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*Full Length Research Paper*

# Fuel specific consumption and emission analysis in a cycle diesel motor generator using diesel and biodiesel from waste frying oil blends

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**One of the main fuels that can be helpful in emissions reduction when compared with diesel oil is the biodiesel. Moreover, it is a renewable fuel and may be obtained from different animal fat and vegetable oil. The purpose of this work was to evaluate fuel specific consumption and emission of exhaustion gases using the biodiesel produced from waste frying oil in a cycle diesel internal combustion engine (ICE) to produce electrical energy. The used motor generator has a power of 7.36 kW (10 HP) and 5.5 kVA /5.0 kW of nominal power. The used fuel was composed of a biodiesel and diesel oil blend and the following proportion in biodiesel composition was used: 0% (B0), 5% (B5), 10% (B10), 20% (B20), 50% (B50) and 100% biodiesel (B100). The nominal load applied varied between 0.5 and 5.0 kW. The analysis test was just performed with (B0) and (B100) blends. To quantify the gases emission, combustion and emission analyzer were used. The quantified gases were: CO, NO, NOx and $SO_2$. Generally, the utilization of biodiesel from waste frying oil showed fuel specific consumption statistically similar to that of the diesel oil. It was observed that the biodiesel from waste frying oil provided an emission reduction of combustion gases.**

**Key words:** Combustion, energy production, biofuel.

## INTRODUCTION

The growing of social and technological development, summed to the rising of world population, has resulted in a great demand for energy and an increase of pollution. The use of oil and its derivatives has been responsible for most part of atmospheric emissions that cause global warming. A strategic source of renewable energy which can turn down the environmental pollution rate and replace the diesel oil is the biodiesel.

The biodiesel is produced through chemical processes, usually a transesterification, in which the glycerin produced is removed. The use of biodiesel in a cycle diesel engine needs no adjustments (Volpato et al., 2009).

The reduction of gases emission by using biodiesel as a replacement for diesel oil is a common knowledge. In some cases, the use of biodiesel from vegetable oil has allowed a greater reduction of NOx than the biodiesel from waste oil. Pereira et al. (2007) obtained a reduction of 10.3% of CO, 55.5% of $SO_2$, 8.7% of NO and 8.9% of NOx. On the other hand, the biodiesel from waste oil, in some cases, had greater rates of reduction for CO, $SO_2$ and NO in comparison with biodiesel from vegetable oil. Some studies performed by Dorado et al. (2003) showed that the use of biodiesel from vegetable oil yielded lower emission rates in comparison with Diesel oil reaching even 58.9% for CO, 57.7% for $SO_2$, 37.5% for NO and,

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as quoted by Utlu and Koçak (2008), 1.45% for NOx. However, the reduction of $SO_2$ was similar for both quotes.

The biodiesel may be obtained from renewable sources as vegetable oils and animal fat (Monyem and Van Gerpen, 2001), and it is used as a replacement for fossil fuels in cycle diesel engines (Haas et al., 2001). However, the challenge about producing a biofuel from vegetable oil is the competition between the production of fuel and production of food, having the effect of increasing of food prices (Somerville, 2007). A tempting solution for this problem is the production of biodiesel from waste frying oil.

There are three main advantages coming from the use of waste frying oil as a raw material for biodiesel production: The first one, of a technological nature, is based on the dispensation of biodiesel extraction process; the second one, of a economic nature, is based on the cost of the raw matter, because as a waste from the frying oil it has a established price; and the third one, of an environmental nature, is based on the right destination of the waste that generally, is thrown away in the wrong place yielding bad consequences for the soil and the groundwater, and so leading to problems in the habitat of these systems (Dib, 2010). With the purpose of being used as fuel, the biodiesel must have some characteristics as: Complete transesterification reaction (absence of fat acids), to be as pure as possible, taking out any glycerin that was present, and an excess of residual catalyst and the alcohol used (Costa Neto, 2000).

