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ENERGETIC ANALISYS OF A PORTABLE GASOLINE POWER GENERATOR

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Abstract.

Fossil fueled motor generators are largely employed in countryside Brazilian remote villages, despite their pollutant emissions, because there is lack of electricity transmission grid to some of these villages, and due to these generators being a simple and accessible alternative for electricity generation. In this context, this manuscript presents the performance analysis of a small gasoline generator (1 kW) aimed to identify the influence of the power load and type of fuel on the thermal efficiency and specific fuel consumption (SFC). Experiments were conducted with variable power load, and with three types of fuel: (i) type C regular gasoline (fuel E27) which contain 27% by volume of anhydrous ethanol (AEAC); (ii) pure gasoline (fuel E0), and (iii) a mixture of fuel 27 and hydrous ethanol (AEHC) to produce a fuel with 35% by volume of anhydrous ethanol (fuel E35). All experiments were conducted at an environment with temperature of 25 ° C. The result indicated that the engine thermal efficiency largely increases with the applied load. The results also indicated that the maximum efficiency is obtained with the fuel E27, although the difference between the efficiency of this fuel e the other ones, is within the experimental uncertainty. Regarding the SFC, as expected, it increases with the amount of ethanol in the fuel. Moreover, considering the mean fuel price in six Brazilian states, the economic analysis indicated that the utilization of fuel E27 is the cheapest choice.

Keywords: *Rural electrification, Ethanol, Gasoline, Power-generator.*

1. INTRODUCTION

According to data from the Brazilian Institute of Geography and Statistics (IBGE), in 2010, 97.8% of households in Brazil had access to electricity, with greater coverage in urban areas (99.1%). In the countryside, coverage reached 89.7% except in the northern region, where only slightly more than half (61.5%) of the households had access to electricity (IBGE, 2010). According to the data released by the Paulista Energy Company from a survey carried out with the National Electric Energy Agency (ANEEL) and other electricity distribution companies from Brazil, the number of households without access to energy is approximately one million (COPEN, 2011).

The electrification deficit in rural areas is one of the problems faced by the Brazilian electrical system, and the high number of countryside dwellers without access to electricity can be explained by their great distance from the power plants, and low density of consumers per square kilometer which causes a lack of enough distribution electricity grid (SILVA et al., 2002). Due to this deficit, the use of fossil fuel power-generators is an alternative for electricity generation in these regions, despite the environmental problems caused by the exhaust gases emitted from burning fossil fuels and the growing incentive for the use of renewable energy in remote areas.

The utilization of fossil fuel power-generators can be justified to the consumers by their relatively simple operation and by the fact that they employ fuels easily found. Furthermore, looking at the renewable power options, the electricity generation through wind turbines might be unfeasible in Brazilian north because, in addition to the high installation cost, the greatest wind potential is located in the Brazilian coastal region. Regarding generation through photovoltaic modules, there is no technological barrier, but there are also technical, social and economic parameters that must be taken into account and that significantly influence and even make the application of this technology unfeasible. (WALTER, 2003).

In this context, it is important to access how the energetic performance of fossil fuel driven power-generators are influenced by the operation condition and the type of fuel consumed. Taking this into account, the influence of the power load and the proportion of ethanol mixed in gasoline on the performance of a portable power-generator was investigated and presented in this manuscript. To complete this study, an economic analysis to check the feasibility of increasing in the volume of anhydrous ethanol in gasoline through the insertion of hydrated (regular) ethanol was carried out considering the average fuel price in six Brazilian states (Santa Catarina, Paraná, Rio Grande do Sul, São Paulo, Minas Gerais and Roraima).

2. STATE OF ART

Studies on the use of mixtures of gasoline and hydrated ethanol (AEHC) are diverse and were motivated by environmental concerns, due to the need of finding environmentally and economically viable solutions for the replacement and/or reduction of fossil fuels utilization.

