



Effect of anhydrous ethanol/gasoline blends on performance and exhaust emissions of spark-ignited non-road engines

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Abstract

Ethanol is a renewable fuel and it is considered an alternative to gasoline in Otto-cycle engines. The present study evaluated the behavior of exhaustion gas carbon monoxide (CO) and total hydrocarbons (THC) according to the levels of anhydrous ethyl alcohol (AEA) added to gasoline in different proportions (E0, E10, E20, E27, that is, pure gasoline and its blends with AEA at 10, 20, and 27% v/v) in the use of non-road single cylinder engines of different powers (13 and 6.5 hp), to the loads applied to engine-generators and the air-fuel ratio (A/F) admitted to the engine cylinders. Also, the performance of engine-generators was verified in terms of mass, specific and energetic consumption and efficiency of the evaluated systems for the same blends and loads. The results showed that an increase in the AEA content in the blend resulted in significant drops in CO and THC concentrations for both engine-generators, while fuel consumption showed a slight upward trend; the increases in applied loads resulted in an increase in CO and THC concentrations and fuel consumption. In general, a higher AEA content (oxygenated) in the blends had a greater effect on gaseous emissions compared to the effect on consumption and system efficiency.

Keywords Biofuels · Combustion assays · Exhaust emissions · Otto-cycle engines · Oxygenated additive · Renewable energy

Abbreviations

A/F	Air/fuel
AEA	Anhydrous ethyl alcohol
CO	Carbon monoxide
E%	Percentage of ethanol added to the gasoline
HC	Hydrocarbons
NO _x	Nitrogen oxides
SI	Spark ignition

Introduction

Concern over the reduction or even the future depletion of non-renewable energy sources such as crude oil/petroleum associated with the environmental damage resulting from its use has contributed to the adoption of new energy sources (Agarwal 2007; Elfasakhany 2016). In Brazil, initiatives for the synthesis and commercialization of alternative fuels began in the 1970s with the use of ethanol motivated by the National Alcohol Program (Proálcool), with the objective of reducing dependence on fossil fuels in vehicles (Costa, Pereira and Aranda 2010).

Ethanol is a renewable fuel, and it represents an alternative to gasoline in Otto-cycle engines. Many studies also point to a significant reduction in the emission of pollutants into the atmosphere with the addition of ethanol mixed with gasoline (Agarwal 2007; Clairotte et al. 2013; Ghazikhani 2013; Iodice and Senatore 2014; Masum et al. 2015; Najafi et al. 2015). Schirmer et al. (2017) found emissions of CO, HC and NO_x in a single cylinder four-stroke engine with 4.85 kW of maximum power, using pure gas formulations mixed at 5, 10, 15, 20, and 25% v/v (E5, E10, E20 and E25) of AEA and different

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A/F ratio conditions admitted into the engine cylinder (determined by the lambda factor). The authors showed that the addition of AEA to gasoline contributed to reducing emissions of polluting gases for all lambda conditions adopted. Li et al. (2015) conducted tests with pure gasoline and gasoline mixed with 10% v/v AEA (E10) in three single cylinder engines (four-stroke), with volumetric displacement of 110, 125, and 150 mL and equipped with a carburetor. The emission factors for THC and CO for E10 showed reductions of 26–45% and 63–73%, respectively, compared with engines fueled with pure gasoline. According to the same authors, the oxygen content of AEA is 34.8%, which makes combustion more complete, significantly reducing THC and CO. Yao, Tsai and Wang (2013) evaluated the effect of mixing 15% v/v of AEA mixed with gasoline in two types of four-stroke single cylinder engines; one system was equipped with a carburetor and the other with fuel injection. Reductions in CO concentrations emitted by both engines were observed when the E15 blend was subjected to combustion when compared to emissions from engines running on pure gasoline.