Therefore, the research for new kinds of alternative energy, cleaner and renewable, has increased in the last few years. The biodiesel has been used in addition or replacement to the diesel oil, especially on the transport and energy production sectors all over the world, being an alternative to minimize the environmental problems (Knothe et al., 2006). As reported by Laforgia and Ardito (1994) the biodiesel may replace the diesel obtained from oil with no substantial changes on the engine performance.

Santos et al. (2006) have performed a comparative analysis of the fuel specific consumption of a steady cycle diesel engine working with (B0) and (B100) diesel, steady rotation rate and they have observed that the engine performance running with both fuels were close.

In this study, the purpose was to evaluate fuel specific consumption and emission gas rate in a cycle diesel motor generator of Branco brand of low capacity, using proportions of biodiesel waste frying oil and mineral diesel.

## MATERIAL AND METHODS

The experiment was performed at the State University of West Parana bioenergy laboratory, Cascavel campus, and a cycle diesel motor generator, BRANCO brand, BD 6500CF model with a power of 7.36 kW (10 HP) and a nominal power of 5.5 kVA/5.0 kW, and a single phase output voltage of 120/240 V was used. The used biodiesel was produced in a batch process performed in a mini biodiesel plant from State University of West Parana which has a nominal capacity of 1000 liters per day. The biodiesel and diesel blends essays were: 0% (B0), 5% (B5), 10% (B10), 20% (B20), 50% (B50) and 100% (B100) for biodiesel. To quantify the fuel consumption, a precision balance of GEHACA brand and BG-2000 model and a digital chronometer was used. The average specific consume refers to consume arithmetic mean for each blend. The equation shows how to calculate the fuel consume in a time interval considered:

$$Cons = \frac{Mi - Mf}{\Delta t}$$

where, Cons is the fuel consumption, g/s; Mi is the initial quantity of fuel, g; Mf is the final quantity of fuel, g and $\Delta t$ is the essay time, s. The loads simulation was made by using an electrical resistance system. The loads cycle used begun with the smallest loads, running in cycles of: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 kW. Four repetitions were made for each assay. The FSC (fuel specific consumption) evaluation was determined as a load variation function of the motor generator using as fuel the biodiesel from waste frying oil and diesel blends. The equation shows how to calculate the specific fuel consumption for a determined load:

$$FSC = \frac{3600 * \text{Cons}}{V * I}$$

where, FSC is the specific fuel consumption, g/kWh; Cons is the fuel consumption, g/s; V is the output voltage, V and I is the electrical current, A.

Figure 1 shows the assembly of the essay at the bioenergy laboratory. The statistical test for the specific fuel consumption was based on Variance analysis (ANOVA) and the treatment average was compared using the Turkey test at 1% of significance, which was run by the ASSISTAT “free software”.

The kinematic viscosity was obtained at the laboratory with a Cannon-Fenske viscometer at a constant temperature of 40°C (313.15 K).

To obtain the density pycnometer in a thermostatic bath kept at 20ºC (293.15 K) for 10 min was used. To obtain the density value to calculate the cetane index the bath temperature was kept at 15°C (288.16 K).

The methodology to determine the fuels boiling points was based on the recommended procedures by the D86 method that is used for fuel analysis, maintaining a distillation stream about 5 ml/min of fuel. The tests were performed with a solvent distiller of QUIMIS brand, Q 286-1 model, 110 V. The equipment is placed in the physicochemical laboratory at the State University of West Parana, Brazil, in the Chemical Engineer department.

The cetane index is linked to the ignition quality. There is a correlation between the index and the number of cetane which is determined by industry as a replacement for its practicality. It is calculated considering 50% of product density and the temperature of distillation. The used equation was developed by ASTM (American Society for Testing Materials, 1994), it is presented as the D976 method and it’s expressed as:

$$IC = 454 - 1641{,}416D + 774{,}74D^2 - 0{,}554B + 97{,}803(logB)^2$$

where, D is the density at 15°C, (g/cm³); B is the temperature istillation of 50% of product, (°C).

