DIESEL ENGINE EMISSIONS CARACTERIZATION, FUELED WITH BIODIESEL/DIESEL MIXTURES .

Jovílson da Costa Mercês
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
celselva@yahoo.com.br

Genesio Batista Feitosa Netto
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
bachverdi@hotmail.com

Rafael Leão Correia
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
leaum.ufpa@gmail.com

Hendrick Maxil Zárate Rocha
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
henzaro@hotmail.com

Sinfrônio Brito Moraes
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
sbrito@ufpa.br

Manoel Fernandes Martins Nogueira
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
mfmn@ufpa.br

Gonçalo Rendeiro
Universidade Federal do Pará, Faculdade de Engenharia Mecânica. Rua Augusto Corrêa, nº 1, Guamá, Belém, PA. Brasil – CEP: 66075-110
rendeiro@ufpa.br

Abstract. *Drived for environment benefits, renewable energy use has largely increased during later years and one of them, biodiesel, has a trend to be largely applied in diesel engines on coming years. This work measured the gas composition of diesel engine emission fueled with a mixtures of biodiesel/diesel and compared it with emissions from diesel fuel. The engine used was a Agrale-M85 driving a Kohlbach generator of 4 kVA. The gases measured were NO,* NO_2, SO_2, NO_x *and CO. Test with three differents mistures of biodiesel/diesel were performed (2, 5 and 10 %). The biodiesel bought was produced from palm oil through transesterification process and it fulfills ANP 255/2003 requirements. Measurements with comercial diesel S500 also was performed and used as reference for the data coming from biodiesel/diesel mixture. The results present the relation betweeen the species concentration in the exit gases with the generator output power and checking if these concentration are under the legislation limits (CONAMA 08/90 and 08/93). The work also evaluated the engine efficiency with the three different mixtures and compared with pure diesel fuel.*

Keywords*: Diesel, Biodiesel, atmospheric pollution, engine efficiency.*

1. INTRODUCTION

Later years have highlighted the potentiality for biodiesel to displace diesel as the major fuel for compression engines. The economic and social advantages are well understood and can be seen at PRODIESEL program (Probiodiesel, 2004). On the other hand, uncertainty exist related to the impact that biodiesel cause on engines performance and maintenance as well as the impact that its emissions cause on the environment when compared with diesel fuel "Leung *et al*, (2006)" and "Geanezi *et al*, (2006)". They reported, when consuming biodiesel, reduction on CO emission (48%), and particulate matter (47%), on hydrocarbons (67%), lack of sulfur emission and an increase on NO_x emission (10%) when the engine operates at 100% of its load, "Raheman *et al*, (2007)" performed experiments with a blending of methyl ester and diesel and "Kalligeros *et al*, (2002)" performed test with blending biodiesel/marine diesel and the they reported facility to be easy to obtain table blending of biodiesel with diesel and the emissions have concentration results similar and proportional to the amount of biodiesel added to diesel with very low increasing on NO_x concentration.

Brazilian program to replace diesel for biodiesel, PRODIESEL, defined that initially a blending of 2% of biodiesel, moving to 5% in 2008, and from these to higher concentration of biodiesel. This word measured the exhaust emission concentration of CO_2, CO, NO_x and SO_2 for a diesel engine driving a power generator, fueled by pure diesel and blending with 2%, 5%, and 10% of biodiesel in diesel. The biodiesel used are the ethyl ester from vegetable palm oil. The generator load was also varied from 25% to 100%.

2. EXPERIMENTAL APPARATUS

The system choosed to be monitored was a stand alone power generator of 4 kVA. The engine was a AGRALE-M85 of 7,5 hp (5,6 kW) at 1800 rpm, driving a KOHLBACH generator of 4 kVA. Figure 1 shows a schema representing the setup.

