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# The study of the spark ignition engine operation at fuelling with n-butanol-gasoline blends

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**Abstract.** For conventional internal combustion engines alternative fuels such alcohols (ethanol, methanol and butanol) have attracted more attention. This aspect is due to the fact that alcohols have good combustion properties and high oxygen content. Butanol is a viable fuel for blending with conventional fuels such as gasoline or diesel because of its high miscibility with these conventional fuels. The high combustion speed of butanol compared to that of gasoline ensures a shorter burning process thus the engine thermal efficiency can potentially be improved. Moreover, the additional oxygen content of the alcohol n-butanol can potentially improve the combustion process and can lead to a reduction of carbon monoxide and unburnt hydrocarbons emissions level. Utilizing butanol-gasoline blends can provide a good solution for the reduction of greenhouse gases level ($CO_2$) and pollutants level (CO, HC, and NOx). An experimental study was carried out in a spark ignition engine which was fueled with a blend of n-butanol-gasoline at different volume percentages. The objective of this paper is to determine the effects of butanol on the engine energetic performances and on the emissions (HC, CO and NOx). At first the engine fueled with pure gasoline to set up a reference at the engine load $\chi$=55%, engine speed of n=2500 min-1 and different excess air coefficients ($\lambda$). After setting the reference the engine was fueled with butanol-gasoline blend (10% vol. butanol - 90% vol. gasoline) with the same engine adjustments. At butanol use the CO, HC and $CO_2$ emissions level decreased, but the NOx emission level increased. The butanol can be considered a good alternative fuel for the spark ignition engines without modifications.

## 1 Introduction

Current worldwide fossil fuel consumption will lead to a depletion of conventional fuels in a matter of decades, thus more researches have been focused on alternative fuels. The great consumption of fossil fuel is also associated with greenhouse gases such as $CO_2$ and pollutants products, especially for passenger vehicles over the last years. For internal combustion engines, alcohols have gained a lot of attention in recent years. The use of the alcohols like methanol, ethanol or butanol - conventional fuels such as gasoline or diesel

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blends can improve the combustion process in the engine cylinder and reduce the fossil fuels consumption. Due to their better combustion proprieties, alcohols can increase the thermal efficiency for a given engine size and compression ratio, improve of the combustion resulting in lower conventional fuel consumption and thus lower $CO_2$ emissions [1, 2, 3]. A well-to-wheel analysis carried out by Wu. M. et al, [4], concluded that on a life-cycle basis, the use of the butanol resulted from corn production as fuel could reduce the consumption of gasoline by 39-56% and reduce the greenhouse emissions by up to 48%.

Out of all the alcohols mentioned before, n-butanol is regarded as encouraging solution because of its better properties over the other alcohols such as higher energy density, low viscosity and good blending properties, [5]. When compared to ethanol, butanol is much less corrosive and hygroscopic as makes it more compatible with the fossils fuels distribution infrastructure, [6]. Liu et al. [7, 8] studied the flame natural luminosity and spray of different oxygenated fuels using laser diagnostics. The levels of soot concentration were much lower for n-butanol and more restricted when compared to biodiesel. Another study by Liu et al., [9] studied the effects of oxygenated compounds on engine emissions and thermal efficiency. For this study five different fuels were used for testing such as n-heptane, iso-octane, n-butanol, 2-butanol and methyl octyonate. The study found that oxygenated compounds have little impact on engine pollutants such as nitrogen oxides, carbon monoxide and unburned hydrocarbons. He also noticed that there is no impact on the indicated thermal efficiency. A study by Yuqiang Li et al., [10] analyzed the impact of isopropanol-n-butanol-ethanol gasoline blends on performance and emissions of a spark ignition engine. The blended fuel (IBE30) is made of 30% isopropanol-butanol-ethanol and 70% gasoline. Results with IBE30 show an improvement of the brake thermal efficiency by up to 4,3% for the blended fuels and lower HC (15,1-20,3%), lower CO (4%) and $NO_x$ (3,3 -18,6%) in some cases. The study concluded that IBE30 can be considered as a good alternative to gasoline. J. Serras-Pereira et al., [11] analyzed of the combustion process in a direct injection engine by using ethanol, butanol, iso-octane, gasoline and methane. Results show that ignition is more difficult for butanol in a cold environment (they indicate a high coefficient of variability of IMEP and longer duration of MFB in the early stages of fuel ignition of 0-10%). The initial combustion phase was longer for all alcohols with 5-7$^o$CA. The coefficient of variation of IMEP was higher for some alcohols but for butanol and ethanol did not exceed 8%. The COV for iso-octane has increased beyond 10-20%. The ignition timing increased for all alcohols with 10-15$^o$CA to reach maximum indicate mean effective pressure with minimum variation. Butanol as a standalone fuel was used in a homogenous charge compression ignition engine. Studies were focused on using n-butanol as fuel, engine performances were limited by the reduction of combustion stability at lean fuel mixtures [12]. At low to mid-engine loads, it was possible to obtain low $NO_x$ and soot levels without the use of exhaust gas recirculation, [13]. Brake thermal efficiency is similar to diesel engines. Alasfour measured the efficiency in a single-cylinder engine at fueling with a blend of 30% butanol-gasoline. The study indicates a reduction of 7% engine power at fueling with the blended mix vs pure gasoline, [14]. In another study also carried out by Alasfour [15], nitrogen oxides emissions were measured at different air-fuel ratio ($\lambda$). Results indicate a reduction in nitrogen oxides emissions for $\lambda$ between 0,9 and 1,05 at fueling with the blended fuel. A 9% decrease of $NO_x$ emissions level was also observed. The highest $NO_x$ emissions level was found at a slightly leaner mixture for the blended mix vs gasoline due to the additional oxygen content. Another study, [16] concluded that the increase the spark timing will lead to higher $NO_x$ emissions.

