fuel reservoir; *19* – fuel flowmeter; *20* – Kistler pressure transducer; *21* – charge amplifier; *22* – power supply; *23* – data acquisition computer; *24* – angle encoder; *25* – data acquisition system; *26* – temperature / pressure indicators; *27* – AVL Dicom 4000 gas analyzer; *28* – gas analyzer speed sensor.

3. EXPERIMENTAL INVESTIGATIONS AND RESULTS

The experimental research were developed for an experimental single cylinder engine designed from a four cylinder automotive engine mounted on a test bed and equipped with the following instruments (Fig. 3).

The experimental engine is a single cylinder concept derived form the 4 in line cylinder automotive engine 810-99. In order to assure the bio-ethanol-gasoline blends or ethanol fuelling and running conditions the engine was equipped with some special systems as: intake heating electric resistance in order to preheat the inlet air, the inlet air temperature being setup by an electric rheostat.

The regime engine temperature is controlled by a cooling circuit for oil pan and one for the cooling system radiator and is monitored by thermocouples and thermoresistances for exhaust gases, inlet air, intake mixture, oil, cooling system fluid.

The fuelling system includes a carburettor with a special construction for the main jet that's offer the possibility of fuel flow adjustment for dosage control and possibility of stable running in a wide values area for air-fuel ratio.

The experimental investigations were carried out for different operating regimes recording parameters for determination of mechanical running, efficiency, power and pollutant emissions engine performances at gasoline and bio-ethanol-gasoline blends. The results for wide open throttle regime (WOT), 3200 and 3500 rpm speed regimes, for gasoline (E0), E20 and E85 fuelling are presented.

The pressure data's registered by the data acquisition system was used for maximum pressure and indicated mean effective pressure determination. The increase of bio-ethanol content in gasoline blends leads to an increase in maximum cycle pressure, for all operating speeds, values till 54 bars being reached (Figs. 4 and 5). The wide limits of bio-ethanol ignitability comparative to gasoline allow stable operating conditions also for lean dosages.

At full load, wide open throttle (WOT), and 3200 rpm the increase in maximum pressure is around 33% for E20 and 66% for E85 at stoichiometric regime and similar increasing percents for power dosage, figure 4. For 3500 rpm the values of maximum pressure rise with 27% for E20 and with 52% for E85 at stoichiometric dosage, comparative to gasoline fuelling (Fig. 5).

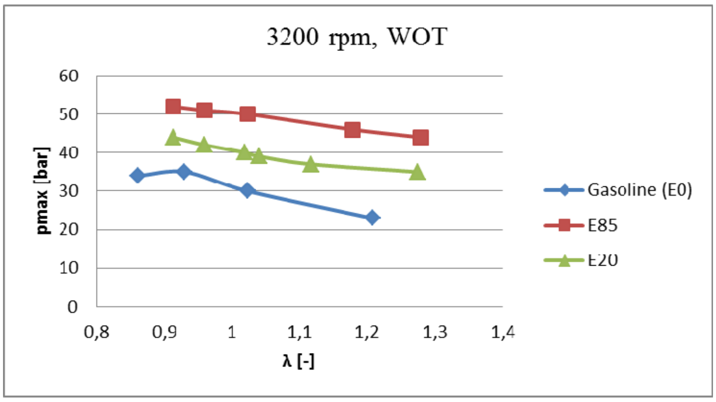

Fig. 4. Maximum pressure versus air-fuel ratio at WOT and 3200 rpm [8].