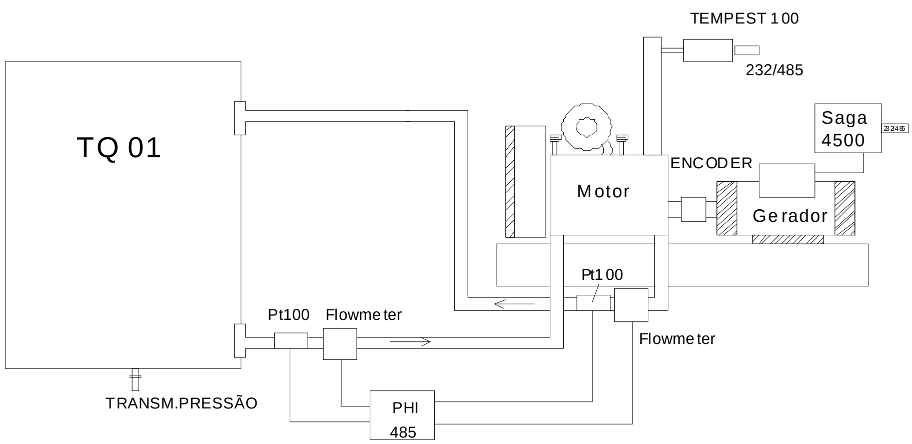

Figure 1. Experimental set up.

Tank 01 is where the fuel is stored. It can be diesel or blending fuel. The fuel is removed from TQ01 a flow to the injector pump passing through a thermocouple PT-100 and flow meter (TECHMETER). Here the inlet fuel temperature and volumetric flow rate are measure and recorded. Most of the fuel goes from the injection pump to the cylinder, but a fraction returns to tank. The return flow also pass through another PT-100 thermocouple and TECHMETER flow meter and its temperature an volumetric flow rate are recorded. The inlet air flow rate is not measure. The exhaust gas composition is monitored through an electrochemical device named TEMPEST-100. This analyzer is not able to record on-line measurement. It means that periodically the operator had to command one sample extraction and CO, SO_2, O_2 and NO_2 concentration, and the specific time were recorded. TEMPEST-100 is able to measure gases temperature and pressure and also gives CO_2 and NO_x concentration but it comes from calculation once fuel composition is informed. Particulate matter and smoke, together with SO_2 are measure at same port using an isokinetic extractor, CIPA, made by ENERGÉTICA. The extraction and gas analysis with the device was made on demand, too. To measure the generator output power, it had a device named SAGA 4500 that continuously monitors and record the electricity tension, current and frequency. The generator load was a cluster of lamps. Those lamps were partially turned off to vary the load.

3. EXPERIMENTAL PROCEDURE

The engine was allowed to run for 15 minutes without load, after its start up to warm up. Following, 25% of the lamp at the bulb board were turned on. It is approximately 0,8 kW. The engine rotation were adjusted to obtain at the SAGA 4500 the electricity frequency between 59,5-60,5 Hz and let the engine run for one hour. After then, measurements of gas concentration with TEMPEST 100, mass flow rates, temperature, tension, current and frequency were recorded. After the measurements are completed, the engine conditions are inspected, such oil lubricant level, fuel level and corrections were made.

The electric load were increase to 50% and the above described procedure performed again. The same procedure was adopted to electric loads of 60%, 70%, 80%, 90% and 100% of generator capacity.

4. DATA TREATMENT

The author choose to follow the CONAMA 08/93 specification for species concentration what is g/kWh. It means that mass flow rate of such species in the exhaust gas (g/h) fuel divided by the energy in the fuel delivered to the engine in unit of time (kW).

The TEMPEST 100 results are given in dry basic molar fraction (ppm), therefore following data reduction is needed. Molar fraction is defined as

$$\chi_i = \frac{N_i}{N_T} \tag{1}$$

Were N_i the species number of moles and N_T total number of moles in the sample. Assuming that all species perform like a perfect gas. The mass flow rate for each species can been written as

$$\dot{m}_i = \frac{\chi_i \times P \times \dot{V}}{R_i \times T} = \chi_i \frac{MW_i}{MW} \times \dot{m}_{gas} \tag{2}$$