In the case of Brazil, in addition to the environmental issue, it is important to highlight the country's territorial potential and climatic conditions for cultivating sugarcane for the production of ethanol, facilitating its social and economic acceptance. Moreover, sugarcane has a high rate of growth and CO₂ fixation; during the species' growth cycle, the amount of CO₂ fixed with photosynthesis is equivalent to the total amount generated in the production and use of ethanol (Garcez and Vianna 2009; Costa, Pereira and Aranda 2010).

Driven by the multiple potential benefits of using ethanol as a transportation fuel at the national level, studies involving the production and use of renewable fuels have been gaining increasing proportions. In this context, the present study proposes to evaluate the performance and gaseous emissions resulting from the combustion of gasoline and its blend with different levels of anhydrous ethyl alcohol (AEA) under different operating conditions in two engine-generator systems (13 and 6.5 hp).

Material and methods

Fuel blends and physicochemical analyses

The tests used anhydrous ethyl alcohol (AEA), gasoline type A (E0) and gasoline type C (E27) fuels. Brazilian legislation currently establishes the addition of AEA to Type A gasoline by 27% ($\pm 1\%$) (Mapa 2015). In order to verify the influence of AEA on fuel consumption, engine-generator system efficiency, and gaseous emissions, we also chose to include the 10 and 20% v/v levels of AEA added to gasoline type A (respectively represented by E10 and E20).

The parameters MON (motor octane number) and RON (research octane number) were determined, as well as the concentration (%) of hydrocarbons (olefinic, aromatic, saturated) and oxygen compounds present in each sample's composition. Analyses of physical-chemical parameters were carried out using the ERASPEC fuel analyzer, with infrared spectrometer (FTIR) (Eralytics 2017). These parameters are directly associated with the quality of combustion and therefore with gaseous emissions from the engine.

Characteristics and assembly of equipment for combustion tests

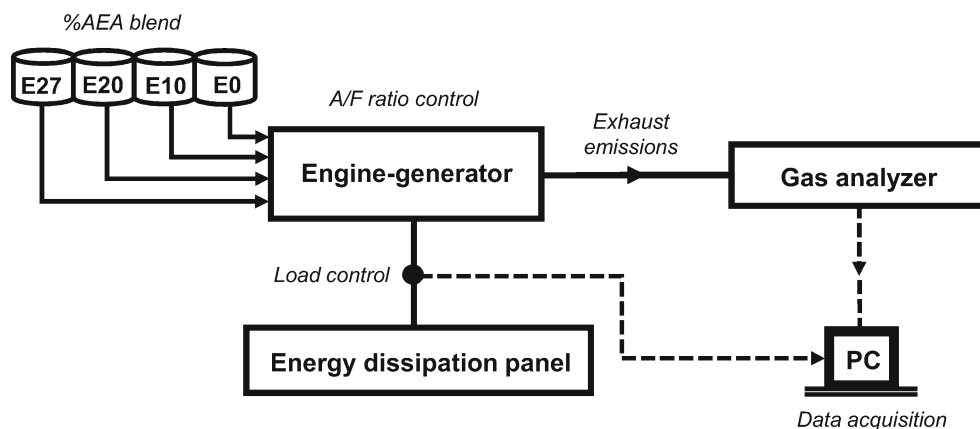
The experimental apparatus consisted of the following items: 2 groups of engine-generators with different powers (13 and 6.5 hp), an energy dissipation panel, a digital clamp multimeter, an automatic gas analyzer, an infrared digital thermometer, a precision digital scale and a computer for data acquisition. Figure 1 shows the schematic diagram of the experimental apparatus.

The engine-generators used single cylinders, four-stroke cycles, were equipped with a carburetor and manual throttle for the mechanical control of the A/F ratio, with a volumetric displacement of 389 and 196 cm³, and reaching maximum power of 13 hp (9.69 kW) and 6.5 hp (4.85 kW), respectively (Toyama brand). The engines were coupled to generators with maximum operating power of 5.5 and 2.5 kVA (TG6500 and TG2800, respectively), both operating at 110 V and a frequency of 60 Hz in this experiment (Toyama 2017a; Toyama 2017b).