To obtain the absorption profile in the mid infrared region, a Perkin Elmer infrared spectrometer was used; which was adjusted to collect a scanning in the spectral bands between 4000 and

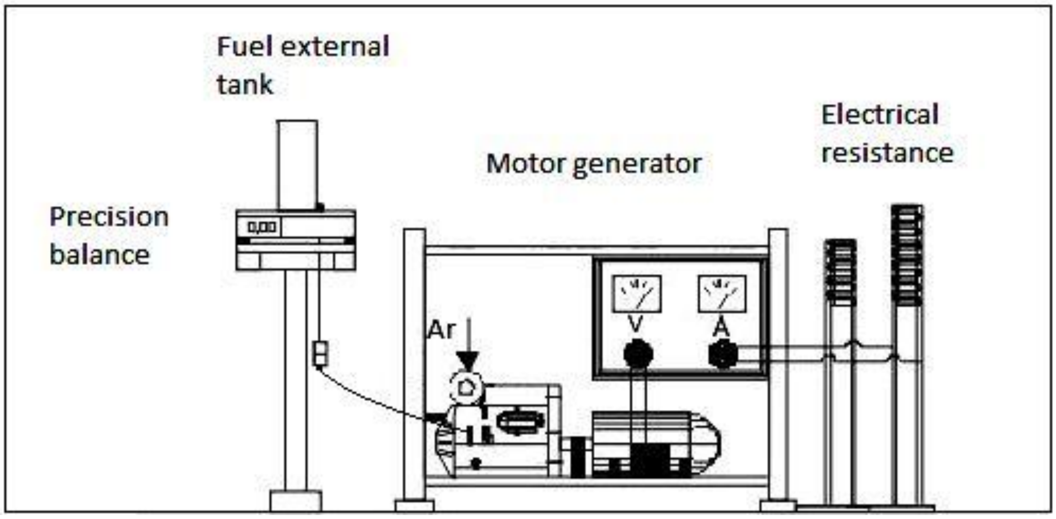


**Figure 1.** Assembly of the experiment.

650 $cm^{-1}$ supported by KBr windows and a separator of 0.025 mm.

To determine the fuels, heat power pump calorimeter E2K model was used. The samples were separated to about 0.5 g of analyzed fuel in an adiabatic system; afterwards the metallic recipient was pressured to 30 atm by a pressure pump (3.04 MPa). The pressured system was taken to the calorimeter. The recipient with the sample was linked to an ignition wire, called firing wire. From this point the process continued and the information given by the equipment was noted.

To quantify the gases emissions, it was used a combustion and emission quality analyzer of PCA3-285KIT / 24-8453 model, QX-1008 serial number, BACHARACH brand. The analyzer has a calibration certificate nº 1011/AN5420, dated of 11/24/2010 for the temperature and concentration items. For the emission essay, the equipment probe was set on gases stream outlet until the stabilization of readings. The equipment performs the suction and read the gases automatically. The procedure was run for four times each loaded. No treatment was made on the gases to test the emissions. The quantified gases were: Carbon Monoxide (CO), Nitric oxide, Nitric oxides (NOx) and Sulfur dioxide ($SO_2$). The analysis was performed with mineral diesel (B0) and biodiesel from waste frying oil (B100).

## RESULTS AND DISCUSSION

Figure 2 shows the average fuel specific consumption of studied blends when compared with diesel oil. The average diesel specific consumption was lower than the biodiesel blends analyzed. The B50 blend showed a greater fuel specific consumption, about 15.1% greater than B0. The B100 blend showed 13.6% greater consumption than the diesel oil. Raslavičius and Strakšas (2011), when testing the biodiesel in a cycle diesel engine, obtained an increase of 14% on the specific consumption when compared to the diesel oil. These results may be explained by the higher kinematic viscosity and lower heat value of blends. The nearest results to the diesel oil was achieved by B10 and B20 showed an average specific consumption of about 1.7 and 1.5% greater, repectively. When Castellanelli et al. (2008) analyzed the performance of a cycle diesel engine using biodiesel and diesel blends they obtained similar results, B20 achieved the lowest fuel specific consumption. Ferrari et al. (2004) observed that B5, B10 and B20 had a greater performance than B0 using a energy generator YANMAR brand NSB50 model.