The objective of this paper is to determine the impact of n-butanol on the engine energetic performances and pollutants (HC, CO and $NO_x$) in a 4 cylinder spark ignition 1,5l type Cielo Nubira A15MF. The engine is turbocharged and was firstly fueled with pure gasoline to set the reference at the engine load $\chi$=55%, engine speed of n=2500 min$^{-1}$ and different air-fuel ratios ($\lambda$). After setting the reference the engine was fueled with n-butanol-gasoline (10% vol. butanol - 90% vol. gasoline) with the same engine adjustments.

## 2 Experimental environment

The experimental test bench is presented in Fig. 1.

The engine used is a 4 cylinder, turbocharged, 1,5l type Cielo Nubira A15MF. The engine is fueled by gasoline and the engine load of $\chi$=55% and speed of 2500 min$^{-1}$ ; different parameters are recorded such as air and water temperature, intake air temperature, exhaust gases temperature, fuel consumption, air consumption, boost pressure and emissions level. In cylinder pressure is measured across 250 engine cycles and the mean values of these measurements are used to determine of the maximum pressure ($p_{max}$), maximum pressure rise rate $(dp/d\alpha)_{max}$, heat release rate ($dQ/d\alpha$) and total heat released (Q).

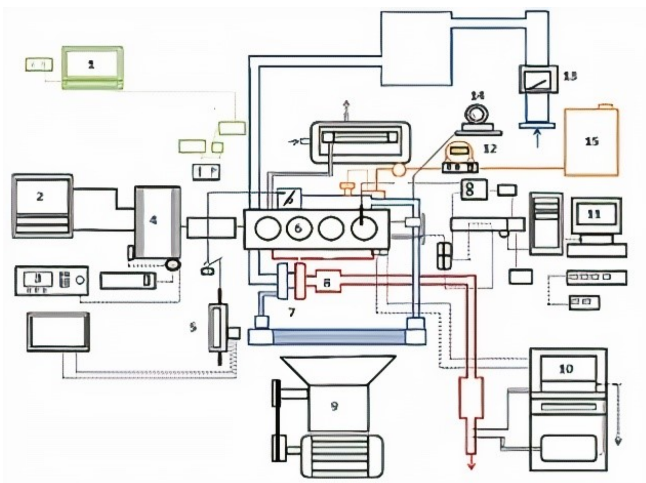

**Fig. 1.** Test bench schema

The main components of the test bench are: 1 – ECU, 2 – dyno cooling system, 3 – dyno control cabinet, 4 – Eddy current dyno, 5 – throttle body actuator, 6 – A15MF engine, 7 – turbocharger, 8 – catalytic converter, 9 – radiator cooling system, 10 – gas analyzer, 11 – desktop, 12 – fuel mass flow transducer, 13 – air flow transducer, 14 – boost pressure transducer, 15 – fuel reservoir.