The energy dissipation panel was designed to ensure constant operating loads and consisted of 10 halogen lamps, each one with 0.3 kW of power (Olanyk 2013). The load applied by the panel (power dissipation generated by the dynamo of the generator) was measured by a digital clamp multimeter.

Measurement of gas concentrations was carried out using a PC-Multigas (NAPRO) gas analyzer used in vehicle inspections. The analyzer consists of a non-dispersive infrared detector (NDIR) for measuring CO, CO₂ and THC, with maximum measuring range of 15%_{v_{o1}} for CO and 20%_{v_{o1}} for CO₂, with a resolution of 0.01%; for THC, the maximum measuring range is 2000 ppm_v, with a resolution of 1 ppm (Napro 2017). Before the tests were carried out, the engine was kept in operation to warm for about 30 min, under a 0 W load. After the engine was warmed, the fuel mixture was added, once the lambda value and conditions had been made stable, the collection of CO and HCT concentration data started. The emission data collection was carried out in periods of 15 min for each test. The analyzer probe was attached close to the engine exhaust system

Fig. 1 Schematic diagram of the experimental setup



during the measurements; the acquisition of gas concentration data was obtained using the PC-MULTIGÁS software, installed on a portable computer connected to the system.

Combustion tests varying the lambda factor (λ), AEA content, and load applied to the engine-generators

The tests evaluated carbon monoxide (CO) and total hydrocarbons (THC) concentrations for the two engine-generators groups with different powers (13 and 6.5 hp) in relation to: the lambda factor variation (λ), the AEA content in gasoline (E0, E10, E20, and E27) and the loads applied to the systems (0, 260, 810, 1350, and 2000 W).

The lambda variation (λ) was performed by manually adjusting the throttle by dividing its course into three equidistant positions: partially open (lean mixture, $\lambda > 1$), intermediate (stoichiometric mixture, $\lambda = 1$), and partially closed (rich mixture, $\lambda < 1$). Lambda values for each throttle position were measured by the gas analyzer.

Literature shows that the variation of ethanol content in gasoline, lambda values, and/or loads applied to the engine-generator directly influence gaseous emissions in Otto-cycle engines, hence the choice for (investigating) such factors in the present study (Chen et al. 2011; Ghazikhani et al. 2013; Heywood, 1988; Iodice and Senatore 2014; Koç et al. 2009; Li et al. 2015; Masum et al. 2015; Najafi et al. 2015; Zhu et al. 2017; Yao, Tsai and Wang 2013).

Checking engine-generator consumption and performance

For all condition load applied to the engine-generators (0 to 2000 W) and for each blend of gasoline A and AEA (E0 to E27), measuring the mass consumption of fuel in both engine-generator systems (6.5 and 13 hp) was carried out by setting the lambda value close to the unit ($\lambda = 1$). The procedure for determining the mass consumption (in duplicate) was performed by comparing the initial and final fuel mass (after the

tank was depleted) after the engine running for periods of 10 min, using Eq. 1.

$$C_{m_n} = \frac{(M_{n-1}) - (M_n)}{t} \quad (1)$$

where C_{m_n} is the mass consumption [g min^{-1}] of the n period; M_{n-1} is the mass at the beginning of the period [g]; M_n is the final mass [g] and t corresponds to the 1-min test period [min].

With the values of mass consumption and variations in the load conditions applied to the engine-generators, data on the specific fuel consumption [$\text{g} \cdot (\text{kWh})^{-1}$] for each blend were obtained according to Eq. 2 (Masum et al. 2015).

$$bsfc = (C_m) \cdot P^{-1} \quad (2)$$

where $bsfc$ [$\text{g} \cdot (\text{kWh})^{-1}$] is the specific fuel consumption and P (W) is the output power.