Figure 3 shows the final average fuel specific consumption (FSC) for the blends in each load. For the B5 blend there was a statistical difference for the specific consumption when compared with the diesel oil just for the 0.5, 1 and 2.5 kW loads. For the B10 blend the statistical difference occurred just for the 2.5 kW load. And for the B20 blend it was not found any statistical difference among the fuels. Soranso et al. (2008) obtained a specific consume values statistically equal between the blends with diesel and blend with biodiesel to the B50 proportion. Castellanelli et al. (2008) analyzed the performance of a cycle diesel engine using biodiesel/diesel blends and obtained similar results, the B5 and B10 blends showed a similar performance to B0 and the B20 blend had a lower specific fuel consumption than others blends. Dorado et al. (2002), in a research with blends of biodiesel and frying oil, verified that with no changes on the engine no harms have occurred at it when B10 was blended with diesel oil. Ferrari et al. (2004) analyzed the fuel specific consumption and observed that the B5, B10 and B20 blends had a higher performance compared to B0. An energy generator of YANMAR brand, NSB50 model was used. At the 1.5 kW loads of the B5, B10, B20 blends had specific consumption average statistically equal to the diesel oil.

The B50 and B100 blends showed statistical difference only for the 1 and 1.5 kW loads. Dib (2010), used several types of biodiesels in a motor generator of 6 kVA, noted that when resistive loads were varied from 0 to 3 kW,

