ASPECTS OF THE BIOETHANOL USE AT THE TURBOCHARGED SPARK IGNITION ENGINE

by

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In the actual content of pollution regulations for the automotives, the use of alternative fuels becomes a priority of the thermal engine scientific research domain. From this point of view bioethanol can represents a viable alternative fuel for spark ignition engines offering the perspective of pollutant emissions reduction and combustion improvement. The paper presents results of the experimental investigations of a turbo-supercharged spark ignition engine (developed from a natural admission spark ignition engine fuelled with gasoline) fuelled with bioethanol-gasoline blends. The engine is equipped with a turbocharger for low pressure supercharging, up till 1.4 bar. An correlation between air supercharging pressure-compression ratio-dosage-spark ignition timing-brake power is establish to avoid knocking phenomena at the engine operate regime of full load and 3000 min^{-1}. The influences of the bioethanol on pollutant emissions level are presented.

Key words: *ethanol, engine performance, ignition timing, combustion, emissions*

Introduction

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

In general, the bioethanol is considered a viable alternative fuel for SI engines due to its advantages [1, 3]:

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

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Several research works highlight the effects of ethanol use on the performance, pollutant emissions, combustion characteristics, and the corrosion effect on some pieces of the SI engines.

Bioethanol has better combustion properties comparative to gasoline:
- greater laminar flame velocity (almost 1.36 times higher versus gasoline) [4],
- lower adiabatic flame temperature (1930 °C, comparative to 2290 °C) [4],
- greater octane number (RON 107 comparative to 95-98 for gasoline) [5],
- larger oxygen content at molecular level (34.7%, comparative to 0.4%), and
- greater autoignition temperature (420 °C, comparative to 257-327 °C) [4].

The operation of the SI engine can be assured by bioethanol use with the maintaining or with the increases of engine energetically performance, without major design modifications of the engine (the engine was equipped with standard equipments: intake-exhaust systems, fuelling system, fuel filters, *etc*.), [6]. In the same time, as Bromberg *et al*. [7, 8] and Pana *et al*. [9] affirm that at the bioethanol use the supercharging pressure can be increased without occurs of the knock combustion at the supercharged SI engines.