Vilanova (2007) and Celik (2008) investigated the performance variation of an engine combustion with the addition of different proportions of AEHC in gasoline. The analysis of both authors was based on specific fuel consumption and exhaust gases (CO and CO2), but Vilanova (2007) also analyzed the effective net torque whereas Celik (2008) analyzed power increase and the influence of compression ratio. The experiments were carried out in steady-state regime of speed and identical operating parameters with the engine being fueled with pure gasoline or pure AEHC or different volumetric proportions of these two fuels.

The results obtained by Vilanova (2007) showed that in general, there was an increase of the effective net torque as the increase of ethanol in the mixture and that the biggest disadvantage of the use of this biofuel was high consumption. Regarding the exhaust gases, there was a fall in the emission of carbon monoxide (CO) and an increase in the emission of carbon dioxide (CO2). The results of Celik (2008) demonstrated that the most suitable fuel in terms of performance and emissions was E50 (gasoline with 50% AEHC), resulting in a greater increase in power with considerable reduction of CO, CO 2, nitrogen oxide emissions (NOx) and Hydrocarbons (HC), and these reductions were even greater with the increase of the compression ratio.

Costa and Sodré (2010), Melo et al. (2012) and Deng (2018) also carried out the study of performance of an engine using mixtures of gasoline and AEHC as fuel. The study of Melo et al. (2012) considered ordinary gasoline as the E0 fuel (without AEHC) and then experiments were carried out with this gasoline mixed with 30, 50 and 80% AEHC and also experiments with 100% AEHC, while the study by Costa and Sodré (2010) was based on the analysis only of E22 fuel (gasoline with 22% AEHC) and Deng (2018) analyzed gasoline pure, E10 and E20 that correspond to a fuel with 10 and 20% by volume of AEHC, respectively. All analyzed specific fuel consumption, energy efficiency and amount of exhaust gases expelled (CO and NOX) varying the engine rotation speed.

As a result, in all studies for all speed ranges there was an increase in specific fuel consumption (amount of volume consumed per kWh generated), but at the same time an increase in energy efficiency. Regarding the emission of exhaust gases, there was a decrease in CO emission in all studies. However, regarding NOx emission, the results are contradictory as one study (MELO et al. 2012) did not show relation between this emission and the engine rotation, but in another study (COSTA and SODRÉ, 2020) there was an increase in emission with rotation, whereas another study (DENG, 2018), revealed the opposite influence of the rotation on the NOx emission.

Schifter (2013) analyzed the performance of a single cylinder engine when employing fuels with 10% volumetric increments of ethanol, starting from fuel E0 (gasoline pure) to E40 (gasoline with 40% AEHC). These mixtures were produced with both AEHC and Anhydrous Ethanol (AEAC), which allowed to identify the influence of the increase in the amount of water in the fuel. As a result, NOx emissions appear to decrease as the content of water in the fuel increases and the difference in fuel consumption between anhydrous ethanol and hydrated is greater as the amount of ethanol increases.

Castro (2014) studied the influence of the insertion of AEHC in gasoline on the performance of a 1.2 kW gasoline engine without any modification and analyzed the power output, voltage and specific fuel consumption. The experiments were done with pure gasoline, with pure hydrated ethanol and with mixtures of these two fuels in different propositions. The influence of fuel composition on the amount of NO_X and CO_2 expelled by the engine was also analyzed. The later work, despite being similar to the work described in this manuscript, did not verify the influence of the load on the generator's performance, which was fixed at 800 W. Moreover, different for the work presented in this manuscript in which the experiments were conducted in an environment at 25 °C, the experiments on the work of Castro (2014) were conducted without control of the ambient temperature, which varied between 26 ° to 29 ° C, with most of the experiments occurring in an ambient at 28 or 29 ° C. The results showed that with the increment in ethanol proportion in the fuel, there was a reduction in the power and voltage generator output, but which were considered irrelevant to the total values obtained. Regarding the exhaust gases, it was observed a reduction in the amount of CO2 expelled, however, the amount of NOx increased with the increase of ethanol.