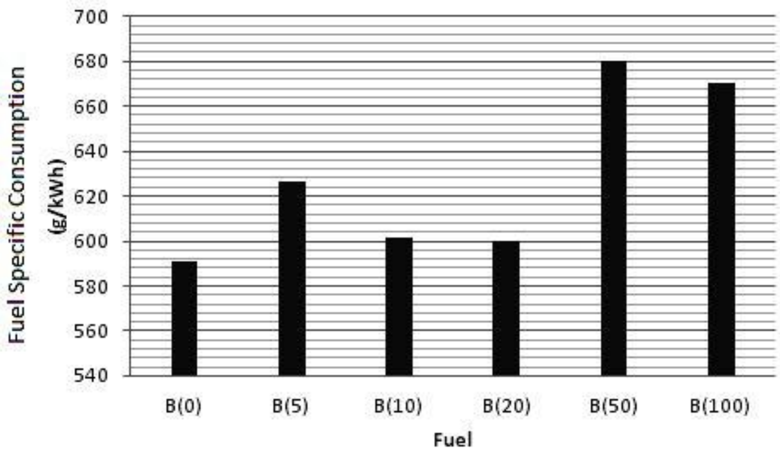


**Figure 2.** Average fuel specific consumption to the blends.

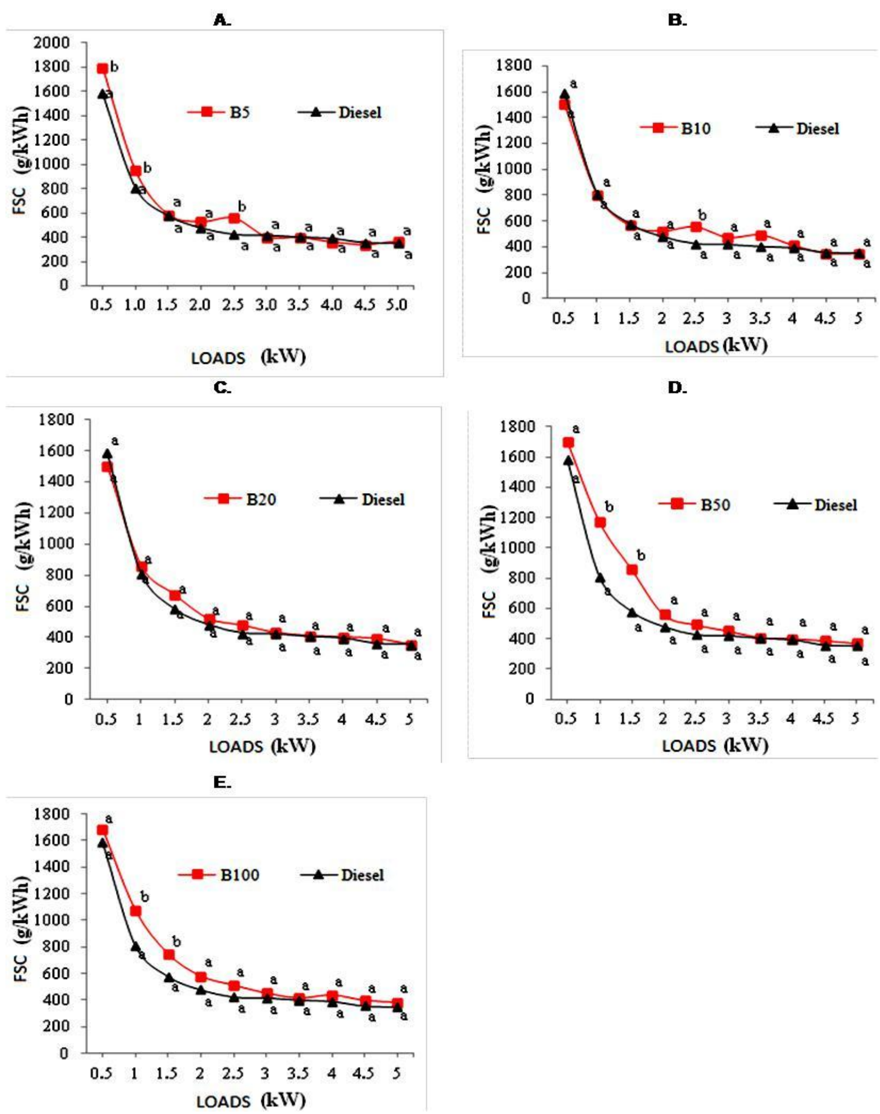


**Figure 3.** Average fuel specific consumption (FSC). *Averages followed by the same letter do not differ statistically by the Turkey Test with 1% of significance.

**Table 1.** Fuel specification.

| Blend | Kinematic viscosity ($mm^2.s^{-1}$) | Density ($kg.m^{-3}$) | High heat value ($MJ.kgs^{-1}$)* |
|---|---|---|---|
| (B0) | 2.87 | 0.845 | $40.56^{a}$ |
| (B5) | 3 | 0.8475 | $40.29^{ab}$ |
| (B10) | 3.03 | 0.849 | $40.25^{ab}$ |
| (B20) | 3.14 | 0.85 | $39.83^{b}$ |
| (B50) | 3.54 | 0.8631 | $37.63^{c}$ |
| (B100) | 4.16 | 0.881 | $35.29^{d}$ |

*Averages followed by the same letter do not differ statistically by the Turkey Test at 1% of significance.

there was a small difference in the consumption when compared with the same blends. Rabelo (2011) reported that the biodiesel from waste frying oil was miscible with diesel oil in all analyzed proportions in his study. With the opportunity of recycling the waste oil and the fossil fuel dependence, the frying oil is a possible alternative as raw matter for fuel.

The greater percentage reduction in the fuel specific consumption, as a consequence of the addition of biodiesel to the waste frying oil, occurred during the use of 4 kW load, while the B5 blend was used. In this situation occurred a reduction of about 8.9% of fuel consumption when compared to mineral diesel (B0).