The greater laminar flame velocity of the bioethanol comparative to the gasoline assures the combustion duration decrease, the engine thermal efficiency increase, the possibilities of leaner mixtures use and the quality adjustment use of the engine load [4, 9]. The use of bioethanol assures an intake air efficient cooling effect due to its higher heat of vaporization, effect which is very important for the supercharged SI engine [7, 9]. 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 the NO_x emissions decrease. At the bioethanol use, when its percentage in blend with gasoline increases, the fuel knock resistance increases and allows the increasing of the supercharging pressure, helping to improve the engine energetically performance [9]. The higher bioethanol octane number increases the auto-igniting resistance of the end-gas zone and from this point of view ethanol may be considered an efficient antiknock agent for the supercharged SI engines [9-11]. Christie [12] and Pana *et al*. [9] show that the use of bioethanol-gasoline blends leads to the increase of the in-cylinder gases maximum pressure and of the maximum pressure rise rate due to better combustion proprieties of the bioethanol, but through optimum ignition timing establishment, the engine mechanical stress can be controlled. At the regime of engine maximum torque speed the brake specific fuel consumption, evaluated in energetically units brake specific energetic consumption (BSEC), decreases with 7-10% at E85 use comparative to gasoline use due to better combustion proprieties of the bioethanol [12]. Ananda *et al*. [13] showed that the brake thermal efficiency significant increases with 13-22% at the increase of bioethanol content in mixture with gasoline at all engine speeds comparative with gasoline. Also, they highlight a significant reduction of the emissions level for CO, CO_2, HC, and NO_x (a SI engine with displacement of 0.8 dm^3). For E60 in mixture with 10% of 1.4 Dioxan (oxygenated additive) the following results were obtained: the CO emission was reduced from 0.25% to 0.05% by volume; the CO_2 emission was reduced with 10% in the range of engine small speeds but increases by ~15% at the engine high speeds; the HC emission was reduced with 66% at all engine speeds; the NO_x emission was reduced with 55% for all engine speeds [13]. Al-Hasan [14] investigated a SI engine fuelled with E0, E50, and E85 at various compression ratios (10:1 and 11:1), at full load regime for entire engine speeds domain (1500-5000 [min^{-1}]). Their experimental investigations show that the BSEC significant decreases. The bioethanol becomes an efficient tool for emissions level control (CO, HC, and NO_x) when is used in blend with the gasoline. Gogos *et al*. [15] showed the effects of the ethanol on CO, HC, and NO_x emissions at an automotive SI engine fuelled with E10, E20, and E50. Their results have shown pronounced decrease of the CO (29-91%) and HC (17-55%) emissions at the ethanol percentage increase in blend with gasoline, but the NO_x emissions level increases at different engine speeds. According to the equipped level of the used engine (the engine was not equipped with catalytic converter), the NO_x emissions level increase is explained by authors by the fact that the air-fuel mixture becomes leaner with increasing of the bioethanol amount in the blends with gasoline. At partial engine loads, at ethanol fuelled engine, NO_x emissions level is lower comparative to gasoline fuelling due to a lower temperature level inside the engine cylinder (ethanol has a higher vaporisation heat *vs*. gasoline). Also, they showed that emissions of CO_2 decreased (19-52%) due to better combustion. Jeuland *et al*. [16] specified that at high engine loads the NO_x emissions level can be controlled by operating at stoichiometric dosage without risk of knock combustion, even at the supercharged engines [16]. An important advantage of the bioethanol use is the brake mean effective pressure (BMEP) increase, advantage mentioned in most research works. Thus, Jeuland *et al*. [16] found at an ethanol fuelled turbocharged engine (E100 fuel type), that the BMEP increased with 15% comparative with gasoline fuelling.

Bio-ethanol contains acetic acid and therefore it corrodes aluminum alloys. It also absorbs the lead in alloys and finally the surfaces become porous. In order to avoid this issue it is recommendable a nickel cladding for all those surfaces. Same phenomena may appear on plastic parts of injection systems, filters or any plastic – rubber gaskets. It is recommendable to be manufactured of nylon or raylon. Thus, different part of the classic fuelling systems must be replacement or protected for ethanol use.

Bioethanol as alternative fuel for a supercharged SI engine can be used in mixture with gasoline or as a single fuel, by injection in the intake manifold or in-cylinder direct injection. The objective of the paper is to analyse the effects of bioethanol-gasoline blends on a turbocharged SI engine performance. As a research novelty is a correlation establish between air supercharging pressure- compression ratio-dosage-SI timing- brake power which assures the maximum pressure limitation and the avoiding of knock phenomena at the engine operate regime of full load and 3000 min^{-1} speed. The indicated mean effective pressure (IMEP) cycle variability study for gasoline and E20 fuelling also becomes a novelty aspect.

Experimental investigations

The experimental investigations were carried out on an automotive modified SI engine of 1.5 dm^3 displacement (the aspirated engine was transformed in a turbocharged engine in the laboratories from University Politehnica of Bucharest). Figure 1 presents the test bed schema. The test bed was equipped with all instrumentations which assure the engine running control and data acquisition.

The specifications of the engine are presented in tab. 1.

The experimental investigations were carried out at full load regime and speed of 3000 min^{-1}, the engine being fuelled firstly with gasoline then with gasoline-bioethanol blend (E20). For maximum pressure limitation and knock avoiding, the dosage (the air-fuel mixture dosage was defined by the relative air/fuel ratio λ), SI timing and supercharge pressure were tuned and a correlation between these parameters and engine power was established. For gasoline engine were used rich dosages ($0.91 \geq \lambda \leq 1$) and for bioethanol engine were used dosages from aria $\lambda = 0.98$-1.07.