Were P, T and $\dot{V}$ are respectively the exhaust gases pression, temperature and volumetric flow rate at such temperature and R_i is the species gas constant obtained from equation (3).

$$R_i = \frac{R_u}{MW_i} \tag{3}$$

Where R_u is the universal gas constant (8,314 J/kg.k) and MWi is the species molecular weight and MW is the exhaust gas molecular weight. In equation (2), TEMPEST 100 is able to supply X_i, P and T. $\dot{m}_{gas}$ was obtained using the software VULCANO (Dynamis, 2007) and the MW was obtained from equilibrium composition for diesel oil and biodiesel as ethyl ester using equation (4). Table 1 shows their elementary composition.

$$MW = Y_{Diesel} MW_{Diesel} + Y_{Biodiesel} MW_{mis,Biodiesel} \tag{4}$$

Where Y_i are mass fraction of diesel and biodiesel in the misture, $MW_{mis,Diesel}$ is the……

Table 1 – Fuel elementary composition mass basics

	Diesel %	Biodiesel methyl ester %
C	85,8	70,4
H	13,5	10,6
S	0,7	0 (-) 19
PCI kJ/kg	39203	37162
PCS kJ/g	42164	39487

VULCANO, having as input the fuel and air composition plus the exhaust gas content of O_2, performs a thermo chemical calculation given as result exhaust composition at equilibrium and the mass air-fuel ratio.

The procedure to calculate $\dot{m}_{gas}$ at equation (2) starts with the calculation of fuel flow ratio through equation (5)

$$\dot{m}_{comb} = \dot{Q} \times \rho_{comb} \tag{5}$$

Where $\dot{Q}$ is the volumetric flow rate obtained from subtraction between inlet and return TECHMETER flow meters and ρ_{comb} comes after the fuel temperature obtained from PT-100.

Exhaust mass flow rate in obtained through equation (6)

$$\dot{m}_{gas} = \left(\frac{\dot{m}_{gas}}{\dot{m}_{comb}} \right)_{vulcano} \times \dot{m}_{comb} \tag{6}$$

The energy coming with the fuel was calculated using equation (7)

$$\dot{W}_{comb} = PCI \times \dot{m}_{comb} \tag{7}$$

Where PCI was obtained from table 1 and $\dot{m}_{comb}$ comes from equation (5). Therefore, the species concentration is given by equation (8)

$$C_i = \frac{m_i}{W_{comb}} \qquad \left[\frac{g}{kWh} \right] \tag{8}$$

5. RESULTS AND DISCUSSION

Figures from 2-5 shows the results as obtained for pure diesel, B2, B5 and B10 respectively.