## 3 Results

In the figures 2-11 experimental results are presented while fueling the engine with gasoline and butanol-gasoline blended mix.

In Fig.2 the pressure diagrams for both fuels are represented. Because the spark timing was kept constant at the butanol-gasoline blend use the initial combustion phase duration increased and the combustion is moved after the fuel ignited.

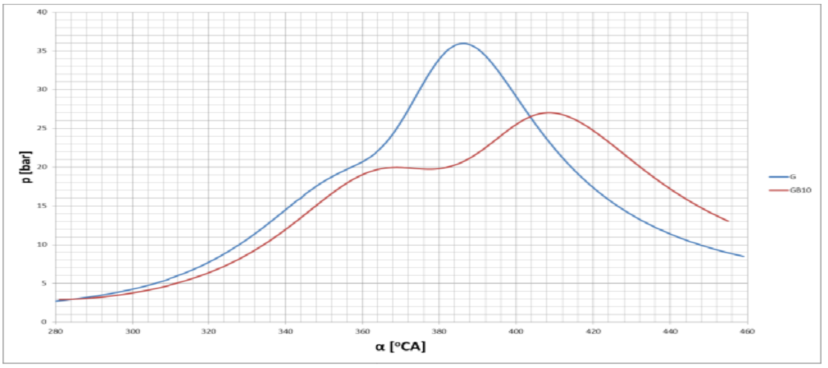


**Fig. 2** Pressure diagrams for gasoline and blended mix

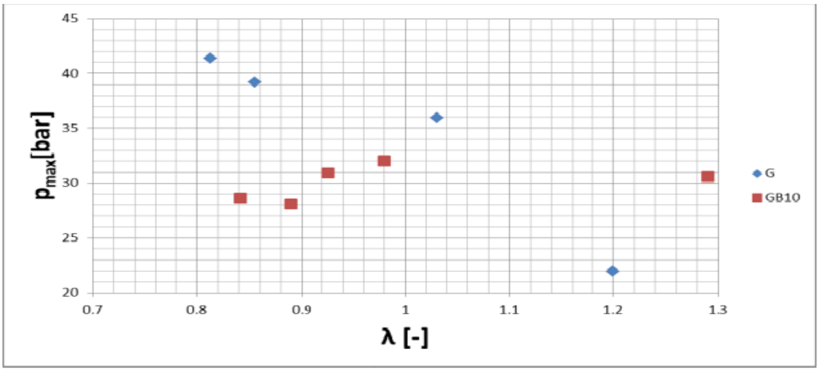


**Fig. 3** Maximum cylinder pressure for gasoline and blended mix

The maximum pressure for gasoline and butanol-gasoline blend is presented in the Fig.3. It is observed the higher maximum pressure value for gasoline, with 25%, at rich mixtures comparative to the blended mix because the spark timing was the same in both cases. This difference decreased in the lean mixtures zone due to the combustion improvement at the butanol use. It is possible that by increasing the spark timing, the maximum pressure for butanol-gasoline blend to become higher than gasoline. Same observations and for maximum pressure rise rate, Fig. 4.

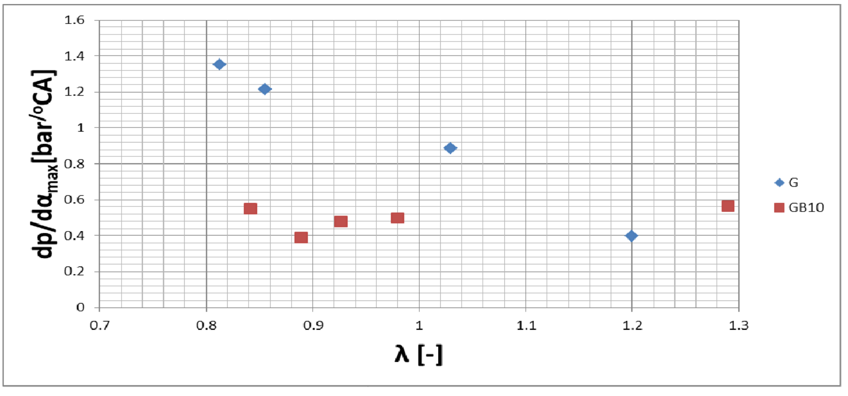


**Fig. 4.** Maximum pressure rise rate for gasoline and blended mix

The heat release rate is calculated with the relation:

$$\frac{dQ}{d\alpha} = \frac{V}{k-1} \cdot \frac{dp}{d\alpha} + \frac{k}{k-1} \cdot p \cdot \frac{dV}{d\alpha} \quad (1)$$

where:

- $\frac{dU}{d\alpha}$ -the internal energy variation
- $\frac{dL}{d\alpha}$ - the mechanical work variation
- $k$ - adiabatic exponent
- $V, p$ – the volume and pressure

The heat release rate is presented in Fig 5 where a higher value is observed for gasoline. It is also observed the main combustion phase move to the expansion at the butanol-gasoline use.

By integration of the (1) relation the heat release laws were obtained for both fuels, Fig. 6. The burning process duration of the butanol-gasoline is longer comparative to gasoline, because the spark timing was kept constant.

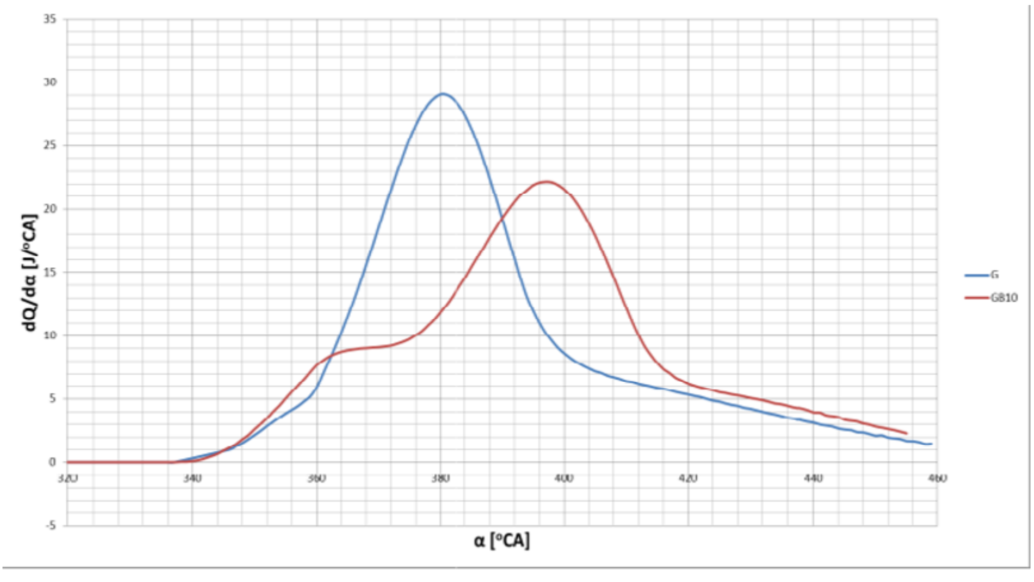


**Fig. 5.** Heat release rate for gasoline and blended mix

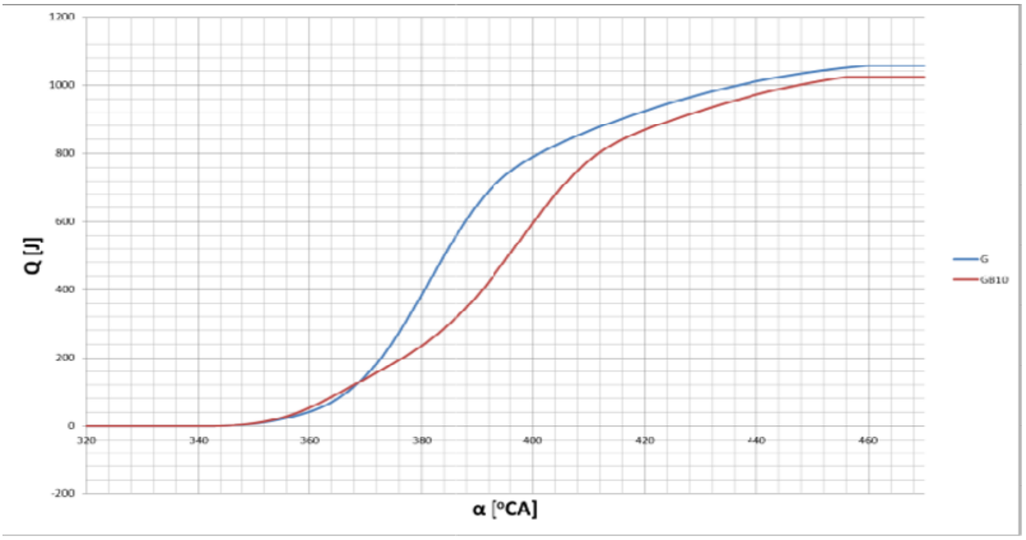