Higher calorific values (HCV) on a dry basis were obtained according to the standard ASTM E711/2004, and lower calorific values (LCV) were calculated according to these values. Based on the mass consumption and LCV values, the fuel energy consumption of each blend was determined according to Eq. 3 (Conde 2007).

$$C_{en} = C_m \times LCV \quad (3)$$

where C_m is the mass consumption [$\text{g} \cdot \text{min}^{-1}$]; C_{en} is the energy fuel consumption [$\text{cal} \cdot \text{min}^{-1}$]; LCV is the lower calorific value [$\text{cal} \cdot \text{g}^{-1}$].

Finally, according to Silva et al. (2012), the efficiency of engine-generators systems (conversion of chemical energy to the generation of electricity) was evaluated using Eq. 4.

$$\eta = \frac{3600}{LCV \times bsfc} \times 100 \quad (4)$$

where η is the system efficiency (%); LCV is the lower calorific value of the fuel blend (MJ kg^{-1}).

Statistical analysis of the experiment

The analyses were performed in the STATISTICA® software with the data in a completely randomized design. The gas concentrations (CO and THC) were analyzed by analysis of variance (ANOVA) with 3 factors (fuel composition, loads applied and lambda values) in a factorial arrangement. The consumption data (mass, specific and energy) and engine-generator efficiency were tested by ANOVA with one factor (one-way ANOVA). In both cases, the presumption of normality and homogeneity of variance were checked by the Shapiro–Wilks and Bartlett tests.

Pearson correlations were performed to test the similarity between the engine-generators (13 and 6.5 hp), and $\alpha = 0.05$ was assumed for all statistical analyses.

Results and discussion

Chemical composition and octane rating of gasoline and AEA blends

Table 1 shows olefin, aromatic, and saturated hydrocarbon contents and oxygenated compounds, octane numbers (MON and RON), higher calorif values (HCV) as well as specific gravities (SG) of gasoline type A and blends of gasoline and AEA.

Gasoline type A (E0) is predominantly composed of hydrocarbons belonging to the olefin, aromatic and saturated hydrocarbon classes (formed by chains of 4 to 12 carbon atoms). The addition of AEA (C₂H₅OH) to gasoline implies changes in its chemical composition, volatility properties, and in the octane number of the fuel blends, also presenting a close relationship with the stoichiometry of the combustion reactions. The different levels of AEA in gasoline result in a “pre-mixed oxygen effect” to the fuel blend; therefore, the higher the AEA content, the greater the mass of oxygen concentration in the blend subjected to combustion (Ceviz and Yuksel 2005; Koç et al. 2009).

Table 1 Chemical composition data, octane numbers, HCV and SG for E0 to E27

Chemical characteristics (%)	E0	E10	E20	E27
Olefin	13.6	13.2	12.5	7.8
Aromatic	15.4	13.3	13.9	11.7
Saturated	71.0	63.2	53.9	53.9
Oxygenated	0.0	10.3	19.7	26.6
(MON+RON)/2	88.1	89.3	90.8	92.5
HCV (Kcal/g)	9.61	8.62	8.33	8.51
SG	0.718	0.722	0.731	0.739

According to Table 1, octane numbers increased as the AEA content was increased. The higher auto-ignition capacity and the latent heat of vaporization of AEA (923 KJ/Kg) compared to that of gasoline (349 KJ/Kg) justify the increase in the octane numbers of E10, E20 and E27, in this order. Overall, higher octane numbers in the blend may imply in a higher quality of the combustion process, reducing concentrations of carbon monoxide and hydrocarbons (unburned or partially burnt) issued by the engine-generators (Anderson et al. 2012; Koç et al. 2009).

Evaluation of gaseous emissions by varying the engine power, lambda values (λ), AEA-gasoline blend, and load applied to the engines

THC and CO concentrations—13 hp engine

THC and CO concentrations for all lambda values (λ), fuel blends and loading conditions are shown in Fig. 2 (a: $\lambda > 1$; b: $\lambda = 1$; c: $\lambda < 1$) and 3 (a: $\lambda > 1$; b: $\lambda = 1$; c: $\lambda < 1$).