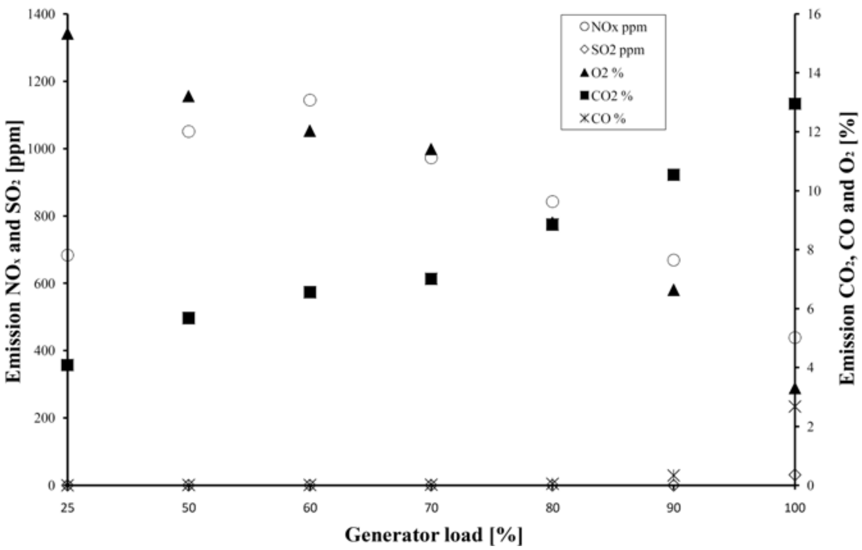

Figure 2. Results for pure diesel

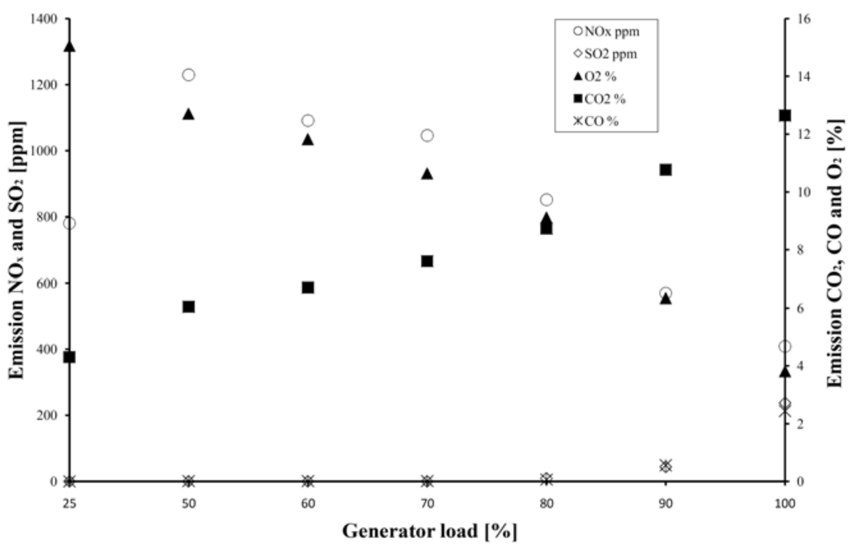

Figure 3. Results for B2 (2% biodiesel)

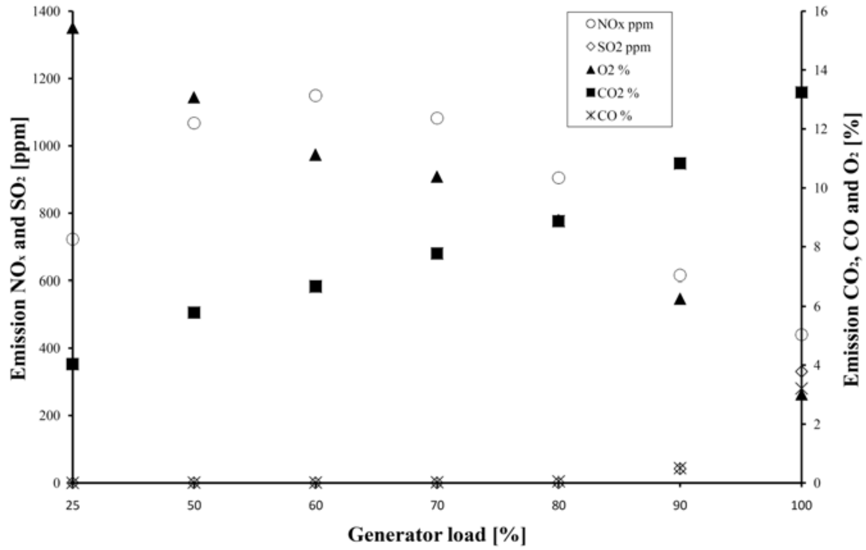

Figure 4-Results for B5 (5% biodiesel)