The addition of ethanol in a fuel mixture is justified by the fact that ethanol can be considered a renewable fuel and an alternative to gasoline. In Brazil, its attractiveness is even greater since the country has characteristics that favor the cultivation of sugar cane and the ethanol production process is dominated, with the country occupying a prominent position worldwide in the production of this biofuel (RIBEIRO e SCHIRMER, 2017).

In general, mixtures of gasoline and AEHC do not present any problem regard operation of the engine, when these are inserted into an internal combustion without adaptations, but it is proven that when these are carried out, positive results are maximized, with a greater reduction in the emission of polluting gases and increase in the efficiency of the system, as identified in the work of Celik (2008). Furthermore, when adaptations are not made, it is still possible to identify an increase in efficiency with the increase in ethanol in gasoline, although there is an increase in fuel consumption, as identified in the works by Costa and Sodré (2010), Melo et al. (2012) and Deng (2018).

Therefore, the increase in fuel consumption with the increase in ethanol in the mixtures can be offset by increased energy efficiency, effective net torque and reduced greenhouse gas emissions, provided that detailed analysis is carried out and the suitable proportion of these fuels in the mixture is employed.

Hence, the work presented in this manuscript complements previous studies, by investigating not only the influence that the proportion of ethanol and gasoline has on the motor-generator efficiency, but also how the load influences the power-generator performance.at controlled ambient temperature of 25° C.

3. MATERIALS AND METHODS

To experimentally investigate investigated the influence of the power load and the proportion of ethanol mixed in gasoline on the performance of a portable power-generator, the A TG1000l gasoline power-generator manufactured by Toyama was used. It is an air-cooled 53.5 cc, 5500 rpm (maximum), four-stroke single engine operating under the Otto cycle that produces a maximum alternating current (AC) power of 1 kW and a rated AC power of 900 W. This power-generator has a tank with a capacity of 2.6 liters and an autonomy rated power of five hours, it is single-phase with output voltage of 110 or 220 V and it has an intelligent rotation function, adjusting the rotation when the generator has no charge. Figure 1 Illustrates the power-generator.

Figure 1 – Power-generator.

The performance analysis was carried out with fuel E27 in an environment temperature of 25 °C and at five different power load levels: 200 W, 300 W, 520 W, 750 W and 850 W. The aim of this analysis was to estimate under what condition the performance of the power-generator will be maximized, in addition to making it possible to estimate the equipment thermal efficiency under other load conditions, as long as it is within in the studied range.

Due to the need to control the room temperature to keep it at 25 ° C, it was necessary to channel the exhaust gases from the power-generator since the work was developed in a closed environment and the released gases in the combustion process are toxic and represents a health risk. For this channeling, a copper tube connected to the gas outlet of the generator was used and was handled out of the environment. For temperature control, an air conditioning equipment model BE09F from Electrolux with a cooling capacity of 9000 BTU/h (2,64 KW) was utilized. Figure 2 (a) shows the exhaust gas channeling and Figure 2 (b) the load panel.

(a) (b)

Figure 2 – (a) Exhaust gas channeling; (b) Charge panel.

The influence of the proportion of ethanol mixed in gasoline on the power-generator performance was analyzed considering the operation of the generator under a 520 W charge in an environment temperature at 25 ° C and three types of fuel: pure gasoline (fuel E0), C type gasoline (fuel E27) and a mixture of gasoline and 35% in volume of anhydrous ethanol (fuel E35). Results from these experiments were used to access the influence that the ethanol proportion in motor-generator fuel has on the engine performance.

The performance analysis was based on rate of fuel consumption (FC), specific fuel consumption (SFC), and thermal efficiency. Regarding the number of experiments, it was carried out three 20 minutes experiments for each fuel type at the intermediate load condition of 520 W. For each other load condition with the fuel E27 was carried one experiment and the standard deviation considered was that obtained in the experiment with intermediate load. In addition, an economic analysis was conducted to compare the generated electricity and the operating cost for the fuels E35 and E27.