Although there is a high significance for all statistically analyzed factors, the lambda variation values ($F_{(THC)\lambda} = 1428.74$; $p < 0.01$); ($F_{(CO)\lambda} = 953.39$; $p < 0.01$) resulted in a greater effect on the concentrations of both gases (THC and CO), followed by the variation of the blends ($F_{(THC)blends} = 1240.85$; $p < 0.01$); ($F_{(CO)blends} = 672.37$; $p < 0.01$) and of the loads ($F_{(THC)load} = 1061.06$; $p < 0.01$); ($F_{(CO)load} = 435.20$; $p < 0.01$).

According to Heywood (1988), the formation of the polluting gases THC and CO present similar behavior. In other words, variations of lambda value (λ) increased AEA content in fuel blends and increased load applied to the engine are factors that influence both unreacted THC emissions (unburned or partially burned) and in CO emissions formed from poor combustion.

According to Figs. 2 and 3, the minimum concentration values for THC and CO were found for λ values above the unit, in which the condition of greater equilibrium between the oxidant and fuel parts was observed. As the stoichiometric values of the reactions changed and the lambda factor decreased, the oxidant concentration became insufficient to oxidize all the chemical fuel energy (excess fuel in the A/F blend), implying in the loss of equilibrium in the combustion reactions and in the engine operation quality; thus, THC (unburned or partially burnt) and CO concentrations reached their maximum values under these conditions (Brunetti 2012; Heywood 1988; Manahan 2005). The lowest THC and CO concentrations observed for the λ values above the unit and for blends with higher levels of AEA may be associated with two factors acting together, both resulting from the addition of oxygen to the combustion (change in the combustion reactions’

