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COMPARISON OF CYCLE VARIABILITY BETWEEN GASOLINE AND E20 FUELLING OF A SUPERCHARGED SPARK IGNITION ENGINE

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The reduction of pollutant emissions from the automotive engines by use of alternative fuels becomes a priority. The paper presents the preliminary results of cycle variability study for a turbocharged spark ignition engine fuelled with gasoline and bioethanol for rich, stoichiometric and lean dosages. The influence of bioethanol content in blends with gasoline on cycle variability of the combustion process is reflected in the calculated values of the cycle variability coefficients. The cycle variability decreases at E20 use comparative to gasoline.

Keywords: Bioethanol, cycle variability, combustion, maximum pressure, lean mixture.

1. Introduction

To improve spark ignition engines energetically and pollution performance research looks to alternative fuels use. From the alternative fuels used for automotive spark ignition engines, bioethanol represents a viable fuel due to its better combustion proprieties, make inexhaustible renewable resources and to diminishing of the classic petroleum products consumption [1]. Is recommend the use of the bioethanol as an alternative fuel for the automotive spark ignition engines and because of actually pollutant norms which become more severe, especially for NO_x emissions and for the greenhouse gas CO_2. At the bioethanol use the NO_x emission level could be reduced by 50-60 %, [2].

Bioethanol is considered an alternative viable fuel for spark ignition engines due to its advantages [1, 3]:

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- bioethanol has compatible properties with SI engine required operate conditions
- it can be manufactured from agricultural and waste products
- the distribution and storage possibilities are facilitated by the actual infrastructure for gasoline.

Bioethanol has better combustion properties comparative with the gasoline:

- greater laminar flame speed (almost 1,36 times higher) [4]
- lowering adiabatic flame temperature (1930 ^{o}C, comparative to 2290 ^{o}C) [4]
- greater octane number (RON, 107 comparative to gasoline RON of 95-98) [5]
- larger oxygen content at molecular level (34.7 %, comparative to 0.4 %)
- greater auto ignition temperature (420 ^{o}C, comparative to 257…327 ^{o}C) [4].

Spark ignition engine running can be assured by bioethanol use with the maintaining or with the increases of engine energetically performance, without major modifications of its design (the engine was equipped with standard equipment's as intake and exhaust systems, fuelling system, filters of fuel and oil etc.) [6]. At the supercharged SI engine, the bioethanol use can allows the increasing of boost pressure without appearance of knock phenomena [7, 8, 9]. The use of bioethanol assures an intake air efficient cooling effect due to its higher heat of vaporization, effect which at the supercharged SI engine is very important [7, 9]. Thus, the intake air cooling effect leads to a volumetric efficiency improvement and reduces the risk knock development. Also due to a lower in-cylinder temperature level is estimated that the pollutant emissions decrease, especially NO_X. At the bioethanol use the knock resistance increases and allows the increasing of the boosting pressure when the bioethanol percentage in blend with gasoline increases, helping to improve the engine energetically performance [9]. The higher bioethanol octane number increases the auto-igniting resistance of the end-gas zone thus bioethanol may be considered an efficient antiknock agent for the supercharged SI engine [9, 10, and 11]. The use of bioethanol-gasoline blends leads to the increase of the in-cylinder gases maximum pressure and of the pressure rise maximum rate due to better combustion proprieties of the bioethanol, but through optimum ignition timing establishment the engine strengths can be controlled [9, 11]. The cycle variability can be characterized by coefficients of in-cylinder pressure variation. The intensity of the cycle variability phenomena is defined by the coefficient of cycle variability, as relation (1) shows. The coefficient of cycle variability is defined as a relative average deviation of maximum pressure values [5]. For "n" consecutive cycles, if is considered a normal distribution of the deviation probabilities, the squared average deviation can be calculated and the cycle variability coefficient is defined as:

$$(COV)a_i = \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(a_i - \frac{\sum_{i=1}^{n} a_i}{n}\right)^2}{n-1}}}{\frac{\sum_{i=1}^{n} a_i}{n}} \cdot 100\% \qquad (1)$$

where n is the number of cycles, a is the parameter of which variability is studied and is defined for indicated mean effective pressure IMEP, maximum pressure p_{max}, maximum pressure rise rate $(dp/d\alpha)_{max}$ and the angle where maximum pressure occurs, α_{pmax} in the cycle number "i".

