

# **Impact of New Biofuels on Pollutant Production and Motor Performance and Study of Deno<sub>x</sub> Technologies to Achieve Zero Emission in Real Conditions**

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**ABSTRACT:** A series of biodiesel-petrodiesel blends were prepared, characterized and fed in a motor bench in order to study the engine parameters and the emission. The increment of the amount of oxygenated with the biodiesel content cause an increase of density, viscosity and fuel consumption and the decrease of the higher calorific value and the cetane number, reducing the motor efficiency and moving the preinjection to lower angle. The contaminant production is reduced in the studied operation conditions, although after treatment catalytic technologies are needed to achieve zero emission. The NSR+SCR system in monolithic structure is able to cushion the impact of biodiesel blends in the emissions, improving the conversion and nitrogen selectivity.

**KEYWORDS:** biofuels, engine parameters, zero emission, NSR+SCR.

## **I. INTRODUCTION**

Today, diesel engines are widely used in transportation, industry and agricultural areas because of its high fuel efficiency and ease of operation [1]. The demand for diesel engines continues to increase worldwide as a result of the expansion of industrialization [2], because diesel engines have several advantages compared with spark ignition engines such as low fuel consumption, high torque and longevity [3]. Despite these advantages, diesel engines are now one of the main responsible for the air pollution [4,5]. Nowadays, studies are carried out to change the operation parameters of the engine, such as valve timing, injection timing and speed in order to reduce harmful emissions [6]. In addition, researchers have carried out studies of different renewable fuels like biodiesel and alcohols due to the decrease of the reserves of fossil energy sources and their negative effects on the environment [7-9].

The global share of renewable energy (including biofuels) is about 9% but is expected to reach 12% in 2040. Moreover, in 2012 the percentage of fossil fuels in the energy demand represented the 82% and is scheduled the reduction to 80% in 2040, promoted by the greater availability of credit and tax incentives and state programs considering renewable sources; with the intention of decreasing the cost of the biofuels in order to reduce the emissions of greenhouse gases.

Biodiesel, which can be defined as mono-alkyl esters of long chain fatty acids, is a type of green energy widely used nowadays blended with petrodiesel because of its non toxic and biodegradable nature, the decrease of CO<sub>x</sub> and SO<sub>x</sub> emissions [10]; although a slight increase in nitrogen oxide (NO<sub>x</sub>) emissions is observed. The production of biodiesel starts with the choice of feedstock and even though several kinds of sources can be used such as vegetable oils, animal fats, waste or recycled cooking oil and algae, almost 95% of the biodiesel produced comes from vegetable oils such as soybean oil, rapeseed oil and palm oil which utilization compete directly with food uses. [11]. The advantages of

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biodiesel as diesel fuel, in addition to the renewable character, are the minimal sulphur and aromatic content, the higher flash point, the higher lubricity, the higher cetane number and the non-toxic nature. However, biodiesel represents some disadvantages such as high viscosity, lower volatility and lower calorific value, lower oxidation stability and therefore up to now, their use in blends with petro-diesel is limited to 20% [12].

This study explores the emission scenario and how the engine emission is dependent on some factors such as engine operating condition, the biodiesel feedstock and the blending. The final objective has been to compare the performance, emissions and combustion characteristics of fuel blends in the unmodified diesel engine by analysis of fuel properties, biodiesels (biodiesel, green-diesel/HVO) and blends considered, in addition to knowing if the after treatment technologies (LNT+SCR) are able to cushion the impact of the emissions in the working conditions tested.

## II. EXPERIMENTAL

### 2.1. Preparation and characterization of fuels

Commercial petrodiesel and biodiesel from palm oil were supplied by CEPSA and Bio-Oil companies and were used to obtain the different blends. The series of fuels were denoted as B#, where # corresponds to the biodiesel percentage in volume. Therefore, B0, B4, B10, B20 and B100 were tested in the engine, being B0 and B100 pure petro-diesel and biodiesel, respectively. In this study, commercial diesel was used as B4. The consumption of blend fuels was studied in an external system that allowed the measurement by difference of weight of the amount of fuel along the time.