To determine the fuel consumption, the generator was weighed with fuel before and after the experiments, and in this way the consumption was determined through the mass variation identified. Through the mass of fuel consumed with its respective uncertainty and fuel density, measured in laboratory, it was possible to determine the fuel consumption rate presented in the Eq. (1).

$$FC = \frac{V_c}{t} \tag{1}$$

Where V_c is the volume of fuel consumed in liters and *t* the time in hours. The SFC parameter is present in Eq. (2) and represents the amount of fuel needed to produce a certain amount of energy, and allows all different engine sizes to be compared as well as determining which fuel is more capable of generating work and, therefore, which results in greater efficiency (YANDRI and PANJAITAN, 2013).

$$SFC = \frac{V_c}{E} \tag{2}$$

The thermal efficiency, is an important performance parameter, as it is able to define which fuel is more efficient, as it relates the heating power to generation and work:

$$n_t = \frac{E}{Q_f} \tag{3}$$

Where, E is the electrical energy generated (kWh) and Qf the thermal energy of the fuel that is determined through the relationship between the fuel mass (mf) and its lower calorific value (PCI), as shown in Eq. (4).

$$Q_f = m_f * PCI \tag{4}$$

The PCI of fuel E27 is well known, but for the analysis of the thermal efficiency of the generator when it is subjected to experiments with the fuel E35, it was necessary to determine PCI of the mixture used. In such cases, the PCI mixture can be determined by the sum of the products of the mass or volume fractions of each constituent in the mixture by respective PCI (VILANOVA, 2007) as described in Eq. (5).

$$PCI_M = \sum n_i * PCI_i \tag{5}$$

In this work, to determine the PCI, the volumetric fraction was considered, and the mass PCI determined using the fuel density measured in the laboratory with a hydrometer. The proportion of fuels in the mixture considered was 88,5% gasoline and 11,5% hydrous ethanol. These values were determined considering the final volume of the mixture and the quantity in volume of each fuel used. Eq. (6) shows the conversion performed.

$$PCI_{(Mássico)} = \frac{PCI_{(Volumétrico)}}{\rho} \tag{6}$$

Regarding the economic analysis, the final price of the mixture was determined by making the composition according to proportion of each fuel previously presented. The proportions were applied to the average fuel price and the table below shows the average prices considered and the final price for E35. The prices referring to the month of August 2020 (ANP, 2020).

Table 1. Fuels price per state

Fuel	Price per State [R$/L]					
	Rio Grande do Sul	**Santa Catarina**	**Paraná**	**São Paulo**	**Minas gerais**	**Roraima**
Gasoline	4,50	4,13	4,04	4,01	4,38	3,87
Hydrous Ethanol	3,98	3,49	2,85	2,56	2,84	3,46
E35	4,44	4,06	3,90	3,84	4,20	3,82

4. RESULTS AND DISCUSSION

The analysis of the experimental results enables us to conclude that there is a strong dependence of the power-generator efficiency with the applied load. Figure 3 shows the efficiency variation as a function of the applied load, and it is possible to identify that it varies from 6% for a load of 200 W up to 16.5% for a load of 850 W, close to the rated power of the equipment. The equation included within Fig. 1 presents the relation between the load and efficiency. It provides an estimation of the power-generator efficiency under different charges, as long as they are within the analyzed range and the power-generator operates in an ambient at 25 ºC.