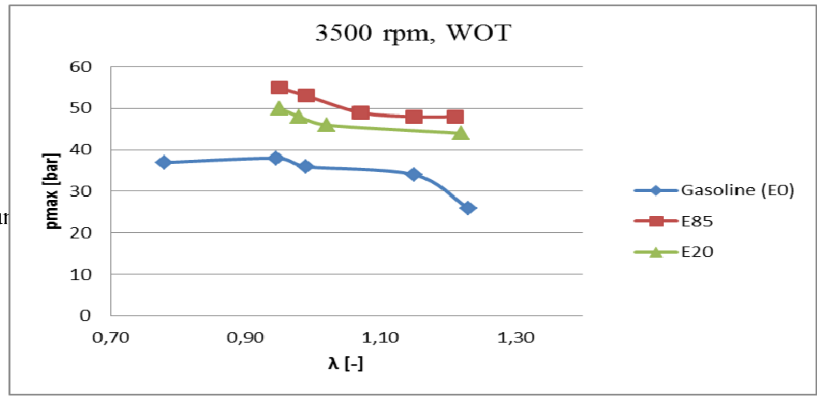

Figure 5. Maximu

At the same λ air fuel ratio, the engine effective power reached the highest values for E85 use, with an 11…16 % bigger comparative to gasoline standard fuelling. Depending on air-fuel ratio and speed, the power increases with 7…10% for E20, maximum values being obtained for 3500 rpm and λ=0.93. This increase in power for bio-ethanol-gasoline blends is related with the better properties of combustion for bio-ethanol and combustion duration decreases (Figs. 7 and 8). However, a deficiency of this issue is the increase of thermal loses because of much higher burning temperatures reached during air-bio-ethanol-gasoline blend combustion, fact related forward with the increasing of nitrous oxide emissions at gasoline-bio-ethanol blends fuelling, [8].

Even if the oxygenated fuels has a lower heating power comparative to gasoline, the experimental investigations shows lower fuel consumptions for ethanol blends fuelling for all speed regimes. Thus, for all speeds of 3200 and 3500 rpm, in the area of lean and also rich dosages, the gasoline brake specific fuel consumptions were bigger comparative to the specific consumptions for E20 and E85, respectively. Also, the BSFC decreases with the increase of engine power. Comparative to gasoline, the decrease in BSFC is between 8…12% for E20 and E85 (Figs. 10 and 11).

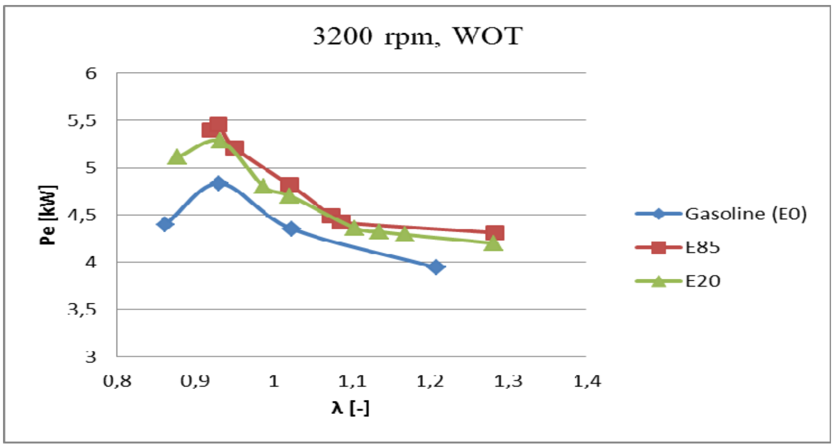

Fig. 7. Engine effective power versus air fuel ratio at WOT and 3200 rpm [8].

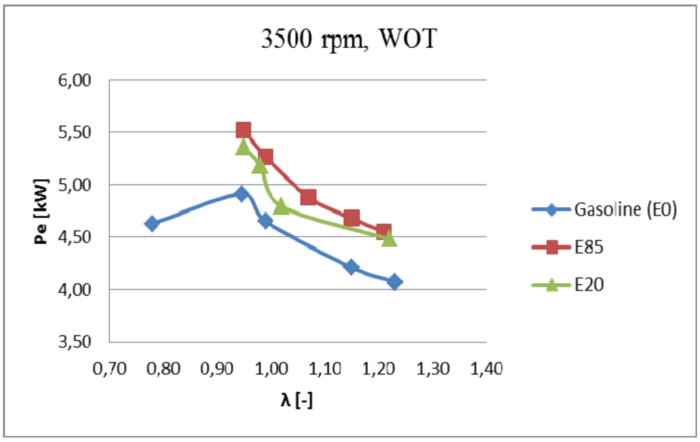

Fig. 8. Engine effective power versus air fuel ratio at WOT and 3500 rpm [8].