All the prepared fuels were characterized. The density was determined at 20 °C according to EN ISO3675:1988 and cetane number (CN) was estimated by EN ISO5165:199. Kinematic viscosity was measured according to EN ISO 3104:1996. Higher Heating Values (HHV) was also determined from the elemental analysis by Dulong’s formula, eq. (4);  $HHV=8140*C+34400*(H-O/8)+2220*S$  (4)

### 2.2. Emission study and motor performance

The analysis system consists of a real motor and exhaust placed in a test bench, which has been modified in order to incorporate a monolithic device (1x4 inch) to study the NO<sub>x</sub> removal technologies, maintaining the configuration. The parameters of the engine are summarized in Table 1 and the modified system is schematized in Fig. 1.

Table 1. Engine and injection system basic data

Engine model and type	RHY DW10TD HDI
Bore x Stroke	85 x88 mm
Number of cylinders	4
Speed range	4000 Rev/min
Engine total displacement	1997 cm <sup>3</sup>
Compression ratio	18/1
Maximum power	66 kW
Maximum torque	205 Nm
Injection system	Common Rail system

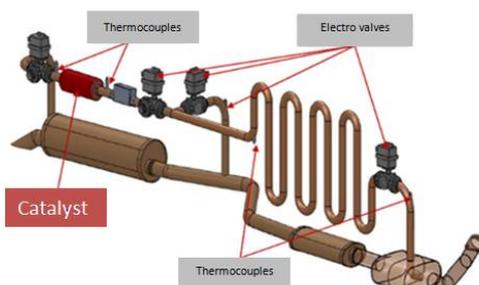


Fig. 1 Scheme of the engine test bench

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The emission of the engine was analyzed and the product distribution such as  $\text{NO}_x$ ,  $\text{CO}_x$ ,  $\text{SO}_x$  and unburned hydrocarbons measured in percentage was obtained using the Testo 350 Analyzer coupled to a Mass Spectrometer. Experiments were carried out in the motor bench varying fed biofuel blends (%v/v biodiesel-diesel), gears, engine accelerations, gas flows, operation temperatures and catalytic formulations. In particular, tests were conducted using the prepared blend fuels, with the engine working at speed of 1928 rev/min and 2548 rev/min, both with 32% of throttle and different brake, these situations correspond to the conditions in a vehicle at 40 and 60 km/h.

### 2.3. After-treatment technologies exhaust emissions

Pt-Ba-K/ $\text{Al}_2\text{O}_3$  and Cu- $\text{SAPO}$ -34 were used as NSR ( $\text{NO}_x$  Storage Reduction) and SCR (Selective Catalytic Reduction) catalysts, respectively. They were synthesized and optimized using impregnation and assisted hydrothermal methods, respectively [13, 14]. The behavior of the powder catalysts in the individualized processes was studied in a fix bed reactor at laboratory scale. Afterwards, they have been incorporated into the cordierite monolithic structure with an alumina coating to be studied in real conditions by impregnation with the stabilized precursor solutions with a percentage of active phases similar to the powder catalysts. In Fig.2 the obtained monoliths with the flow circulation are represented.



Fig. 2 After treatment catalytic system used in the experiments

## III. RESULTS AND DISCUSSION

The properties of the prepared blends are shown in Table 2. The density and the kinematic viscosity of the fuel increase with the amount of biodiesel as a consequence of the increment of the oxygen content in the blends, this can affect the atomization and vaporization processes resulting in a poorer combustion as other authors have reported [12].