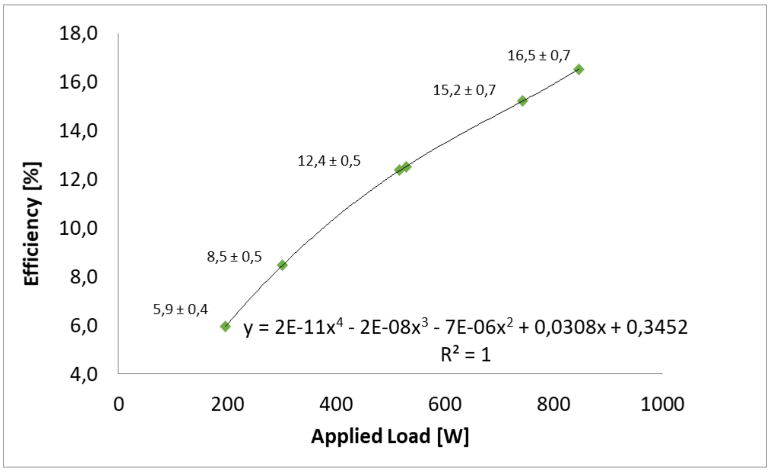
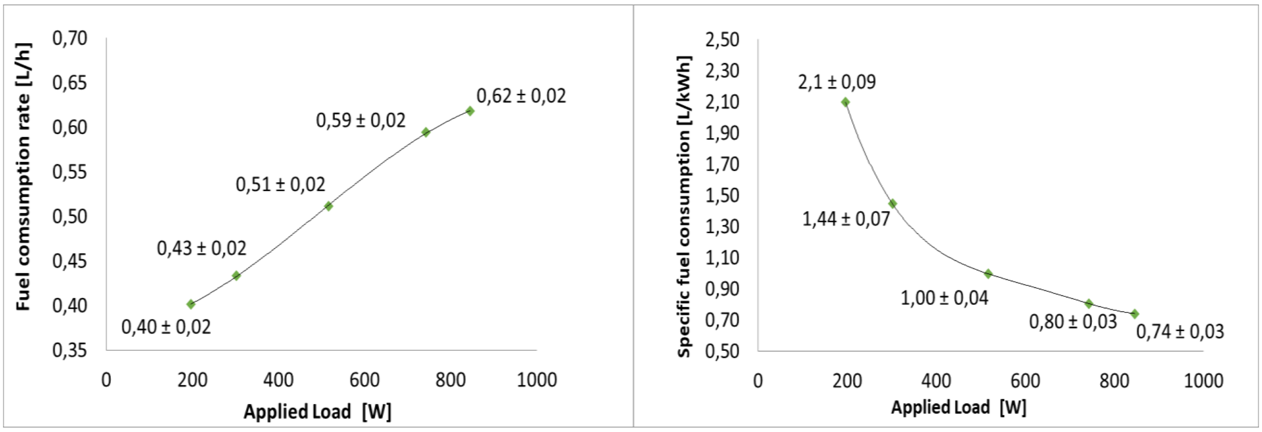


Figure 3 – Power-generator efficiency as a function of the applied charge for operation with Fuel E27.