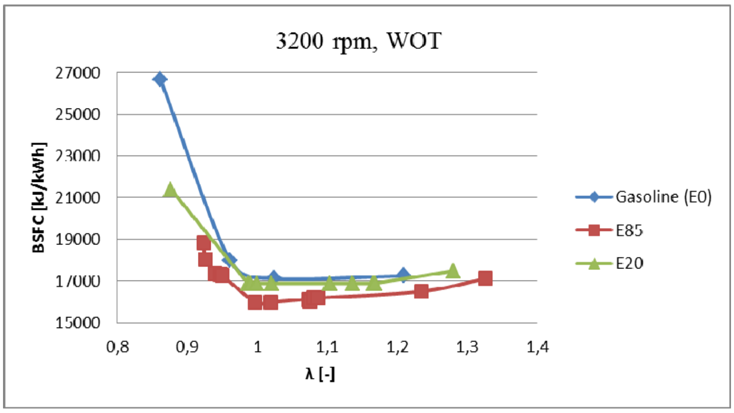

Fig. 10. BSFC versus air-fuel ratio at WOT and 3200 rpm [8].

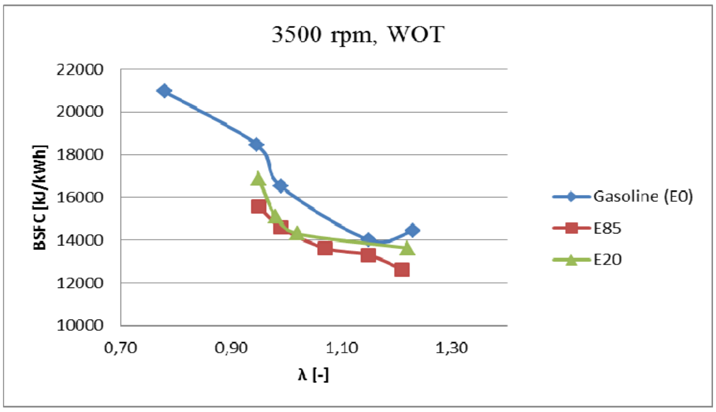

Fig. 11. BSFC versus air-fuel ratio at WOT and 3500 rpm [8].

In Figures 12 and 13 are shown the exhaust emissions of carbon monoxide, established in percents, the reference being defined by gasoline carbon monoxide emissions.

For E20 and E85 fuelling the CO emissions generally are lower comparative to gasoline running and present an decrease tendency with the increase of engine speed and dosage leaning, up till $\lambda = 1,23$. After this dosage value the CO emissions slightly increase but the registered values are very low comparative to reference. In the area of power dosages of $\lambda = 0.85,\ldots,0.9$ and up till $\lambda = 1$, the reduction of CO emission is significant, with almost 70% for all investigated regimes.

Comparative to gasoline, for all operating regimes, the HC emissions also decreases with 20% and up till 75% at the fuelling with E20 and E85, respectively. The decrease is accentuated when the engine speed increases (Figs. 14 and 15). This reduction in carbon monoxide and unburned hydrocarbons is due to oxygen content from the bio-ethanol chemical composition which leads to an improvement of combustion when the bio-ethanol content in gasoline blends increases.

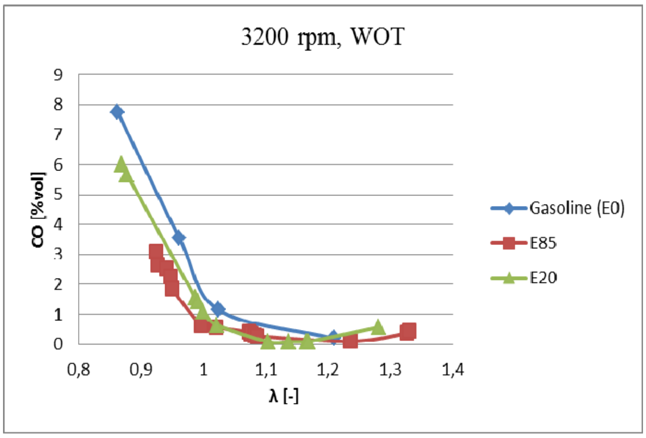

Fig. 12. CO emission level versus air-fuel ratio at WOT and 3200 rpm [8].