Table 2. Properties of petrodiesel and biodiesel-petrodiesel blends

Fuel	Density at 20°C ( $\text{g}\cdot\text{ml}^{-1}$ )	Kinematic viscosity at 40°C (cstk)	Higher calorific value ( $\text{MJ kg}^{-1}$ )	Cetane Number
B0	0.830	4.0005	46.6	66
B4	0.833	4.0905	47.4	63
B10	0.837	4.1504	44.4	59
B20	0.838	4.2308	43.9	45
B100	0.866	5.0181	40.5	42

Additionally, the cetane number of the biodiesel blends is lower than the pure petro-diesel and this can influence the premixed combustion by increasing its duration as the the cetane number decreases. The lower calorific value of the blends containing biodiesel requires higher fuel to air rates at the same load.

The variation of Brake Specific Fuel Consumption (BSF) of the engine with various fuels with two different engine speed is shown in Fig. 3. As can be observed, at the low motor revolutions studied, which are associated with higher brake power, the BSF is almost identical regardless of the fuel used, as other authors have observed for tests below 2000 rpm [15].

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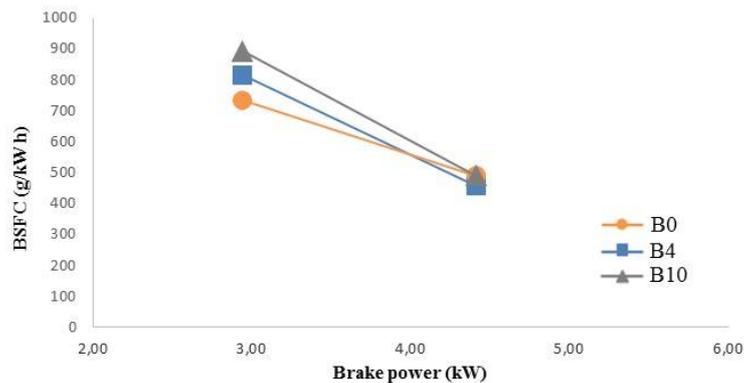


Fig.3 Brake specific fuel consumption, BSFC (g/kwh) versus brake power (kW) with various fuels at different speed

At high revolutions, there is a noticeable difference, increasing the brake specific fuel consumption as the biodiesel content in the blend increases, due to the reduced calorific value and higher densities of the blends. This fact is in line with other studies [16] where methanol blends were fed. In addition, an increase in the speed causes an increment of the fuel consumption, as have been observed by other authors [17] working in similar conditions.

The variation of Brake Thermal efficiency (BTE) of the engine with the blends is shown in Fig. 4. For the commercial diesel, the BTE increases from 10 to 18% with the power rise.

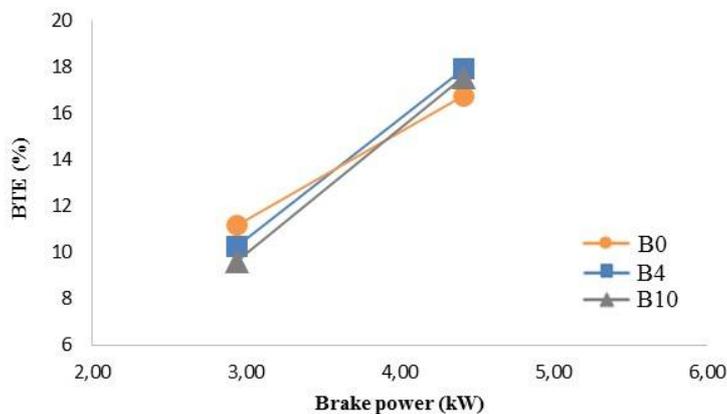


Fig. 4 Brake Thermal Efficiency (BTE) with several fuels at different powers

The fuel consumption was around 0.6 g/s at low revolutions and high power and this value increases at lower brake power up to 0.73 g/s, causing a decrease in the brake thermal efficiency due to the amount of fuel that the engine needs to achieve the same regime is higher. *Ciniviz et al.* [16] have also observed it with the incorporation of methanol to the petrodiesel. The efficiency of the B10 blend was the lowest because of the higher content in oxygenated and the lower cetane number and HHV of the biodiesel.