Generally, the way of cycle variability evaluation for regimes with spark timing closer to the value of spark timing for maximum torque brake (MTB) the COV of maximum pressure is suitable. The COV of maximum pressure angle, when the maximum pressure occurs, is used for characterization of the combustion cycle variability during the initial phase of combustion. The variation of the IMEP, appreciated by $(COV)_{IMEP}$, is the most suitable instrument to define the engine respond to the combustion process variability. From this point of view the limit value of $(COV)_{IMEP}$ defines practically the limit of mixture leaning. This cycle variability coefficient can also indicate the variability of flame development during the initial phase of combustion [5, 11, and 12]. The fuel type influences the cycle variability by the value of its laminar flame velocity. For higher laminar combustion speed, of 1.36 times higher for bioethanol versus gasoline, the flame development is much quicker, comparative to gasoline. A higher combustion velocity reduces the influence of turbulence and reduces the cycle variability [5, 11]. The quality of the in-cylinder mixture influences the combustion process through chemical reaction speed, with a maximum in the area of rich dosage. From this point of view the initial and final phases of the combustion process have minimal duration at the dosage for which the chemical reaction speeds are maximum, λ=0.9 [11, 12, 13, 14]. At the mixture leaning the durations of those two phases increase and the total combustion duration also increases. In the area of very lean mixtures λ=1.4 the stabile running of the engine is also assured by E20 due to bioethanol wider limit of inflammability of 0.3…1.56 versus 0.4…1.4 for gasoline (defined as λ_i…. λ_s at 20 ^{o}C and 1.013 bar) [11, 12, 15].

2. Aspects of cycle variability study for bioethanol use

A natural aspirated automotive spark ignition engine was converted in to a turbo-supercharged engine and fuelled with bioethanol-gasoline blends in order to improve energetic and pollution performance.. For full load regime and speed of

2500 rev/min at different air-fuel ratio values defined by λ=0.9, 1.0 and 1.4 and secondly speed regime of 3000 rev/min and full load at different values of air-fuel ratio defined by λ=0.9, 1.0 and 1.2, a preliminary comparative study of cycle variability was developed. Using a AVL data acquisition system, Indimodul 621 type, a number of 150 consecutive cycles were registered for gasoline and E20 (20 $(\%)_v$ bioethanol 80 $(\%)_v$ gasoline) fuelling.

Were calculated the cycle variability coefficients for indicated mean effective pressure (IMEP), maximum pressure, maximum pressure rise rate and angle of maximum pressure. In order to evaluate the way that the engine running is affected by the variability of the combustion process, these coefficients are calculated and presented in the following figures. In terms of cycle variability, the general tendency shows a significant decreases of this phenomenon when the E20 fuel is used.

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For all running regimes, full load and both speeds, the λ values, defined by 0.9, 1.0 and 1.4 at 2500 rev/min and λ as 0.9, 1.0 and 1.2 at 3000 rev/min, were determined by calculus using the measured values of air and fuel consumptions. At a running regime, defined by engine speed and an unchanged position of the throttle, at the maintaining of the supercharging pressure value, the fuel cycle dose was modified by using of a Dastek Unichip Unit which is connected with the main engine ECU. Also, with the Dastek Unichip Unit software the spark ignition timing was modified. The supercharging pressure was maintained at the value of 0.14 [MPa] by adjustment of the turbine waste-gate valve. The spark ignition timing was initially adjusted to limit the maximum pressure value and to avoid the knock combustion phenomena.

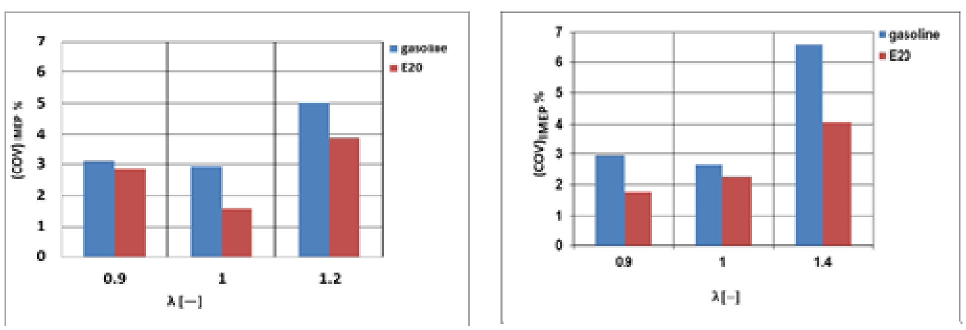

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Fig.1. COV for IMEP versus air-fuel ratio at (a) 3000 rev/min and (b) 2500 rev/min

