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ASSESSMENT OF THE EMISSIONS FROM COMBUSTION OF DIFFERENT GASOLINE-ETHANOL MIXTURES IN A POWER GENERATOR

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Abstract. *In the energy field, it is must know the useful power generation capacity that a given fuel has and compare it to others and determines what is the most appropriate fuel, or which has the best cost-benefit ratio. Thus, this study aims to assess the emissions from the combustion process in a power generator as a function of the applied load and of the ethanol content in the gasoline. The tests were performed in a power generator, which has an electric generator coupled to an internal combustion engine (Otto Cycle). During the operation of the power generator, two parameters were varied: the ethanol percentage in the gasoline and the applied load. The statistical planning methodology called RSM (Response Surface Methodology) was applied. From the measurements, the response surfaces were obtained and the behavior of emissions in function of the parameters studied were assessed. The results showed that the behavior of the* O_2 *emissions was opposite to the behavior observed for carbon dioxide. The highest nitrogen oxides emissions occurred for maximum loads and low ethanol content in the gasoline. The results have revealed that the emissions assessed were dependent of the ethanol percentage in the gasoline and the load.*

Keywords: *power generator, gasoline, ethanol, emissions.*

1. INTRODUCTION

Petroleum-based fuels are limited to reserves concentrated in certain regions of the world. These sources are on the verge of reaching their production peak. The fossil fuel resources are shortening a day by day. The scarcity of known petroleum reserves will make renewable energy sources more attractive (Demirbas, 2009).

The application of gasoline-ethanol mixtures as a vehicle fuel is also one of the measures in the strategy of improvement of the air quality and management plan of greenhouse gases. In general, it is used the nomenclature “Exx” to designate the percentage of ethanol in the gasoline. Thus, the E0 E100 it refers to 0% and 100%, respectively, of ethanol in the fuel. Currently, the use of ethanol-gasoline mixtures in internal combustion engines is widespread (Yao et al., 2013), and in Brazil 25% of ethanol in gasoline is used.

The emissions effects from ethanol-gasoline mixture into the atmospheric pollutant has been investigated in several studies (Stump et al., 1994; Poulopoulo et al., 2001; Hsieh et al, 2002; Hasan Al. 2003; He et al, 2003; Yüksel and Yüksel, 2004; Niven, 2005). One of the main properties of ethanol is its high oxygen content, which can influence the fuel combustion efficiency in internal combustion engines.

Most studies indicate that the burn of gasoline-ethanol mixtures produces lower levels of CO and THC compared to gasoline combustion (Stump et al., 1994; He et al. 2003; and Yüksel Yüksel, 2004). Emission reductions attributed to the ethanol present in the gasoline are due to the increase of oxygen in the process, improving the combustion reaction. Gasoline mixed to the ethanol also diminished the toxic emissions of gases, such as benzene, 1,3-butadieno, toluene and xylene, with increasing levels of ethanol (Stump et al., 1994; Poulopoulos et al., 2001). However, the addition of ethanol to the gasoline can increase the acetaldehyde emission significantly (Poulopoulos et al., 2001).

The effects of adding ethanol to gasoline are known, and its physical and chemical characteristics are well defined. However, there remains a need to characterize mixtures of these two components in order to contribute in the optimization of the process of energy attainment during the combustion in function of the text of ethanol in the gasoline. Having a better understanding of the use of ethanol gasoline blends in engines, is extremely important in developing staff and improving efficiency of combustion mixtures ethanol and gasoline, under this mitigation of pollutants in the atmosphere of the cities with the highest density vehicles and, in general, reduce greenhouse gases.

Despite the effects of adding ethanol to gasoline to be known and its chemical characteristics are well defined, there is still the need to characterize mixtures of these two components in order to contribute to the optimization of the process in function of the ethanol content in the gasoline. Have a better understanding of the use of blends of ethanol in gasoline engines, is extremely important in the professional qualification and in the improvement of combustion efficiency of gasoline-ethanol mixtures. The adding of ethanol in the fuel will result in the mitigation of pollutants in the atmosphere of the cities with the highest density of vehicles and, in General, reduce greenhouse gases.