**Fig. 6.** Heat release laws for gasoline and blended mix

The brake specific energetic consumption (BSEC) for the gasoline-butanol blend is higher than gasoline, Fig.7.The first explanation is that the spark timing has same value both fuels and the initial combustion phase duration increased and the thermal engine efficiency decreased, Fig. 8. The main combustion phase moved to the expansion. The second explanation is the lower caloric heat of the butanol comparative to gasoline.

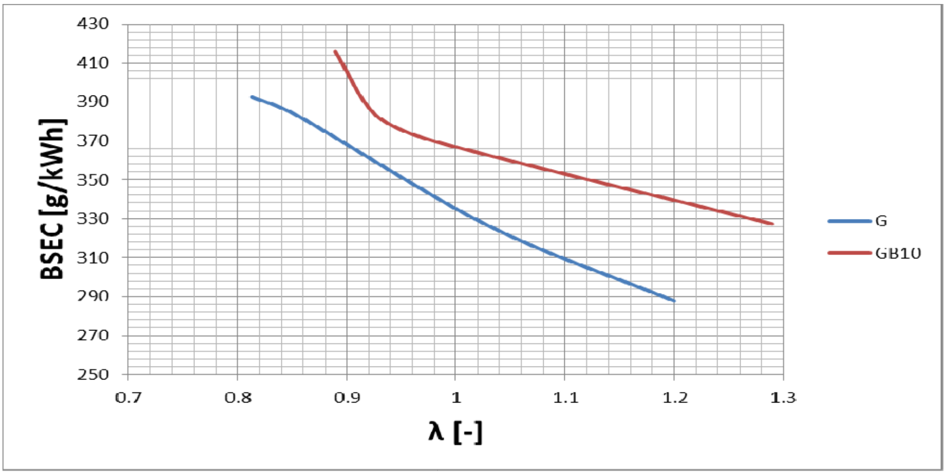


**Fig. 7.** BSEC for gasoline and butanol-gasoline blend

These negative effects can be eliminated by the spark timing increase.

At the engine fueling with butanol, in the lean mixtures zone the engine operation becomes more stable than gasoline. Such, for λ=1.29 the thermal engine efficiency has the same value as gasoline at λ=1.06, Fig. 8.

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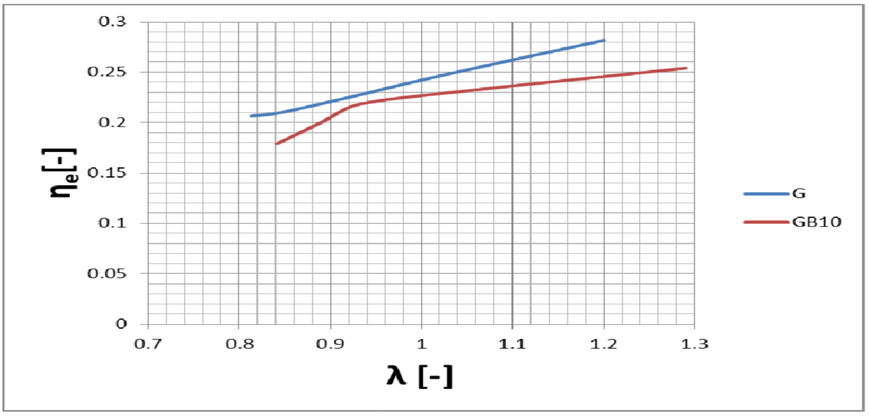