Results and discussion

In fig. 2 is presented the engine brake power *vs*. relative air-fuel ratio. For gasoline engine, the maximum brake power is obtained for $\lambda = 0.91$, the engine performance for this dosage is considered as reference. At the bioethanol-gasoline blend fuelling (E20), the same maximum

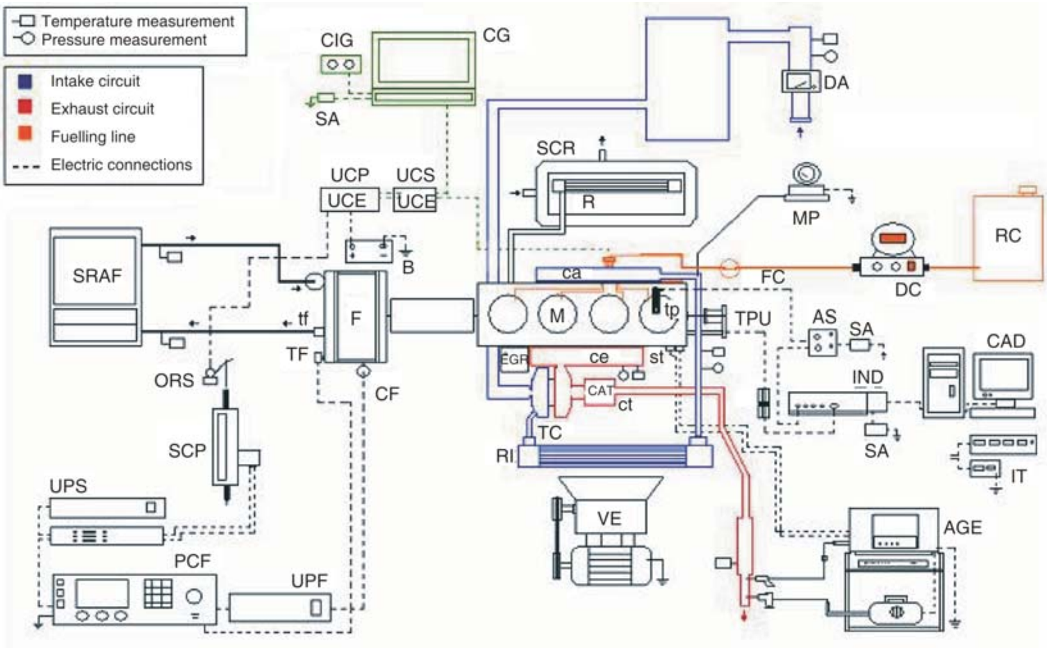

Figure 1. Test bed schema [9]

AGE – exhaust gas analyzer, AS – charge amplifier, B – battery, ca – intake manifold, CAD – data acquisition computer, CAT – catalytic converter, ce – intake manifold, CF – dyno power cell, CG – fuelling system computer, CIG – injectors actuation, ct – three way catalyst, DA – air flowmeter, DC – fuel flowmeter, EGR – exhaust gas recirculation valve, F – eddy current dyno, FC – fuel filter, IND – indimodul 621 data acquisition unit, IT – temperature indicators, M – DAEWOO 1.5 SI engine, MP – supercharging pressure manometer, ORS – throttle, PCF – dyno command panel, R – engine cooler, RI – intercooler, RC – fuel reservoir, SA – power supply, SCP – throttle actuator servomotor, SRAF – dyno scooling system, st – gas analyzer speed sensor, TC – turbocompressor, tf – dyno cooling water temperature sensor, TF – dyno speed transducer, tp – cylinder pressure transducer, TPU – angle encoder, UCP – principal electronic control unit, UCS – secondary electronic control unit, UPF – dyno power unut, UPS – throttle actuator servo motor power unit, VE – cooling electric fan for intercooler, x – electronic emitter-receptor