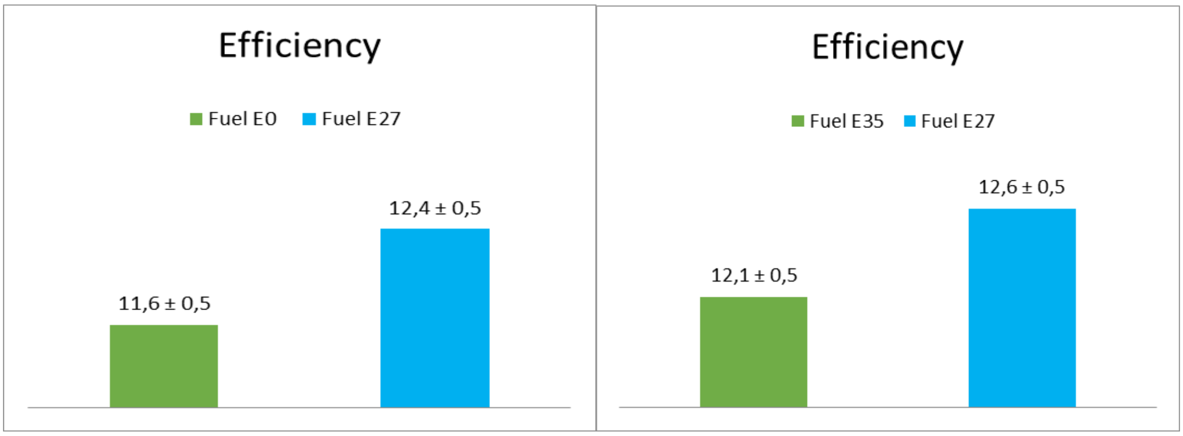
About fuel consumption, as expected, it rose with the increase of the applied charge, whilst the specific fuel consumption had a different behavior, decreasing by approximately 2.8 times when compared the consumption at the highest and lowest charge conditions. This parameter relates the volume consumption by the electricity generated, thus the SFC tends to fall with the increase of the applied charge due to the energy efficiency increase, as previously discussed. Figure 4 (a) and (b) shows the results found to the FC and SFC parameters, respectively.



(a) (b)

Figure 4 - FC and SFC results for operation with Fuel E27.

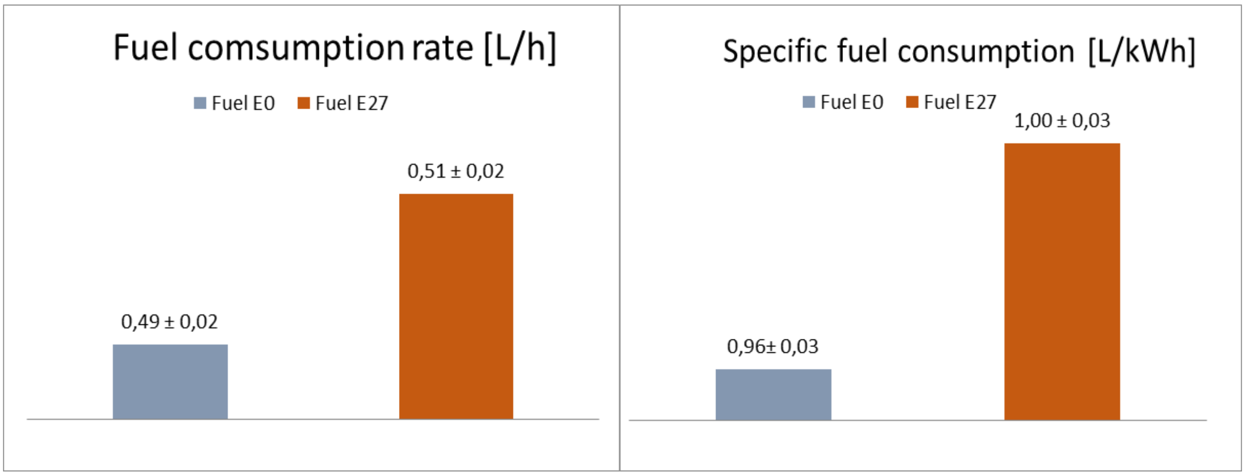
Regarding the power-generator efficiency as a function of the type of fuel utilized, it was identified an increase in the efficiency (around 1%) with the addition of 27% of ethanol when compared to the operation with pure gasoline (E0) at the same conditions, whilst in the comparison between gasoline type C (E27) and fuel E35, there was a downward trend (around 0,4%). Although the slightly efficiency variation, it can be inferred that there is a tendency to increase the efficiency with the presence of ethanol in the fuel, that was also identified in Costa and Sodré (2010), Melo et al. (2012) and Deng (2018) studies, but after some point, there is a tendency to decrease. This result can indicate that for an engine without modifications there is a suitable combination that will maximize efficiency.