**Fig.8.** Brake thermal efficiency for gasoline and gasoline- butanol-gasoline

Carbon monoxide is the product of the incomplete combustion, indicating losses of heat. In general, the carbon monoxide level has high values in the rich mixtures domain. In the Fig. 9 it is observed that CO emissions level is higher for gasoline-butanol blend comparative to gasoline at rich mixtures (λ<0,95) due to lower temperature from the engine cylinder and degradation of combustion (butanol has a higher vaporization heat and the gases temperature from the engine cylinder are reduced and the combustion velocity is lower). At stoichiometric mixtures and lean mixtures the CO emissions level is lower at the use of the butanol-gasoline blend with around 1% less than gasoline because of combustion improvement (butanol has a higher content of oxygen than gasoline). Unburnt hydrocarbons (HC) are also a result of incomplete burning process due to air being absent.

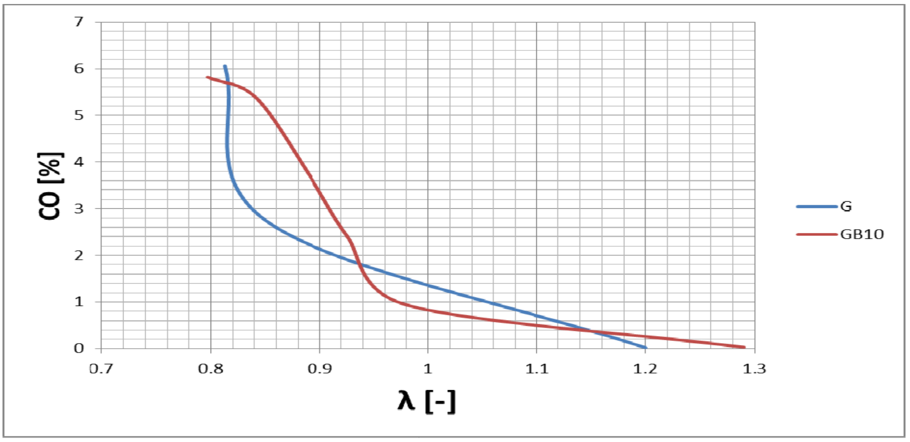


**Fig.9.** CO emissions level for gasoline vs butanol-gasoline blend

Same as in the case of carbon monoxide, HC emissions level is slightly higher at rich mixtures at the use of the butanol-gasoline blend but they significantly decrease with ~20% at lean mixtures due to the combustion improvement, Fig. 10.

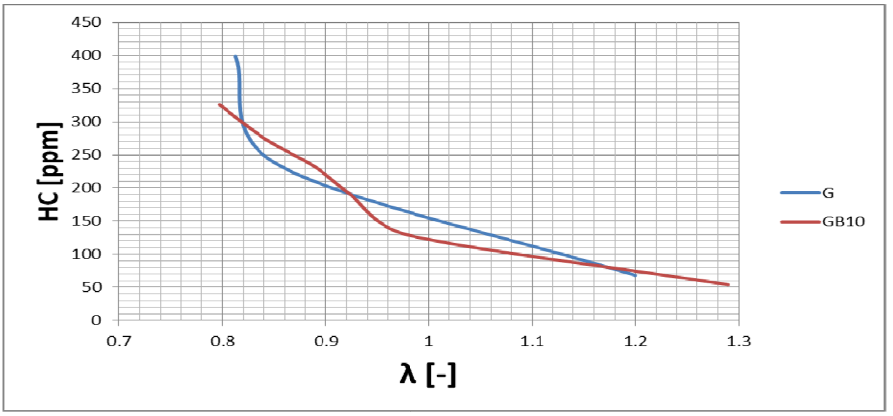


**Fig. 10.** HC emissions level for gasoline vs butanol-gasoline blend

The nitrogen oxides formation is an endothermic process and depends, in special, on temperature and oxygen content. The variation of nitrogen oxides level is presented in Fig. 11. As shown in this figure, $NO_x$ emissions level for the blended mix is significantly higher than gasoline for all excess air coefficients because of the additional oxygen content of butanol. Thus, NOx emission maximum level at the butanol–gasoline blend use is higher with ~50% than gasoline. At the spark timing increase, necessary adjustments for to move the main combustion phase to TDC, when the combustion duration decreases is possible the NOx emission level will continue to increase. This trend can be reduced by the very lean mixtures use.