Regarding the comparison of those two running regimes defined by 2500 and 3000 rev/min speeds, at only E20 fuelling, the following aspects may be formulated: for the stoichiometric dosage, at the speed of 3000 rev/min, the general response of the engine to combustion cycle variability, evaluated by $(COV)_{IMEP}$ is improved comparative to 2500 rev/min regime, decreasing from 2.25% to 1,58% for E20, as fig.1 shows. The decreasing effect appears also in the area of lean mixtures when the COV of IMEP decreases from 4.07% till 3.88%. For E20 fuelling, at rich dosage the cycle variability in terms of indicated mean effective pressure slightly decreases from 2,98% till 1.78% when the engine speed decrease from 3000 to 2500 rev/min at full load

The cycle variability coefficient of maximum pressure $(COV)_{pmax}$, for E20 fuelling decreases from 12.22% to 10.4% at lean dosages when the speed rise up from 2500 to 3000 rev/min, as fig. 2 presents. For stoichiometric dosage the $(COV)_{pmax}$ slightly increases from 4.491% to 5.1% with the increasing of speed. The same tendency is remarked also at rich dosages with an increase of 3.29% $(COV)_{pmax}$ from 4.21% to 7.5%.

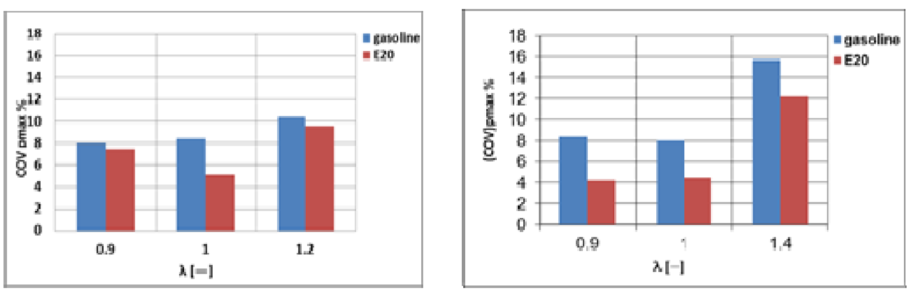

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Fig.2. COV for maximum pressure versus air-fuel ratio at (a) 3000 rev/min and (b) 2500 rev/min

The fig.3 shows that the maximum pressure rise rate cycle variability coefficient, $(COV)_{dp/d\alpha\ max}$ remains at the same value for E20 and for gasoline at stoichiometric dosage, when engine speed increases. For the area of lean mixtures the cycle variability is improved at speed increasing, decreasing with 5% for E20 fuelling. At rich dosages the COV for maximum pressure rise rate decreases at E20 use at both speed regimes. For the domain of lean mixtures operating regimes, this is presented only as a general tendency of cycle variability coefficients suitable for a specific dosages domain, lean dosage area, because the dosages area of lean mixtures is present at both speed regimes but is not defined by the same value, λ=1.2 at 3000 rev/min versus λ =1.4 at 2500 rev/min. The cycle variability of the combustion process increases with the mixture leaning and for λ=1.4 the cycle variability increases because of very lean operating dosage comparative to λ=1.2, the registered values for maximum pressure rise rate takes the highest values.

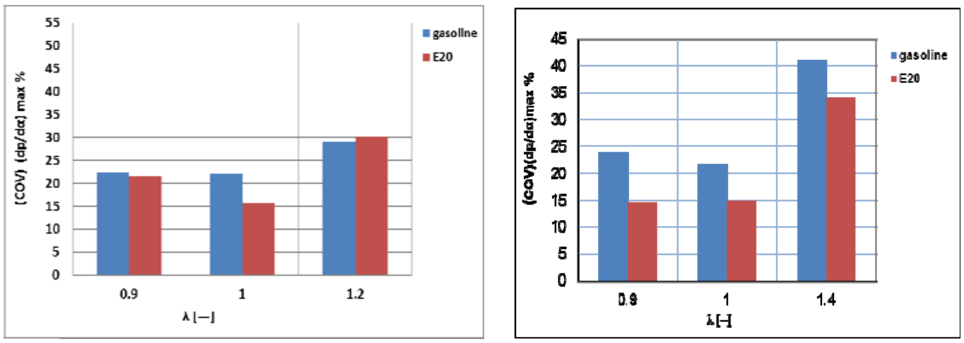

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Fig.3. COV for (dp/dα) max versus air-fuel ratio at (a) 3000 rev/min and (b) 2500 rev/min

In fig.4 is presented the variation tendency for the COV values calculated for moment when the maximum pressure per cycle occurs, α_{pmax}. At stoichiometric dosage the variability registered only during the initial phase of combustion for E20 fuelling, decreases with 13.94%, from 19.04% to 5.1%, at the increasing of the engine speed regime from 2500 rev/min to 3000 rev/min. For rich dosage, λ =0.9, the cycle variability of the combustion initial phase increases with the rise of the engine speed, from 7.626% up till 9.5% in terms of COV for the angle of cycle maximum pressure. Also, generically speaking , in the area of lean dosages the $(COV)_{\alpha pmax}$ decreases from 14.617% to 9.99% when the engine speed rise from 2500 rev/min to 3000 rev/min.