The internal combustion engine is one of the most used technologies nowadays for different purposes, such as car power, industrial machinery, oil testing, among others (Stefani et al., 2007). In this context, this paper presents combustion tests performed in a power generator, coupled to an internal combustion engine (Otto Cycle), using different gasoline-ethanol mixtures. With these results, it is possible to assess the emissions from the combustion process as a function of the applied load and the ethanol content in gasoline.

2. EXPERIMENTAL BENCH

Combustion tests were performed on a Buffalo power generator, BFG 1200 model, which consists an electric generator of 1,2kW/115V coupled to an internal combustion engine (Otto cycle), gasoline-powered with power 2.8 hp (2060 W). The power generator was connected to a panel with 8 incandescent lamps. Each lamp has its individual switch, in order to allow a quantity of resistive loads required for each test was turned on. It is added 150 mL of gasoline with ethanol content desired in the combustion chamber and the motor was running.

To measure the gases emitted by the power generator, it was used a portable analyser of combustion gases manufactured for Chemist 300, 630 model AS0 AE. In addition, it was used a digital thermometer for measurement of the temperature in the escape, one wattmeter, a digital multimeter and a digital tachometer to verify the rotations of the power generator.

3. MATERIALS AND METHODS

3.1 Fuels

It was used gasoline and ethanol commercialized at a gas station located in Guaratinguetá/SP. The ethanol present in the gasoline was removed to obtain the gasoline-ethanol mixtures adopted in the tests with a greater precision.

3.2 Statistical Design of Experiment

Experiments were performed according to an experimental design (Central Composite Rotatable Design – CCRD), which is a statistical technique employed for multiple regression analysis and describes the interactive, cumulative, and individual effects of the test variables on the process yield (Colla et al., 2010). This tool provides a second-order model for the production of a response surface. Replicates at the central point, four axial points, and 2^2 plus start configuration were performed randomly (Mortari et al., 2013).

This methodology has two distinct stages: the first refers to the modelling and the second is known as displacement. Both stages are repeated as many times as necessary, so that is reached a great region of investigated surface. Normally, the modelling is done by adjusting simple models, such as linear or quadratic. The answers are obtained from factorial designs or scaled factorial design. The displacement always occurs along the maximum slope of the path of a particular model, which is the way in which the response varies more pronounced.

For this case, we used the quadratic model, which is for two general expression given in Eq. (1).

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1 x_2 \tag{1}$$

First, it was mount an 11x6 matrix called matrix X, with its six columns corresponding to the six terms of the quadratic model. The y matrix is composed of the experimentally results obtained. After this, the Xt¬X and xy matrices was calculated, and subsequently the b values was calculated by Eq. (2).

$$\hat{y} = (X^t X)^{-1} X^t y \tag{2}$$

Thus, the b_0, b_1, b_2, b_{11}, b_{22} and b_{12} coefficients were obtained and with them, the response surface.

4. RESULTS AND DISCUSSIONS

4.1 Experimental Planning

Table 1 shows the values of the variables that were studied as well as their levels of the experimental design.

Table 1: Levels and values of the variables of the experimental planning.

Variables	Axial Point Low level	Low Point	Central Point	High Point	Axial Point High level
	-1,414	-1,061	0	+1,061	+1,414
% of Ethanol	10	20	50	80	90
Load	0	1	4	7	8

With the determined values of ethanol and load percentage, it was determined the planning, considering three repetitions at the central point, resulting in a total of 11 experiments, distributed as shown in Tab. 2.

Table 2: Design matrix with coded and actual values determined for the design 2^2 with three repetitions at the central point.