The value of the pressure in the cylinder shows how the combustion of the fuel is. In this case, Figures 5a and 5b depict the evolution of the pressure between preinjection point (red line) and 90° after top dead center.

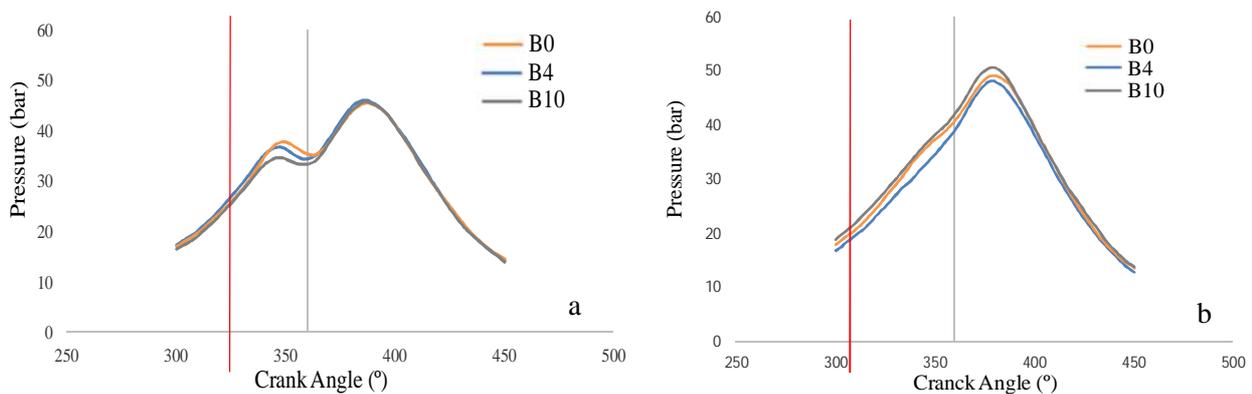


Fig. 5 Evolution of the pressure in cylinder for the different fuels at a) 1953 and b) 2548 of motor revolutions

The combustion speed has a big influence in the maximum value of the pressure and its angle. At 1953 rev/min, the maximum pressure and its angle were 46.19, 46.87 and 46.42 bar and 385.25, 380.92 and 383.81 ° for B0, B4 and B10, respectively. At 2548 rev/min, the maximum pressure and its angle were 49.85, 48.94 and 51.23 bar and 375.15, 375.15 and 373.71 ° for B0, B4 and B10, respectively. At low motor revolutions, higher power is demanded and, therefore, a preinjection is needed, as can be observed in the Fig.5(a). An increase in the biodiesel content causes an advance in the preinjection to lower crank angle.

Regarding the emissions, the evolution of the different contaminants in the exhaust in the operation conditions mentioned above was registered. The average values of CO and NO<sub>x</sub> are shown in Figures 6 and 7, respectively. The behavior of the commercial diesel, despite having intermediate biodiesel content, was slightly deviated from the general trend, due to the incorporation of some additives and other substances. CO formation decreases with the increase of biodiesel content, as other authors have observed [18], since the higher amount of oxygenated compounds in biodiesel leads towards a complete combustion with CO<sub>2</sub> formation. The decrease is even more severe as the biodiesel content increases above the 20%. The rise in the motor revolutions causes an increase in CO emissions associated with the higher fuel consumption.