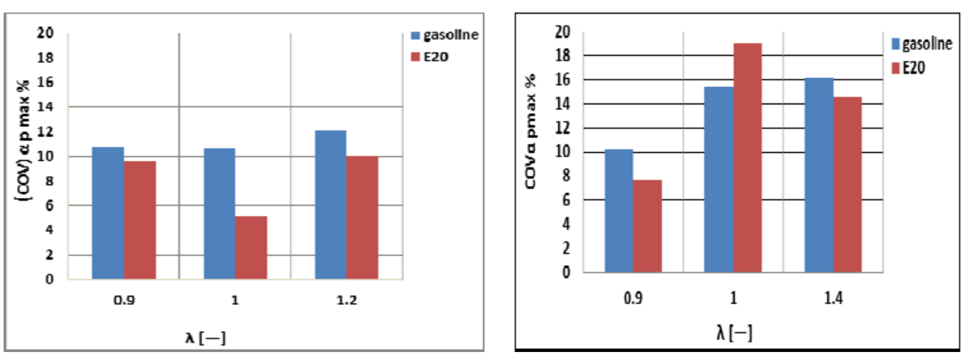

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Fig.4. COV for α_{pmax} versus air-fuel ratio at (a) 3000 rev/min and (b) 2500 rev/min

3. Conclusions

The main conclusions may be formulated:

1. For E20 fuelling, at rich, lean and stoichiometric dosages, at both speed regimes, the values of the variability coefficient for indicated mean effective pressure decreases comparative to the values registered for only gasoline fuelling, fact which shows the improvement of the general response of the engine to combustion cycle variability. Also, comparative to gasoline fuelling, at lean mixtures where, generally, the tendency of cycle variability increase appears, at E20 the value of $(COV)_{IMEP}$ decreases with 2.5% at 2500 rev/min and with 1.2% for 3000 rev/min. For E20 fuelling at stoichiometric and lean mixtures the cycle variability of indicated mean effective pressure is lower for 3000 rev/min versus 2500 rev/min, the engine running being improved once with the increase of speed and E20 use; at rich dosages the $(COV)_{IMEP}$ values are lower for 2500 rev/min regime.
2. The value of $(COV)_{pmax}$, for E20 fuelling decreases from 12.22% to 10.4% at lean dosage when the speed increases from 2500 rev/min to 3000 rev/min. Also, for all speed regimes the E20 fuelling leads to the decrease of cycle variability for maximum pressure value comparative to gasoline fuelling. The decrease tendency registered for $(COV)_{pmax}$ is related with the variation of $(COV)_{IMEP}$ and shows the improvement of the combustion process at E20 use.
3. Maximum pressure rise rate cycle variability coefficient, $(COV)_{(dp/d\alpha)\ max}$ remains at the same value at the increasing of engine speed for stoichiometric dosage. For the area of rich or lean mixtures the cycle variability is improved at speed increasing and E20 fuelling. Comparative to gasoline fuelling, at 2500 rev/min, at E20 fuelling the cycle variability coefficients values for decrease with 10% unit for rich dosage, with 7% unit at stoichiometric dosage and with 8% unit for lean dosage, tendency which is related with the variation registered for $(COV)_{IMEP}$, $(COV)_{pmax}$ and $(COV)_{(dp/d\alpha)\ max}$. At 3000 rev/min the decrease appears especially for the stoichiometric dosages at E20 fuelling.
4. In the area of lean dosages the $(COV)_{\alpha pmax}$ decreases from 14.617% to 9.99% when the engine speed rises from 2500 rev/min to 3000 rev/min. Also, for each speed regime, the COV values for maximum pressure angle decrease at E20 fuelling comparative to gasoline. Thus, at 3000 rev/min the coefficient values decrease from 11% till 9.5% for rich dosage, from 11% till 5% at stoichiometric dosage and from 12% till 10% for lean mixture. At 2500 rev/min, the values decrease from 10% till 7.8% for rich mixtures and from 16% till 14% for lean dosage. The reduction of the dispersion between the values of the maximum pressure angle indicates the reduction of flame

development during the initial phase of combustion when the E20 fuel is used versus gasoline.

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