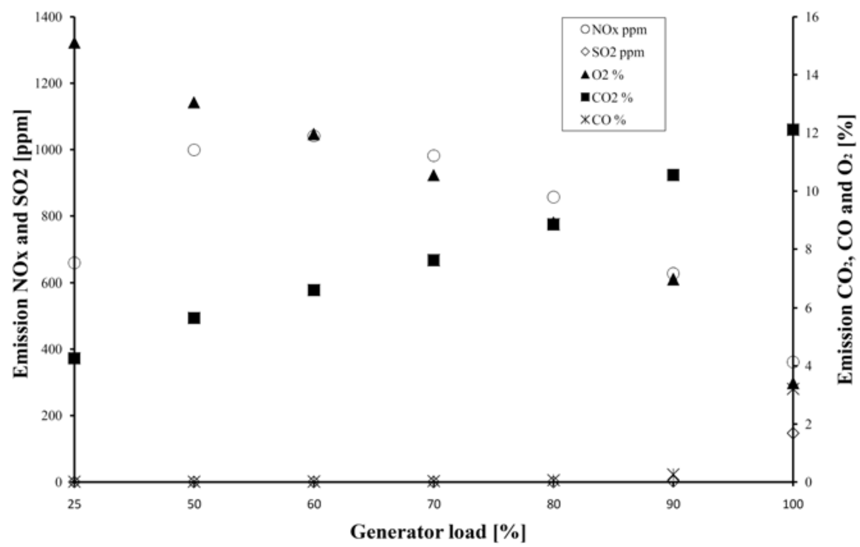

Figure 5-Results for B10 (10% biodiesel)

As can be seen in the figures 2-5, the O_2 concentration in the exhaust gases vary with generator load and with experiment run difficulting comparison. To allow such comparison, the authors decided to normalize concentration using as reference the O_2 concentration when the engine was running with 100% of generator load and fueled for pure diesel, what is 10,93 %.

The normalization was performed using the equation (9). One can see how this equation is obtained consulting (Andrade, 2003)

$$C_{i.cor} = \frac{C_i \times \left(C_{O_2,med} - 0,21\right)}{\left(C_{O_2,ref} - 0,21\right)} \quad (9)$$

Were $C_{i,cor}$ is the correct concentration of the species "*i*"
$CO_{2,med}$ is the measure concentration of O_2
$CO_{2,ref}$ is the O_2 concentration used as reference, in this case 10,93 %.

Figures 6-9 shows how the species concentration performs for different loads and blending.

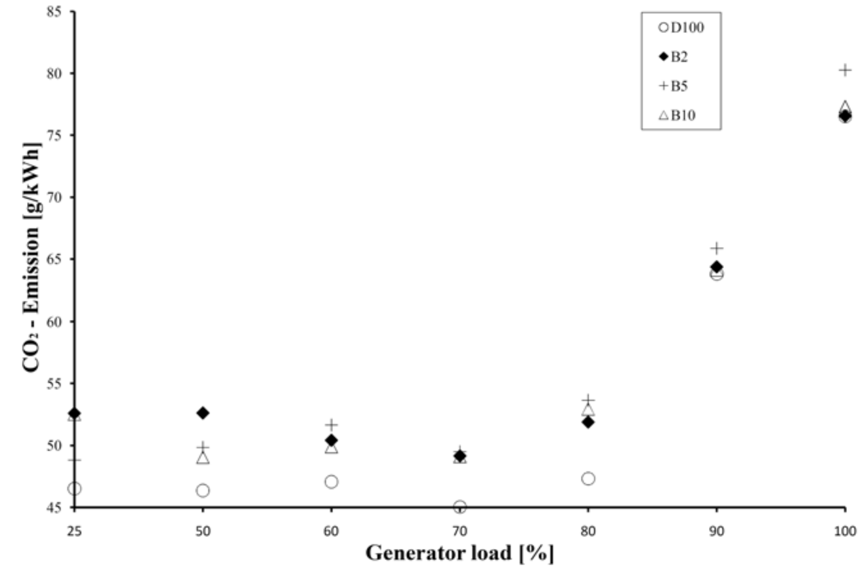

Figure 6 – Corrected CO_2 concentration for different biodiesel concentration and varying the generator load.