(a) (b)

Figure 5 – Thermal Efficiency comparison: (a) Fuel E0 and E27; (b) Fuel E35 and Fuel E27.

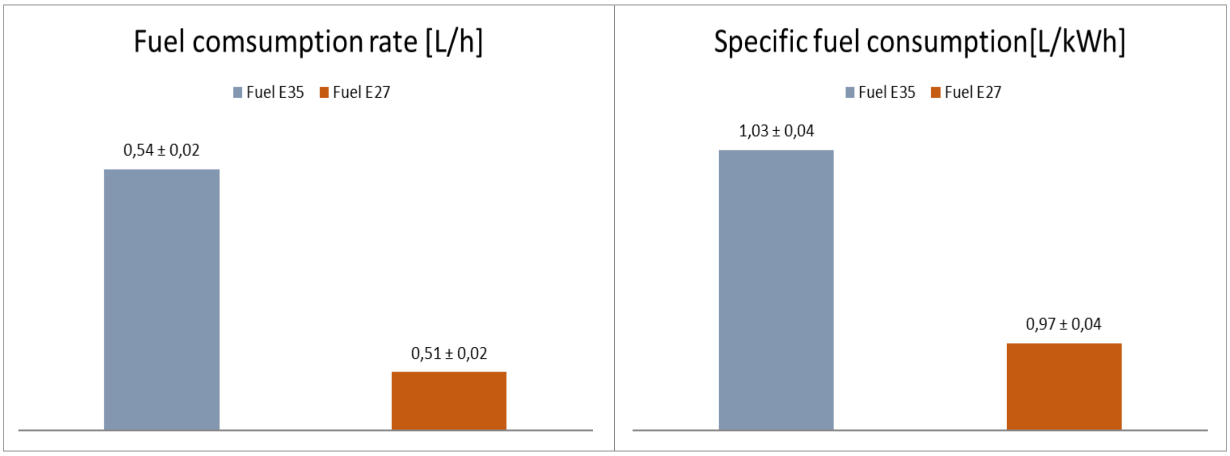
Figure 6 (a) and (b) presents regarding fuel E0 and E27, the comparison between fuel consumption and specific fuel consumption, respectively. It can be observed that there is a tendency for consumption increase (approximately 4%) when fuel has ethanol in its formulation, and this trend is justified by the calorific power of ethanol being less than gasoline. although the slightly difference obtained in this work, the tendency of consumption increment was already verified in previously studies presented in the state of art section.



(a) (b)

Figure 6 – FC and SFC comparison: Fuel E0 and E27.

Looking at the comparison of FC and SFC between Fuel E27 and E35, again it is possible to identify the tendency of consumption to rise with the presence of ethanol (approximately 6%). The upward trend is greater than that identified in the comparison between fuel E0 and E27. Looking at the specific consumption, the same increase tendency was identified.



(a) (b)

Figure 7 - FC and SFC comparison: Fuel E27 and E35.

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Looking through an economic perspective, the mixture of anhydrous ethanol to the fuel E27, although providing environmental benefits, elevates the operation cost for all the analyzed states (RS, SC, PR, SP, MG and RR). Through this analysis, it was observed that the cost of operation varies significantly as a result of the variation in fuel prices throughout Brazil. The figure (8) presents the comparison of prices between fuels while Figure (9) shows the percentage increase.

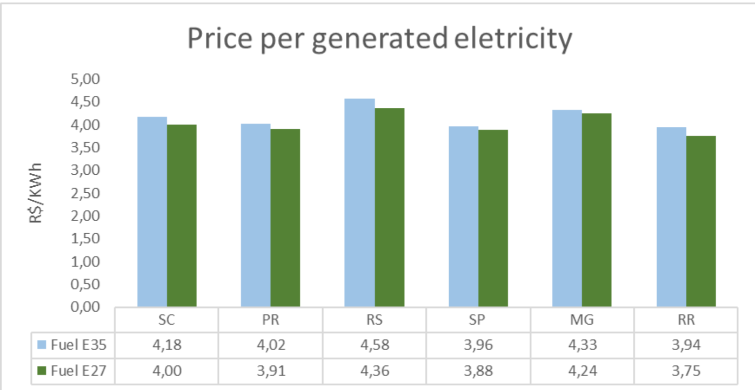

Figure 8 – Price per generated electricity [R$/KWh]