Table 1 shows the measured kinematic viscosities, densities and high heat value of the used blends at the essay.

A gradual increase in the viscosity and density as a function of biodiesel percentage present on the diesel blends was observed. The density and viscosity of biodiesel was greater than diesel for others blends. The difference of viscosity between biodiesel and diesel also may be pointed as an important factor in the specific consumption difference, yielding an incomplete combustion at low rotation rates. Xué et al. (2011) reported an increase at the consumption while the blends are increased due to higher densities and viscosities.

The high heat value of blends showed itself lower than diesel. However, by the statistical test, the B5 and B10 fuels have a heat value similar to diesel. The B5, B10 and B20 blends showed a similar performance to each other. B50 and B100 show themselves different among the blends. The heat value decreased as the biodiesel quantity was increased in diesel oil. In a study of analysis of diesel oil and biodiesel, Neto et al. (2000) verified that the high heat value measured was close to that found in this work. For Diesel oil this value was 42.30 MJ/kg and for biodiesel from waste frying oil it was 37.5 MJ/kg.

One of the parameters related to the fuel condition used in engines is the cetane index. For diesel, the cetane index showed a good result of 54.9. For the biodiesel from waste frying oil the index was lower to the recommended value, and the calculated value was 38.8. The Oil National Agency (Agência Nacional do Petróleo – ANP) states 42 as a minimum value to the cetane index for the fuels used in engines. In diesel engines, fuels with higher value of cetane index (CI) have lower period delays at the ignition than fuels with lower values. The higher the CI the more efficient the ignition is and the greater the engine performance. Low cetane indexes lead to problems at the start of engine when the weather is cold, even allowing the white smoke to appear due to a incomplete combustion, bad engine working, etc.

One tempting alternative is to use the Diesel and biodiesel blends. Valente (2007) reached a cetane index over 42 with even 75% of diesel and biodiesel when he was testing blends.

To know the main components that exist in the biodiesel from waste frying oil and the diesel oil, an infrared spectrum was run. As a comparison purpose with the biodiesel from waste frying oil the spectrum of biodiesel from raw soy oil was analyzed. The biodiesel from soy showed a density of 0.8848 $g/cm^3$, high heat value of 38.7 MJ/kg and viscosity of 4.19 $mm^2/s$.

Figure 4 shows the infrared spectrum of diesel oil, biodiesel from soy and biodiesel from waste frying oil. Checking the average infrared spectra of biodiesel from soy and waste frying oil, both are similar, indicating that the waste frying oil has not introduced any new component at low concentrations. Both spectra are common for biodiesel from soy, and the interference of water, benzene, phospholipids, etc, were not observed indicating a high purity of the biofuel.

The presence of any alkyls and aromatics at the diesel oil was not detected, showing that these components are present in very low concentration or even does not exist. The sulfur content was determined by the Diesel supplier, REPAR, that performed the tests using the D4294 method and the obtained value was 1243 mg/kg, a value within the specified standard that indicates a max limit of1800 mg/kg.

Table 2 shows the measured distilled diesel oil and biodiesel from waste from oil values. The temperature levels obtained in the tests are in accordance with the ASTM E29 Standard. The distillation point of 10% was the only one that showed a high level for biodiesel. For the most part of the points the distillation temperature was higher. Bakir and Fadhil (2011) reported it as a consequence of the low molecular weight of diesel when