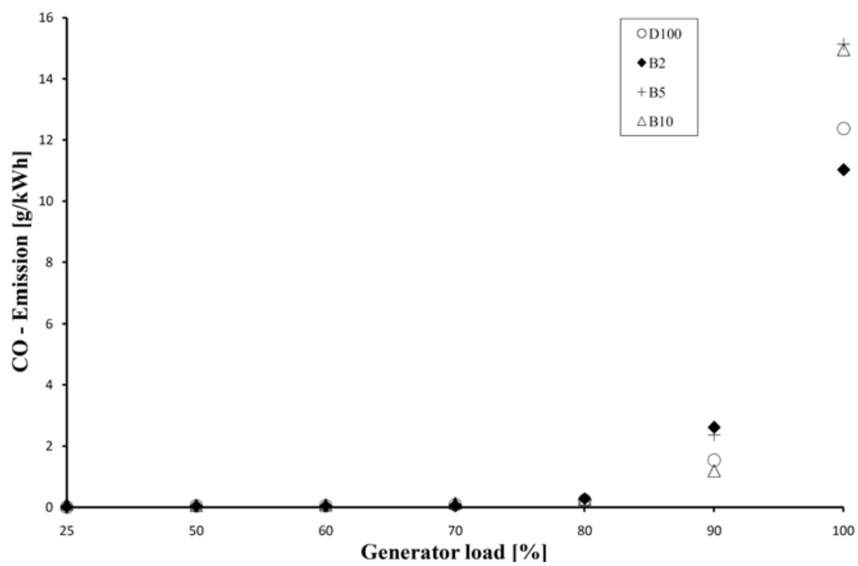

Figure 7 - Corrected CO concentration for different biodiesel concentration and varying the generator load

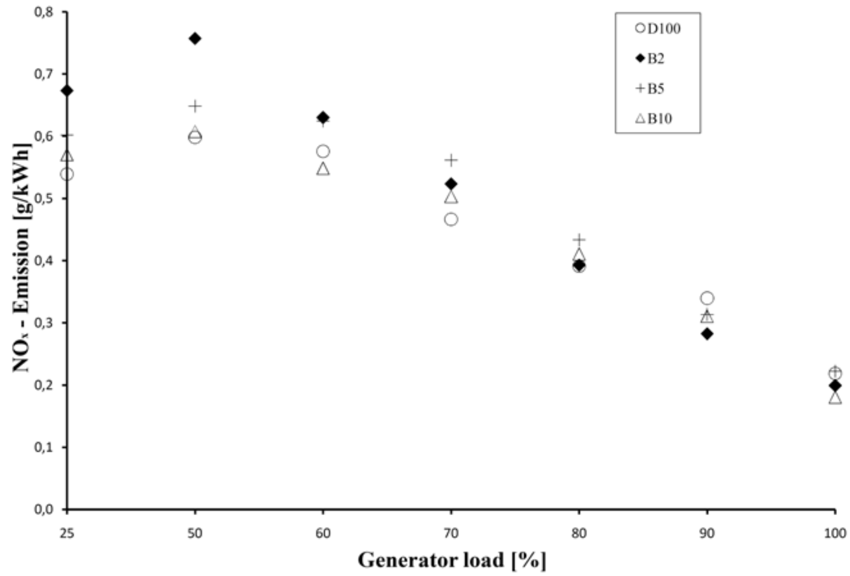

Figure 8 - Corrected NO_x concentration for different biodiesel concentration and varying the generator load.