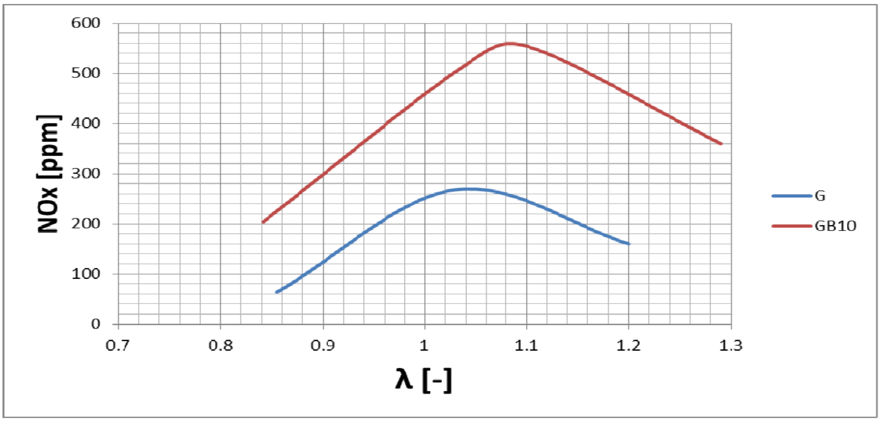


**Fig. 11.** $NO_x$ emissions level for gasoline vs butanol-gasoline blend

Carbon dioxide is the result of the complete combustion, unlike CO and HC. Hydrocarbons burning with the sufficient amount of air will generate heat producing carbon dioxide and water as a final products of the combustion process. The gasoline-butanol blend improves the combustion process and $CO_2$ emission level is smaller than gasoline due to lower carbon content, Fig. 12.

In the domain of λ=1,06…1,29, HC, CO and $CO_2$ emissions levels, at the gasoline-butanol blend use, are lower that gasoline. The results can be improved by the spark timing optimization, Fig. 9, 10 and 12.

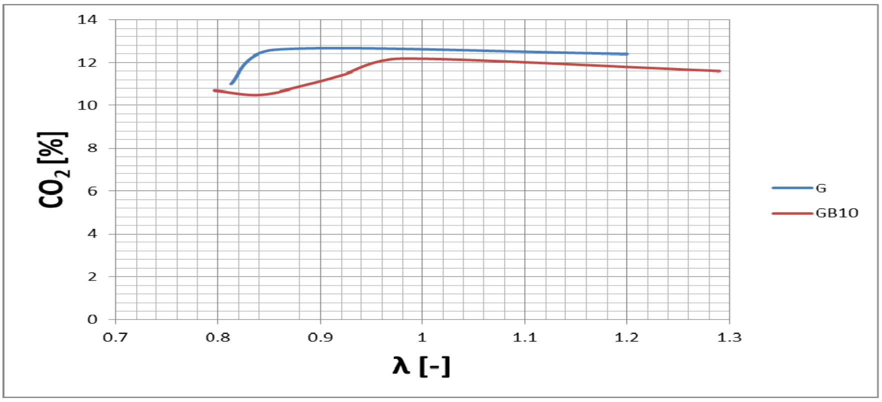


**Fig. 12** $CO_2$ emissions level for gasoline vs butanol-gasoline blend

## 4 Conclusions

The butanol-gasoline blend use at the spark ignition engines is a good solution for pollutants emissions and greenhouse gases reduction for spark ignition engines.

Therefore, CO emission level decreased with 28% comparative to gasoline due to combustion improvement. Just like CO, HC emission level decreased with 20% comparative to gasoline due to combustion improvement. NOx emissions level at the butanol–gasoline blend use is higher than gasoline. This effect can be reduced by the very lean mixtures use.

Brake specific energetic consumption increased at the butanol-gasoline blend use, but by optimizing the spark timing it can become lower than gasoline.

Maximum pressure and maximum pressure rise rate are smaller at the use of butanol-gasoline blend, with favorable effects for engine strengths.

Butanol can be considered a good alternative solution for gasoline engines without any constructive modifications. The researches will continue for the engine adjustments and butanol fraction in mixture with gasoline optimization.

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