Tests	Coded Values		Actual Values	
	Load	% of Ethanol	Load	% of Ethanol
1	-1,06	-1,06	1	20
2	+1,06	-1,06	7	20
3	-1,06	+1,06	1	80
4	+1,06	+1,06	7	80
5	-1,41	0,00	0	50
6	+1,41	0,00	8	50
7	0	-1,41	4	10
8	0	+1,41	4	90
9	0	0	4	50
10	0	0	4	50
11	0	0	4	50

Whereas the experimental planning shown in the Tab. 1, it were executed the 11 tests following itself the presented experimental conditions in the coded matrix (Tab. 2). The results (answers) obtained are presented in the sequence.

4.2 Emissions Analysis

Tests were made in the motor generator and also it were made measurements of the emissions generated in the combustion of the mixtures prepared as described in Tab. 2, being that the generated emissions are related to the equations of combustion of the used mixtures.

It was applied the statistical method of the response surface to the experimental results, obtaining surfaces for each of the measured emissions, as shown in Fig. 1 (Excess air), Fig. 2 (LCV Efficiency), Fig. 3 (CO_2%) Fig. 4 (% O_2) and Fig. 5 (NO_X).

In the same way that was done for other results, it was applied again the RSM methodology, met the equation coefficients Eq. (1) (Tab. 4) for the air excess, LCV efficiency, %CO_2, %O_2 and NO_x and thus elaborated the Surface Contour and Answers for each one.

It is observed in the Fig. 1, that adding ethanol in the mixture produced a mixture "poor" and the mass of air admitted by the engine is greater than the permissible fuel mass. In this case, increasing the air / fuel ratio ensures that the combustion is complete (Hsieh et al., 2002), that is, the CO is oxidized to form CO_2. This behavior is seen in the Figure 14, wherein the region of higher air excess condition is related to the higher percentage of ethanol.

To occur the complete combustion it is necessary to provide to the combustion chamber an amount of air greater than the theoretical air (stoichiometric). When working with only the theoretical air may occur a non-homogeneous distribution, that is, a place in the combustion chamber with excess air volume and one with breathlessness. In the latter case it will cause incomplete combustion and, if there is an air excess in the combustion chamber, the combustion occurs. However, the air excess will decrease the temperature in the combustion chamber and also the engine thermal efficiency (Vlassov, 2008). This behavior is in agreement with the results obtained, for the condition of greater excess air (Fig. 1) was observed at low temperatures.

Table 3: Results obtained experimentally.

Tests	Responses				
	Air excess	LCV Efficiency	CO_2 (%)	NO_x (pmm)	O_2 (%)
1	1,31	86,2	11,40	49,0	5,00
2	1,29	86,7	11,60	187,0	4,80
3	1,45	84,1	10,30	20,8	6,60
4	1,20	84,9	12,50	32,3	3,50
5	1,34	86,2	11,30	19,0	5,30
6	1,34	85,3	11,10	23,0	5,40
7	1,27	86,2	11,80	83,6	4,50
8	1,29	83,9	11,60	43,3	4,80
9	1,27	86,8	11,80	110,0	4,50
10	1,28	86,1	11,70	47,8	4,60
11	1,33	85,1	11,30	70,8	5,20

Table 4: Found coefficients using the RMS method for the analyses of the emissions.

Coefficients for each result	b_0	b_1	b_2	b_{11}	b_{22}	b_{12}
Air excess	1,293	-0,034	0,010	0,023	-0,007	-0,051
LCV efficiency	85,989	0,013	-0,869	-0,083	-0,433	0,067
%CO2	11,599	0,266	-0,058	-0,195	0,055	0,444
%O2	4,771	-0,395	0,087	0,276	-0,074	-0,644
NOx (ppm)	73,700	19,321	-29,528	-17,913	3,313	-28,111