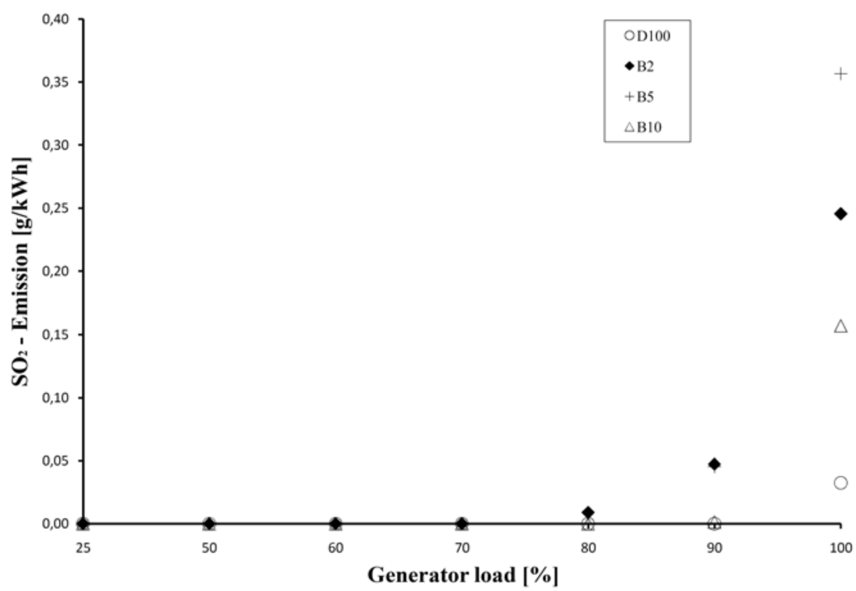

Figure 9 - Corrected SO_2 concentration for different biodiesel concentration and varying the generator load.

Results obtained from the isokinetic sampling are show in table 2.

Table 2-Isokinetic results

	Diesel	B2	B5	B10
Particulate g/Gcal	2808.19	10650	423685	9846
Colormetric density Ringelmann scale	06-07	02-03	03-04	04-05
SO_2 g/Gcal	3119.00	5703	2368	6873

Figure 10 shows the fuel specific consumption for all the experiments. The instrumentation presented repeatability and stability problems. After B100 and B2 measurements the flow meter presented uncertainly problems. The fuel mass flow rate for two blending were calculated from oxygen composition within the exhaustion gases and the fuel chemical composition and mass ratio. Now measurements are required to confirm such calculation and are going to be performed by EBMA in the near future.

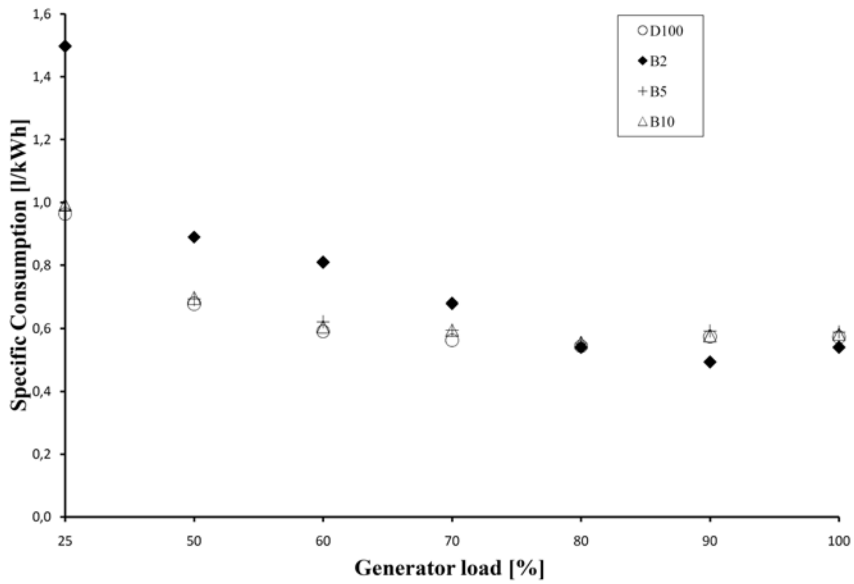

Figure 10 - Engine specific consumption fuel

6. CONCLUSION

The CONAMA 08/93 defines the upper limit for emission as show in table 3

Table 3-Maximum allowable emission after CONAMA 08/93

Gases	Upper limits (g/kWh)
CO	4,0
NO_x	7,0
SO_2	$4{,}29\ 10^{-3}$

The result obtained here are always above such limits. Most certainly it is due the engine size. Small engines has a tendency to have a higher pollutant concentration than the bigger ones.

The emission for all species shows that they had exceeded the CONAMA 08/93 legislation limits. The emissions reach they limits on 100 % of the maximum generator load. With the 80 % of the maximum generator load the system has the minimum consumption of fuel per generate energy.

7. ACKNOWLEDGEMENTS

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