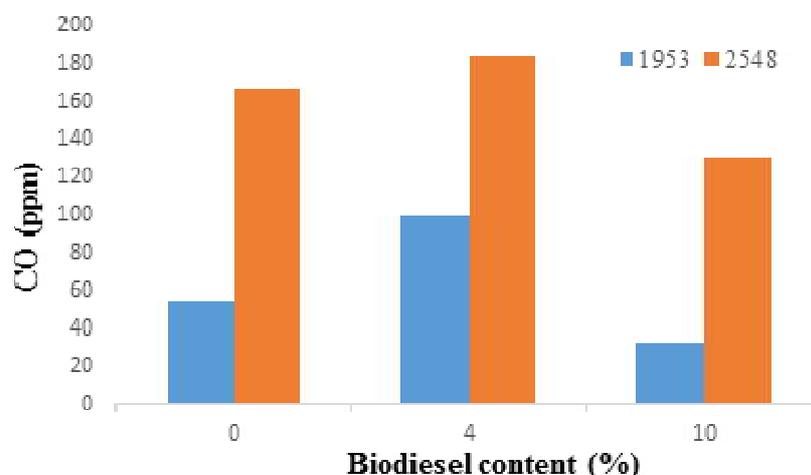


Fig. 6 CO emissions at 1953 and 2548 rev/min vs the biodiesel content

One of the main disadvantages attributed to biodiesel use is the increment of the NO<sub>x</sub> formation. However, as can be observed in Fig.7 related to tests performed under non severe conditions (low speed) and simulating the circulation in urban circuit, the formation of NO<sub>x</sub> decreases up to 30% with the biodiesel content, although higher biodiesel amounts

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of 10% could cause an increase in the production as well as the tightening of the driving conditions. H. Omidvarborna *et al.* [19] have also detected a reduction of the NO<sub>x</sub> emission when the biodiesel content is increased and attributed it to the presence of more C-C and C-H bonds in petrodiesel that causes a higher combustion temperature.

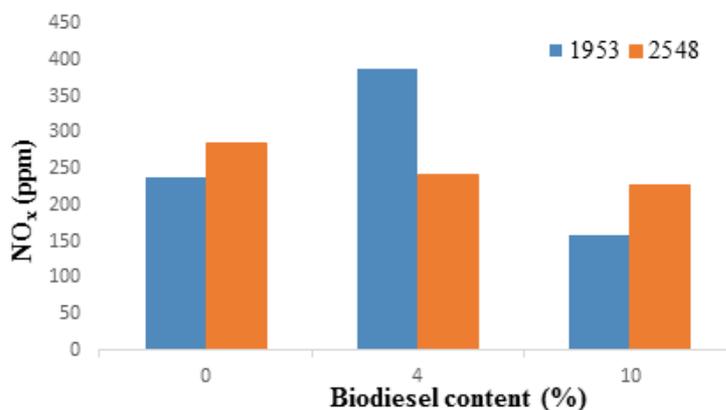


Fig. 7 NO<sub>x</sub> formation at 1953 and 2548 rev/min vs the biodiesel content

At low revolutions, the preinjection detected improves the combustion process and the NO<sub>x</sub> formation is reduced. At high motor revolutions, the amount of nitrogen oxides increases due to the rise in the fuel consumption. In any case, the values are around 300 ppm and the use of after treatment catalytic technologies is needed in order to reduce the contaminant production.

In the emissions analysis, 3 l/min of the pure exhaust gas went through the monolithic system composed of two catalytic beds with the same volume was used in the same conditions. The combination of Pt-Ba-K/Al<sub>2</sub>O<sub>3</sub> as NSR catalyst and Cu-SAPO-34 as SCR catalyst was effective in the reduction of NO<sub>x</sub>, with conversion values around 80% and without NH<sub>3</sub> and N<sub>2</sub>O formation, achieving zero emissions of this contaminant in the operation conditions.

## IV. CONCLUSIONS

The incorporation of biodiesel to the fuel blends and the operation conditions influence the emissions and the motor performance. The increase of density and viscosity and the decrease of the higher calorific value and the cetane number as consequence of the increment of the amount of oxygenated with the biodiesel content cause an increase of the fuel consumption, reducing the motor efficiency and moving the preinjection to lower angle, although the contaminant production is reduced. The study of the hybrid system with these advanced formulations, in monolithic structure and working in real conditions, is able to cushion the impact of biodiesel blends in the emissions, improving the conversion and nitrogen selectivity, near to zero-emission value.

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