Table 1. Engine specifications

Engine type	Modified DAEWOO Engine
Number of cylinders	4
Displacement [dm^3]	1.5
Bore [mm]	76.5
Stroke [mm]	81.5
Ratio of crank radius length to connecting rod [–]	0.33
Compression Ratio [–]	9.2
Fuelling system	Multi point injection

brake power was obtained at the dosage λ= 0.98 due to better combustion properties of bioethanol comparative to gasoline and due to the cylinder filling improvement (the bioethanol produces an intake air efficient cooling with because the bioethanol has the value of vaporization heat three times higher comparative to gasoline). In fig. 3 are shown the in-cylinder pressure diagrams for gasoline and gasoline-bioethanol blend (E20) fuelling at the maximum power dosages (λ = 0.91 for gasoline and λ = 0.98 for E20). In case of E20

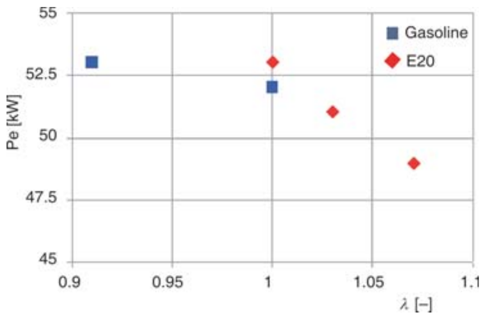

Figure 2. Brake engine power at full engine load and 3000 rpm

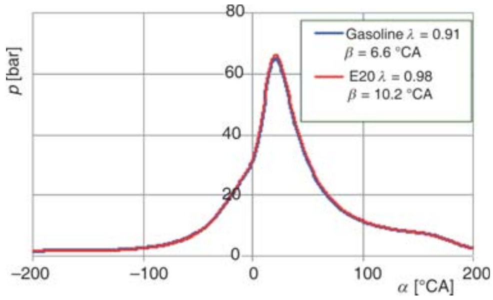

Figure 3. Pressure diagrams at full engine load and 3000 rpm
(for color image see journal web site)

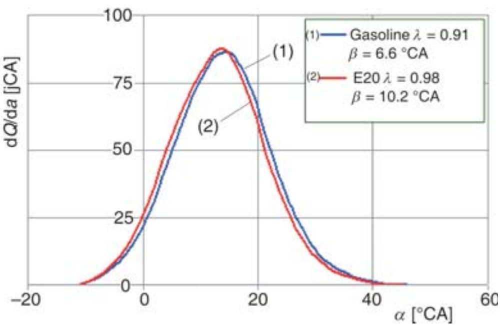

Figure 4. Heat release rate *vs.* crankshaft angle
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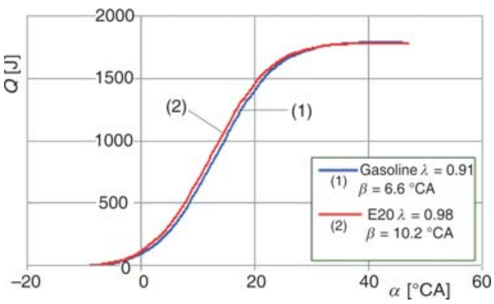

Figure 5. Cycle heat release *vs.* crankshaft angle
(for color image see journal web-site)

fuelling, at the dosage $\lambda = 0.98$, the SI timing is greater comparative to gasoline fuelling at rich dosage.