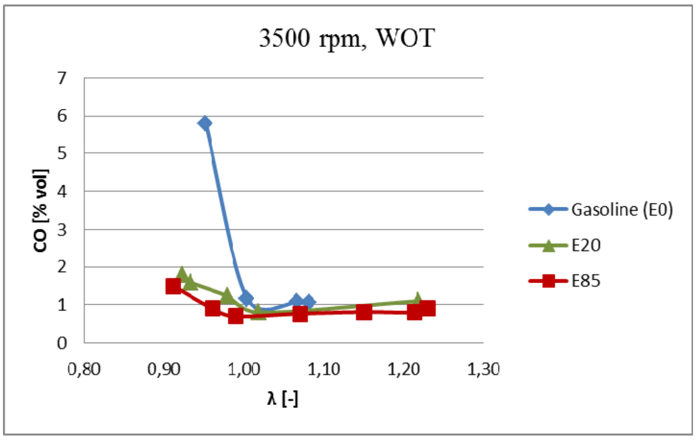

Fig. 13. CO emission level versus air-fuel ratio at WOT and 3500 rpm [8].

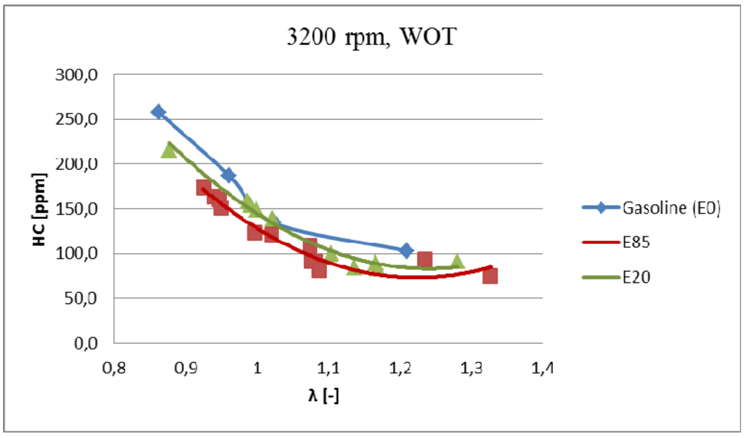

Fig. 14. HC emission level versus air-fuel ratio at 100% load and 3200 rpm [8].

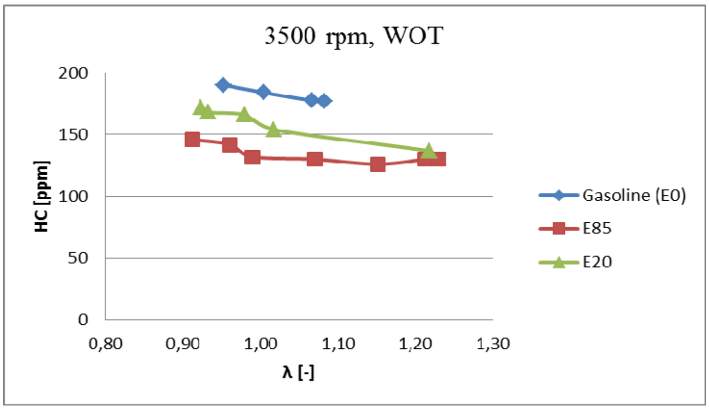

Fig. 15. HC emission level versus air-fuel ratio at 100% load and 3500 rpm [8].

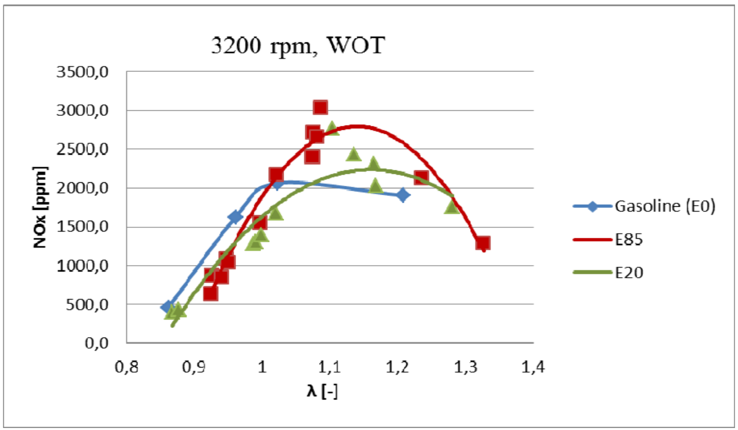

Fig. 16. NO_x emissions level versus air-fuel ratio at WOT and 3200 rpm [8].