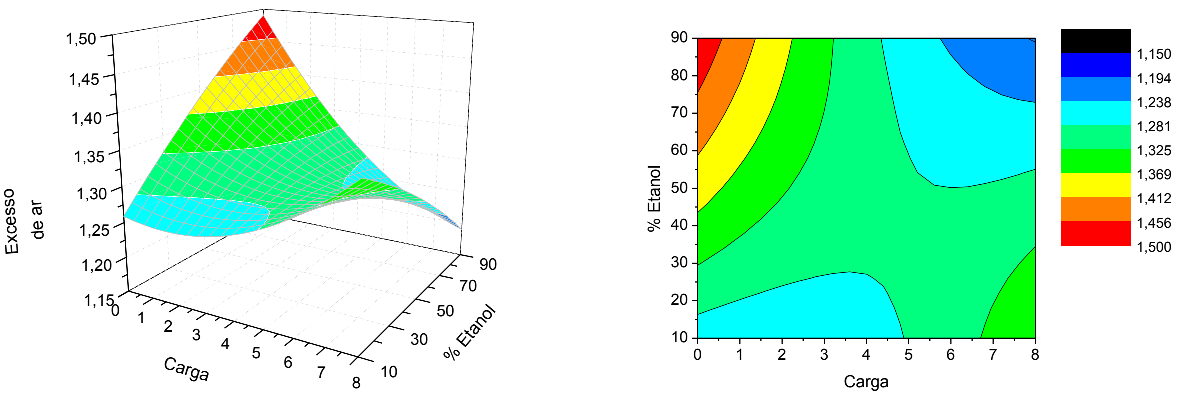

Figure 1: Response Surface and Contour Surface: Excess air in function of the load and the ethanol percentage.

Considering the LCV results of the used mixtures (Fig. 2), it is observed that the higher content of ethanol present in the mixture, the lower is the LCV of the fuel. It is noteworthy that the load variation had little influence on the LCV behavior. This result was expected because the LCV is directly related to carbon in the fuel, since the fuel in the molecule has 6 carbon atoms more than ethanol. It is noted that PCI can be determined using elementary composition of the fuel.

Figure 3 shows that there are two regions of increase of CO_2: the first is related to the high percentage of ethanol, and high load and the second region is connected to the low percentage of ethanol and low load. It is observed that there was a trend of increasing CO_2 emissions with the addition of ethanol to gasoline.

The first region showed that the presence of oxygen in ethanol contributes to the oxidation of CO to CO_2, thus increasing the level of carbon dioxide (Melo et al., 2012). Furthermore, according to Melo et al. (2012), the fuel consumption increased when ethanol was added to the mixture because ethanol has a low calorific value (approximately

26 MJ / kg) than gasoline (around 42 MJ / kg). Therefore, with the increase in the percentage of ethanol, more oxygenated fuel is required and this affects the increase of CO_2 emission.

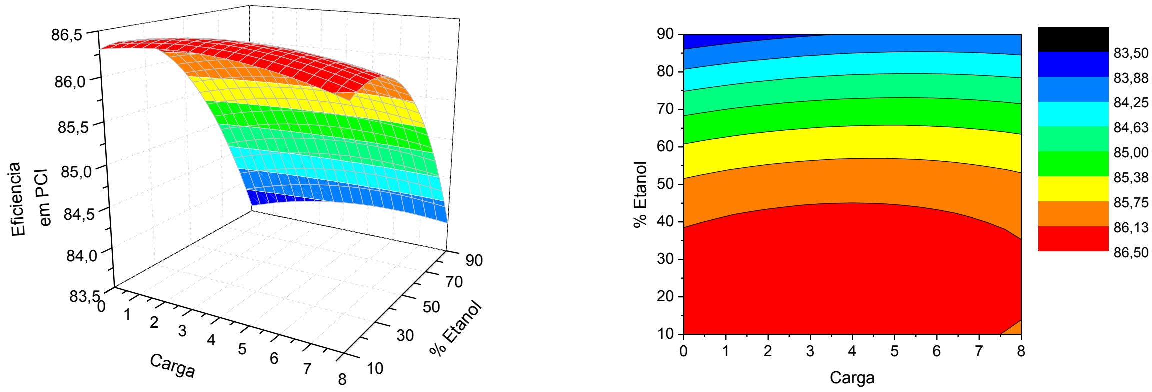

Figure 2: Response Surface and Contour Surface: LCV efficiency in function of the load and the ethanol percentage.