In figs. 4-9 there are presented the dosage effects on some cycle characteristics parameters. The maximum pressure, p_{max}, has same value at the dosage $\lambda = 0.98$ for E20 fuelling comparative to gasoline fuelling at the dosage $\lambda = 0.91$, fig. 3. In the figs. 4-5 are presented the heat release rate and heat release *vs*. crank angle degree, for gasoline and E20 engine, obtained from pressure diagrams processing. Comparative to gasoline, due to a higher burning rate of bioethanol comparative to gasoline, at dosage $\lambda = 0.98$ and E20 fuelling the maximum heat release rate and combustion duration have comparable values with the ones registered for dosage $\lambda = 0.91$ and gasoline fuelling, figs. 4-5. The maintaining of maximum pressure value, at the use of E20, is a big advantage for the engine reliability. The maximum pressure, p_{max}, and maximum pressure rise rate, $(\mathrm{d}p/\mathrm{d}\alpha)_{max}$, have the same values of 6.8 MPa and 0.22 MPa/°CA, respectively, for all used dosages, but the BSEC of

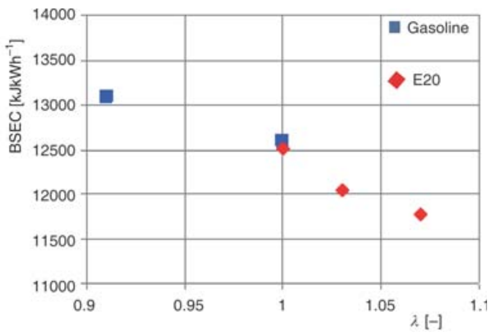

Figure 6. The BSEC *vs.* relative air/fuel ratio at full load and 3000 min^{-1}

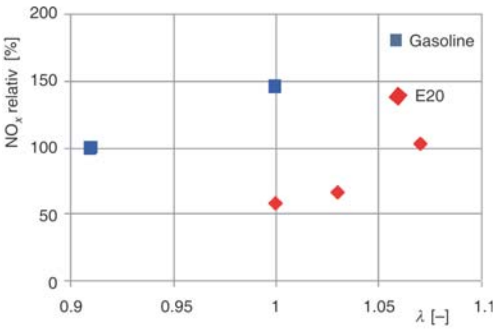

Figure 7. Relative NO_x emissions *vs.* relative air/fuel ratio at full load and 3000 min^{-1}

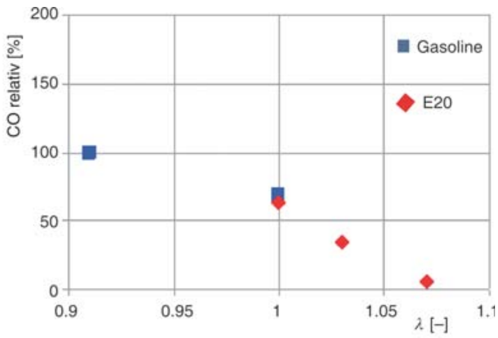

Figure 8. Relative CO emissions *vs.* relative air/fuel ratio at full load and 3000 min^{-1}

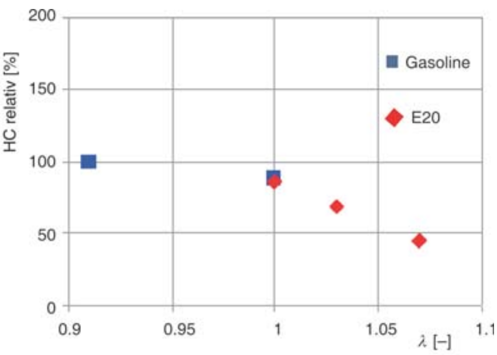

Figure 9. Relative HC emissions *vs.* relative air/fuel ratio at full load and 3000 min^{-1}

E20 fuelled SI engine (12502 kJ/kWh for λ = = 0.98) is lower than the BSEC value of the gasoline fuelled SI engine (13091 kJ/kWh for λ = 0.91) fig. 6

The NO_x emissions level accented decreases at the E20 use fig. 7 due to the higher heat of vaporization of bioethanol comparative to gasoline (the vaporisation of the bioethanol induces a local cooling effect).