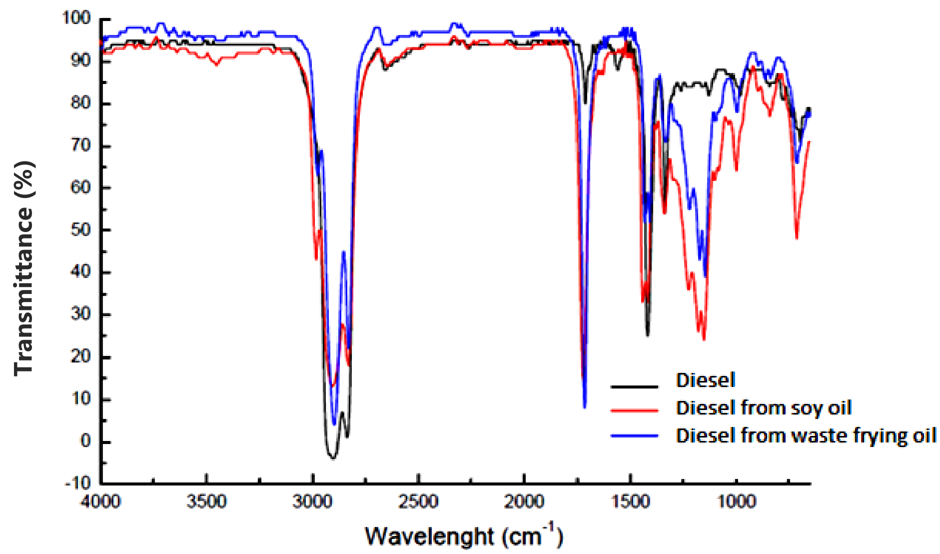


**Figure 4.** Infrared diesel spectrum, biodiesel from soy oil and biodiesel from waste frying oil.

**Table 2**. Points in the boiling range.

| Points in the builing (%) | Method | Specification* | Diesel (B0) (°C ) | Biodiesel (B100) (°C ) |
|---|---|---|---|---|
| 10 | D86 | - | 181.4 | 317.1 |
| 50 | D86 | 245.0 - 310.0 | 297.6 | 270.9 |
| 85 | D86 | 370.0 max. | 345.6 | 224.9 |
| 90 | D86 | - | 364 | 209.4 |

*Specification for the Standard ASTM E 29.

compared with the biodiesel, so it is more volatile. During the distillation biodiesel process it showed itself unstable yielding in a high degradation rate.

Phan and Phan (2008) reported that the characterization of fuel volatility and its tendency of making soot and smoke are considered an important long term indicator for the fuel performance analysis and may be specified by a distillation curve. They also verified that the distillation point for the biodiesel waste frying oil blends was lower than that obtained from Diesel oil.

With respect to the emission gases by motor generator the global averages of gases was evaluated and compared during the blends (B0) and (B100) essays. The load cycle tested was the same used to determine the specific fuel consumption. The analyzed gases were: Carbon monoxide (CO), Nitric Oxide (NO), Nitrogen oxides (NOx) and sulfur dioxide ($SO_2$) (Figure 5).

For the Carbon monoxide (CO) it was observed that the biodiesel from waste frying oil obtained a gas emission value of 38.56% lower than diesel (B0). In a study using biodiesel, Makareviciene and Julis (2003), observed an average reduction of 50% for the CO levels. Maziero et al. (2006), testing biodiesel from sunflower oil, had as result a 32.2% reduction. Raslavičius and Bazaras (2010), reported the carbon monoxide gas is a toxic byproduct from hydrocarbon combustion, and it may be reduced by increasing the fuel oxygen. In the test, with a 37 kW diesel engine, with steady rotation rate and biodiesel from rapeseed oil (B100), they obtained a 55% reduction at the CO level in comparison with diesel oil. Arslan (2011), testing biodiesel from waste oil blends in a cycle diesel engine TTF 8000s model with 85 HP, verified that de CO emissions decreased when the engine rate was increased. The results of the test showed that B25 and B75 reduced the CO emissions by 2 to 13%, respectively.