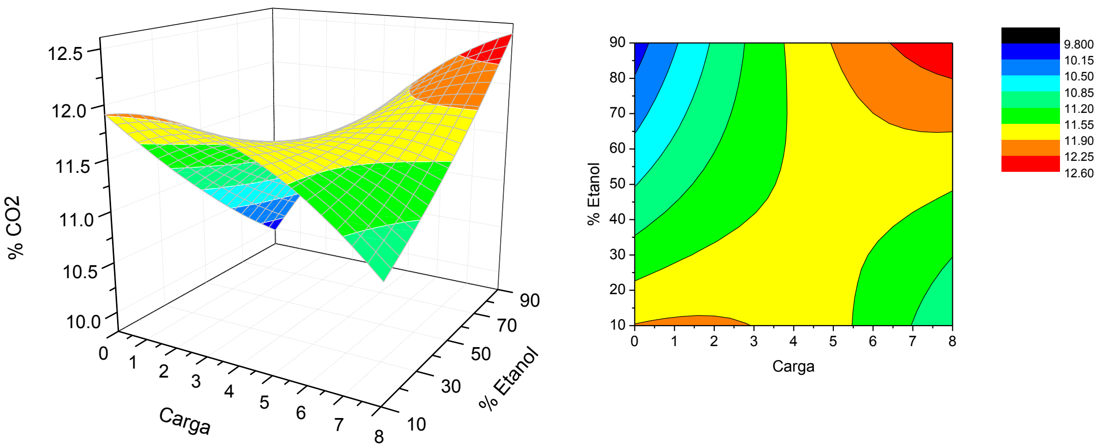

Figure 3: Response Surface and Contour Surface: Concentration of CO_2 in function of the load and the ethanol percentage.

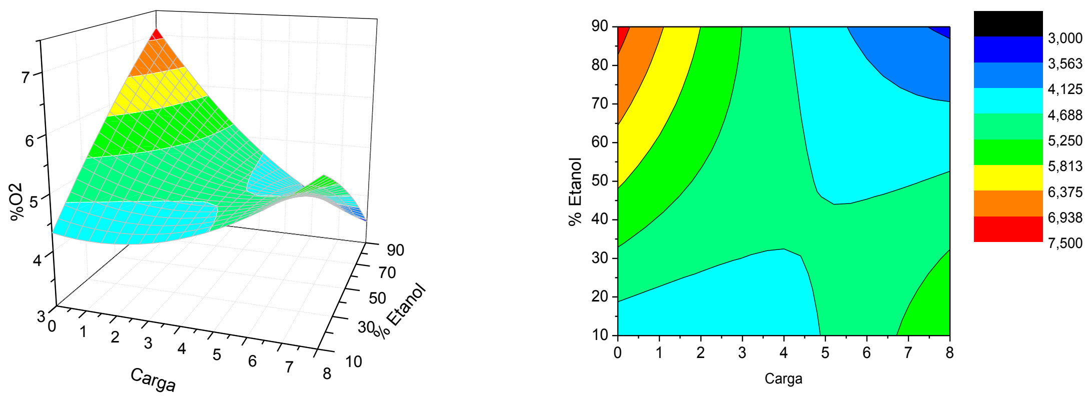

Figure 4: Response Surface and Contour Surface: Concentration of O_2 in function of the load and the ethanol percentage.

The behavior of O_2 percentage (Fig. 4) present in the emissions is opposite to the percentage of CO_2 (Fig. 4). This behavior was expected, since the more CO_2 is formed less oxygen does not react. As found by Carvalho (2011), normally in mixture air / fuel more "Poor" the O_2 percentage results are higher because there is a greater proportion of air to react with the fuel molecules. This can be observed performing the comparison between Fig. 4 and Fig. 1, relating respectively to the percentage of O2 and the excess air, which have similar shapes.