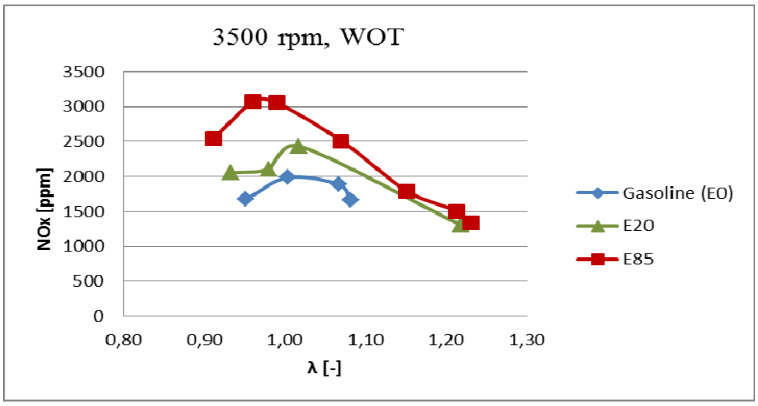

Fig. 17. NO_x emissions level versus air-fuel ratio at WOT and 3500 rpm [8].

Due to the presence of oxygen in the bio-ethanol composition, at the increase of bio-ethanol percent in blends with gasoline, the level of nitrous oxides emission increases. This NO_x emissions increment is maintained at the increases of engine speed, figures 16 and 17. As average increase percent for NO_x emission are resisted increases with ~12% and 50% for E20 and E85, respectively at 3200 rpm and with 25% and 50%, respectively at 3500 rpm for the same fuel blends. The reduction of NO_x emissions can be assured by converter catalyser or EGR use in order to obtain the lower accepted values.

4. CONCLUSIONS

1. Bio-ethanol is defined as a suitable alternative fuel for S.I. Engine due to it's higher laminar burning rate, much higher research octane number value RON, higher flame velocity which allows the improvement of engine performances by higher compression ratios use, combustion duration decrease.

2. The increase of bioethanol percent in blends with gasoline leads to the increase of maximum pressure value, at all operating regimes, especially for E85, when the maximum pressure reach 54 bar at full load and 3500 rpm. Even if the value is with almost 39% higher comparative to gasoline running conditions, the engine reliability is not affected.

3. The engine power performances are improved for gasoline-bioethanol blends fuelling. At 3500 rpm and λ=0.93, the engine effective power increase with 16 % for E85 due to combustion duration decreases and better combustion properties of bio-ethanol

4. For bioethanol-gasoline blends running conditions the engine efficiency is improved for all area of dosages. The BSFC decreases with the increase of engine power. Comparative to gasoline, the decrease in BSFC is between 8 and 12% for E20 and E85, respectively, when the power performance increases. The maximum efficiency at full load is obtained in the dosage area of λ =1,…,1.1 for 3000 and 3200 rpm and at much leaner dosages λ =1.1,…,1.2 for 3500 rpm.

5. Important decreases in CO emissions till λ = 1 and smoother reductions after the stoichiometric dosage. Lower values of CO are registered especially for lean dosages of λ = 1.2,….,1.3 comparative to gasoline engine , for all operating regimes.

6. At all operating regimes, the HC emissions also decreases with 20% and up till 75% at the fuelling with E20 and E85, respectively. The decrease is accentuated at the increases of the engine speed and is related to the improvement of the combustion process.

7. Being also an oxygenated fuel the bioethanol use leads to the NO_x emissions increment. A slightly increase is obtained for low speed regimes and more significant one for 3500 rpm, E85, of almost 50%. The emissions can be reduced by catalytic converter use.

8. At 3200 rpm the emissions level is minimal at λ =1,...,1.1 for CO and HC and is obtained in terms of the best efficiency, with minim values for BSFC. Also, for λ =1,….,1.1 for E20, the NO_x level is under the values obtained for gasoline and this reduction of NO_x being also obtained for the best efficiency, minimum BSFC. At λ =0.85,….,1 the NO_x level for E20, E85 is lower comparative to gasoline.

9. At 3500 rpm speed regime the CO and HC are minimal in the area of engine highest efficiency defined by lower BSFC values λ =1.1,….,1.2 . Also in this area, λ =1.15,….,1.25, the NO_x emission level is lower for E20 and E85 comparative gasoline.

10. Bio-ethanol is a viable alternative fuel for spark ignition engines and can be use in blends with gasoline, for new or in use engines, without major modification, but with an important impact on engine performance, emissions and human health.

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