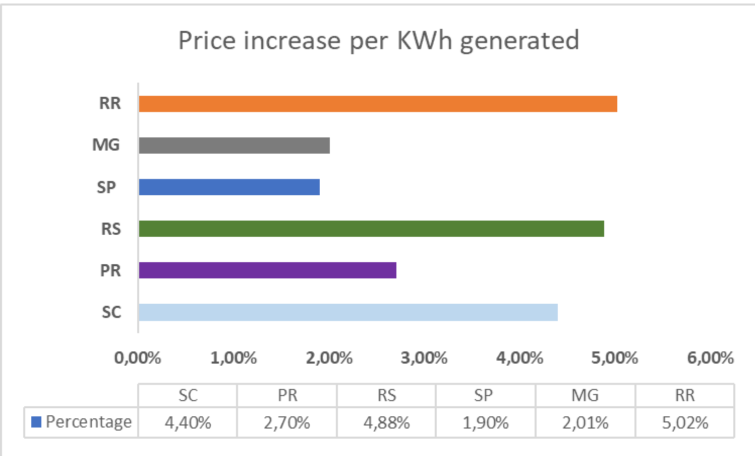

Figure 9 - Percentage increase in the cost of power generation per KWh.

5. CONCLUSION

The developed work presented the results of the experiments carried out in a small power-generator (1 kW) when subjected to ordinary gasoline (Fuel E27) in an ambient temperature condition of 25 ° C with load variation in five levels. The goal of this analysis was to identify how the thermal efficiency of the equipment, the consumption rate and the Specific fuel consumption is affected when the equipment operates in load other than nominal.

In addition, experiments were performed using pure gasoline (Fuel E0) and fuel E35 (gasoline with 35% of anhydrous ethanol) in the same load and environmental temperature (520 W and 25ºC), in order to compare with the results obtained in the same conditions with Fuel E27. The aim is to identify the influence of ethanol in the power-generator performance analyzing the three parameters previously mentioned.

As a result of this work, it was verified that engine efficiency is highly dependent on the applied load, ranging from approximately 6% efficiency for a load of 200 W up to 16.5% efficiency for a load of 850 W, close to the rated power of the equipment. Regarding the fuel consumption, as expected, it increased with the increase in the applied load, while the specific fuel consumption, that determines the consumption per kilowatt hour generated, decreased by approximately 2.8 times (ranging from 200 W to 850 W, due to the increase in thermal efficiency with the increase of the load).

Looking at the comparisons between the fuels to determine the influence of the ethanol in the engine performance, the comparison between fuel E27 and E0 demonstrated that despite the tendency to increase fuel consumption (approximately 4%) with the presence of ethanol, there is also a tendency to increase the thermal efficiency of the equipment (approximately 1%). Looking at the comparison between Fuel E27 and E35, again there is a tendency to increase the fuel consumption (approximately 6%), with this increase higher than in the previous comparison, but in this case, there is a tendency to reduce in thermal efficiency (approximately 0.4%). Looking at the efficiency, it can be inferred that there is suitable combination of gasoline and ethanol that will maximize it.

In addition to that, for the fuels E27 and E35, an economic analysis was developed, which showed that the inclusion of hydrated ethanol in E27 to increase the proportion of Anhydrous ethanol up to 35% elevated the operation cost for all states analyzed (RS, SC, PR, SP, MG, RR). Although, it was observed that the cost of operation varies significantly due to the variation in fuel prices in the country, and that depending on the region, this mixture can become economically viable, while also providing environmental benefits.

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