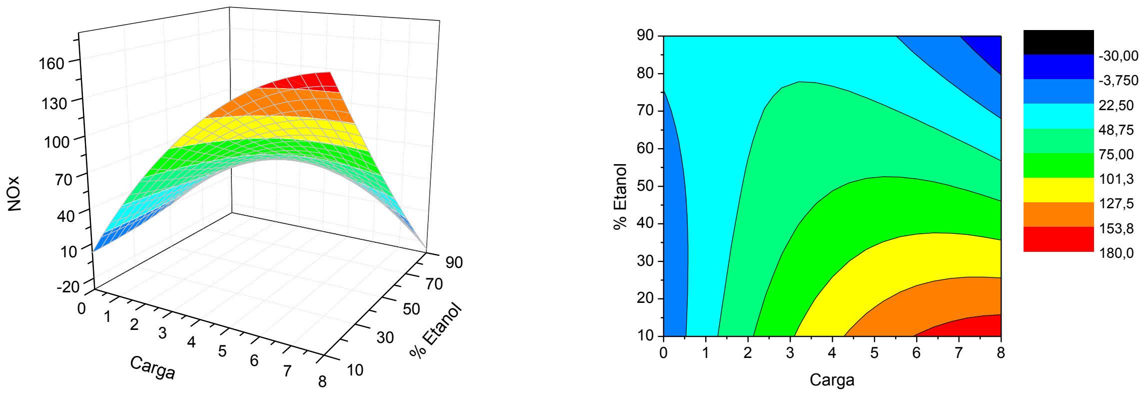

Figure 5: Response Surface and Contour Surface: Concentration of NO_x in function of the load and the ethanol percentage.

In the second region, it is observed that the high calorific value of gasoline and less effort of the power generator contributes to a more efficient combustion, that is, higher percentage of CO_2.

The higher emissions of NO_x (Fig. 5) occurred for maximum loads and low ethanol content. It is also observed that these high emissions occur in conditions where temperatures were lower and for low air excess values (Fig. 1). The results obtained in this study for NO_x, proved to be inverse in relation to these two parameters compared to other authors that have investigated the effect of adding ethanol in gasoline. However, as discussed in the literature review, the behavior of the NO_x emissions is controversial regarding the effect of ethanol on NO_2 emissions in gasoline-ethanol. Most authors, however, agree that the rise in temperature has great influence on the increase of NO_x emissions (Najafi et al, 2009; SANTOS et al., 2008). Another factor is that many authors consider that NO_x reaches its maximum value at stoichiometric conditions, ie $\lambda \cong 1$ (HSIEH et al, 2002; Çanakçı et al, 2013).

5. CONCLUSION

In this work, the behavior of a power generator was evaluated using mixtures of gasoline/ethanol in different percentages, varying the applied load.

It was used a methodology of statistical planning known as RSM (Response Surface Methodology), that is one technique of optimization based on factorial planning. It was determined a delineation 2^2 with 3 repetitions in the central point, resulting 11 experiments.

After the accomplishment of the 11 tests, was possible to obtain the Surfaces of Answers and Contour for the power, tension, chain, RPM, average temperature of exhaustion, air excess, efficiency in LCV and emissions generated (CO_2, O_2 and NO_x) in function of the percentage of ethanol and the applied load to the power generator.

The results showed that the emissions of CO_2 had two regions increase, related to a higher ethanol content and a lower applied load, or to the lower content of ethanol and less load applied. The first region of increase, possibly, is due to the presence of oxygen in the ethanol contributes to the oxidation of CO in CO_2. The second is due to the high calorific value of the gasoline and less effort of the power generator, which contributed to a more efficient combustion, in other words, higher percentage of CO_2.

The highest values of NOx were found to low levels of ethanol and low load. The literature describes that this behavior of NO_x is due to addition of the ethanol to the gasoline, but the NO_x emissions is controversial. These results must be better researched in future works.

The results obtained in this work showed that the experimental planning adopted was adjusted for the evaluation of the behavior of the curves obtained (Surfaces of Answers and Contour) in function of the percentage of ethanol and of the applied load to the power generator.

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