The nitrogen oxide (NO) showed a 12.12% reduction, but it was the only gas that showed no statistical difference when compared to diesel by Turkey Test. This result is in accordance with the study of Pereira et al. (2007) in electrical energy production using diesel and biodiesel from soy oil blends and found that the biodiesel showed similar or even lower emissions of NO than pure Diesel. One possible explanation for this may be that given by Rakopoulos and Giakoumis (2009). They say that the NO is strongly dependent on the combustion temperatures, the oxygen level in the chamber combustion and the time combustion. As Glassman and

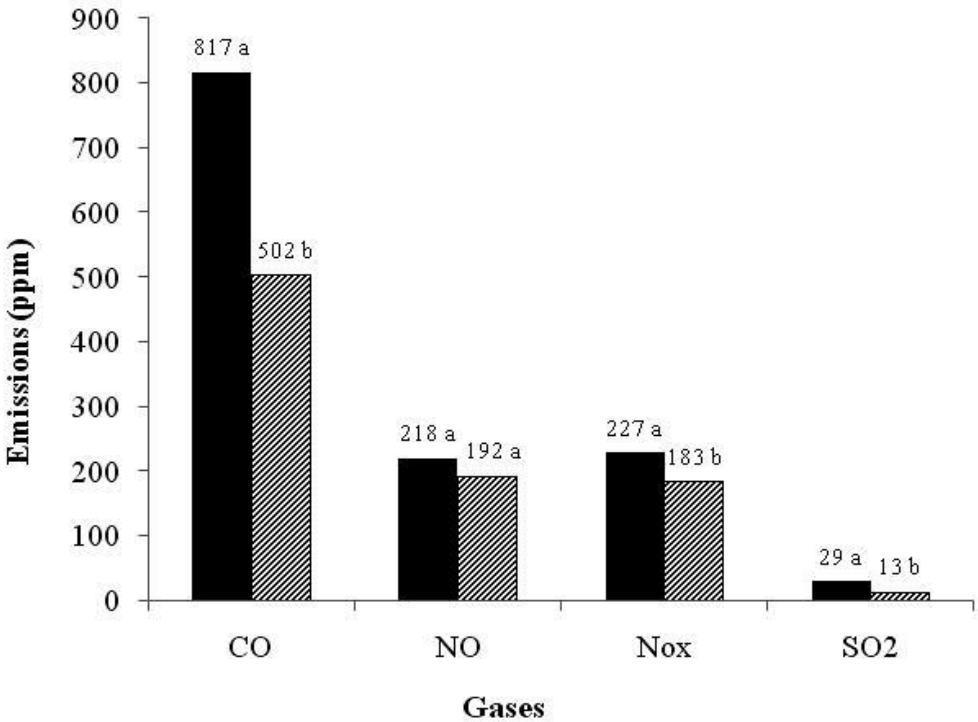


**Figure 5.** Global averages for the emission gases in a motor generator using resistive loads. *Averages followed by the same letter, for each gas, do not differ statistically by the Turkey Test at 1% of significance.

Yetter (2008), higher NO levels may occur in stoichiometric equilibrium situations in an oxygen-rich combustion.

About the nitrogen oxides (NOx) the use of biodiesel (B100) showed a 19.38% reduction when compared to diesel, a similar result to the study of Peterson and Reece (1996). They used biodiesel from rapeseed oil and obtained a 10% reduction of NOx. While the study of Schumacher et al. (2001), related an increase of NOx in about 11.6% for the B100 blend. Raslavičius and Strakšas (2011) verified in their biodiesel test that the NOx emissions increased proportionally to fuel oxygen mass. For Shi et al. (2005), the increase at NOx emissions is a signal of higher heat release and may be explained by the cetane number, with oxygen compounds added.

For the sulfur dioxide ($SO_2$) the biodiesel emissions reduction to diesel was about 55.47%. The low level of $SO_2$ is a consequence of a low sulfur proportion at the present biofuel. It demonstrates the high capacity of emissions reduction of $SO_2$ when biodiesel is used. Pereira et al. (2007) observed that beyond the $SO_2$ emission reduction the energy production was assured.

## Conclusion

At the most part of the essays, the use of biodiesel from waste frying oil showed a fuel specific consumption statistically equal to the mineral diesel. It was verified that the biodiesel from waste frying oil yielded a reduction at combustion gases emissions.


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