At the same maximum power, NO_X emissions level decreases with 50% for E20 fuelled engine at dosage $\lambda = 0.98$ comparative to gasoline fuelled engine for $\lambda = 0.91$, SI timing having an important effect on NO_x emission and engine efficiency increases due to better combustion proprieties of the bioethanol. And for the same dosage $\lambda = 0.98$, the NO_x emissions level is smaller for E20 fuelled engine *vs*. gasoline fuelled engine, the engine power being greater, fig 7. Figure 8 shows the effect of bioethanol in blend with gasoline on CO emission. Since carbon content of bioethanol is smaller comparative to gasoline and the oxygen content is greater, the combustion process is improved and CO emission level decreases with 50% for E20 fuelling at dosage $\lambda = 0.98$ comparative to gasoline fuelling at $\lambda = 0.91$.

The effect of bioethanol-gasoline blend (E20) on HC emissions is shown in fig. 9. The HC emissions level decreases with 25% for E20 fuelling at dosage $\lambda = 0.98$ comparative to gasoline fuelling at $\lambda = 0.91$. The decrease of HC emissions level is similar to that of the presented CO emissions level.

Also, another novelty aspect of this paper is the cycle variability study for the IMEP, of turbocharged engine fuelled with bioethanol. The cycle variability can be characterised by coefficients of in-cylinder pressure variation and the intensity of the cycle variety phenomena is defined by the value of cycle, coefficient variability of (COV), [5]. The general response of the engine at cycle to cycle combustion variability is well evaluated by the value of coefficient of cycle variability calculated for defined as COV_{IMEP} [5]. The COV of IMEP defines the engine response to the combustion variability and practically establish the limit of mixture leaning. The normal automotive engine manoeuvrability is assured if the values of COV are fewer than 10%

[5]. The COV_{IMEP} was determined for 150 consecutive cycles. The cycle variability of the combustion process is also affected by the bioethanol use. At λ = 0.98, the E20 use improves the general response of the engine on cycle variability of the combustion process. For this dosage, the value of COV_{IMEP} decreases, from 2.93% at gasoline fuelling down till 1.58% for E20 fuelling.

From the point of view of cycle variability there is no need to set-up a limitation criteria for the quantity of bioethanol in blends with gasoline.

Conclusions

This paper has presented the advantages of using bioethanol as fuel at turbocharged SI engine.

At the E20 use, the same engine maximum power is obtained at dosage λ= 0.98 comparative to gasoline fuelling, when this is obtained at rich dosage (λ = 0.91). At the E20 fuelling the BSEC is smaller comparative to gasoline fuelling due to improvement of the combustion process. For the investigated engine operating regime (full load and 3000 min^{-1}), the maximum pressure was limited by SI timing adjustment and dosage λ= 0.98 use. Thus, the NO_x emissions level is controlled, obtaining a substantial reduction. Due to better combustion proprieties of bioethanol, the CO and HC emissions level accented decreases. Bioethanol can be defined as an efficient agent for knock avoiding. Thus, was possible to operate with the turbocharged engine at the full load, with dosage λ= 0.98 without occurs of knocking phenomena comparative to gasoline turbocharged engine which uses richer mixture dosages. A correlation established between air supercharging pressure-compression ratio-dosage-spark ignition timing-brake power leads to the avoiding of knocking phenomena. There are not required engine design modifications at E20 use. The E20 fuelling reduces the cycle variability of the combustion process comparative to gasoline fuelling.

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Nomenclature

BMEP – brake mean effective pressure
BSEC – brake specific energetic consumption, [kJkW^{-1}h^{-1}]
CA – crankshaft angle, [deg.]
p – in-cylinder gases pressure, [MPa]
E20 – gasoline (80%)-bioethanol (20%) blend
Q – cycle heat release, [J]

Greek symbols

α – crankshaft angle, [°CA]
β – spark ignition timing, [°CA]
λ – air excess coefficient, [–]
dQ/dα – heat release rate, [J°CA]

Acronyms

COV – coefficient of variation
IMEP – indicated mean effective pressure
SI – spark ignition

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