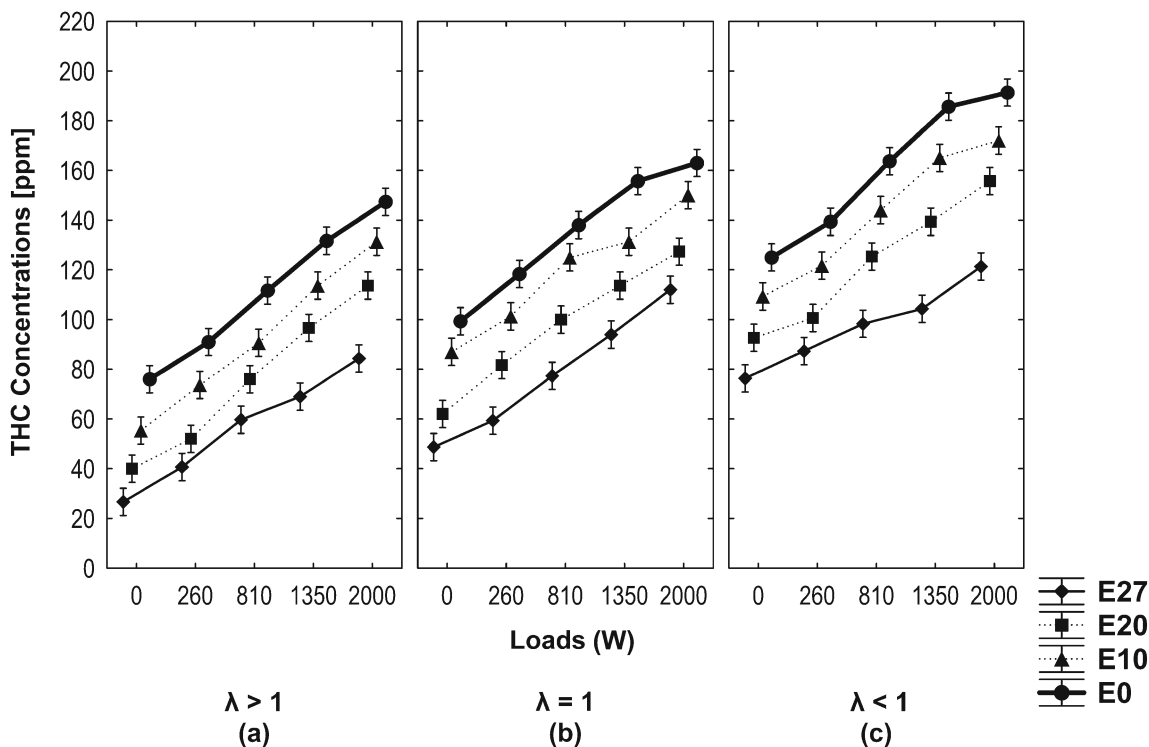


Fig. 2 THC concentrations varying the content of AEA in the gasoline and the load applied to the system, for conditions of $\lambda > 1$ (a), $\lambda = 1$ (b), and $\lambda < 1$ (c)

stoichiometric values). The first factor concerns the opening of the engine throttle, releasing an admission of greater oxidizing volumes to the combustion; the

second factor refers to the relative stoichiometric ratio of AEA (9) being lower than gasoline (15), considering that the AEA has on average 35% oxygen mass in its

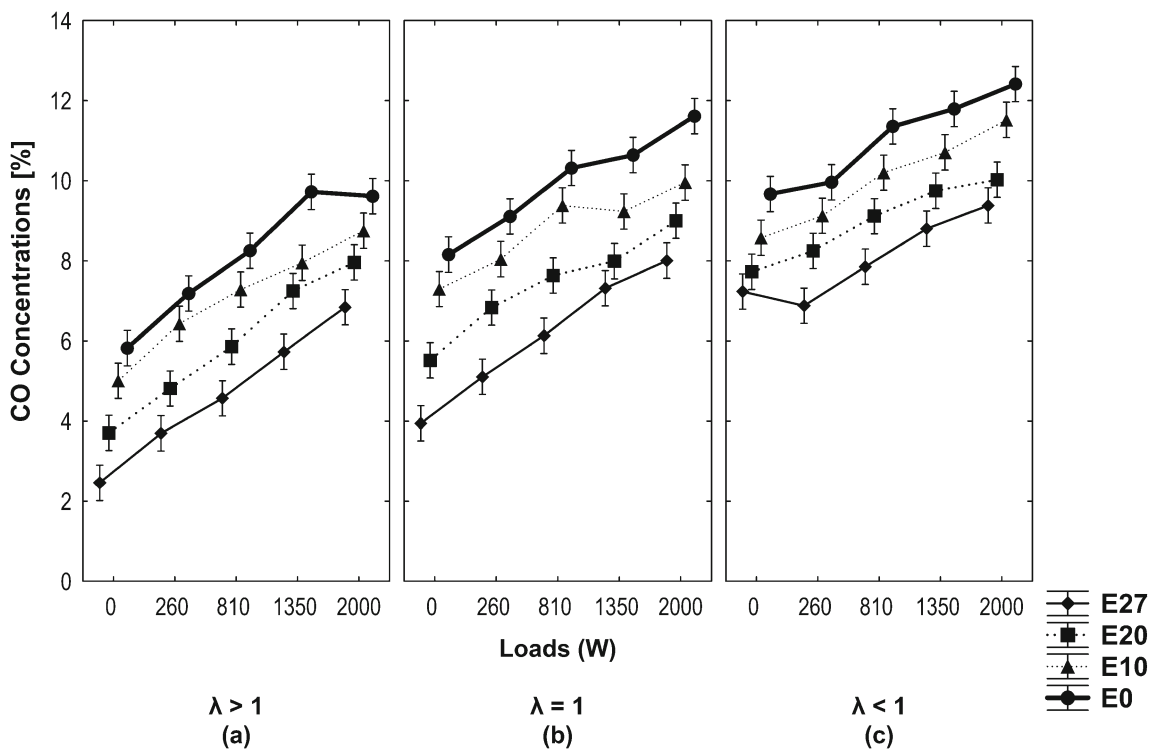
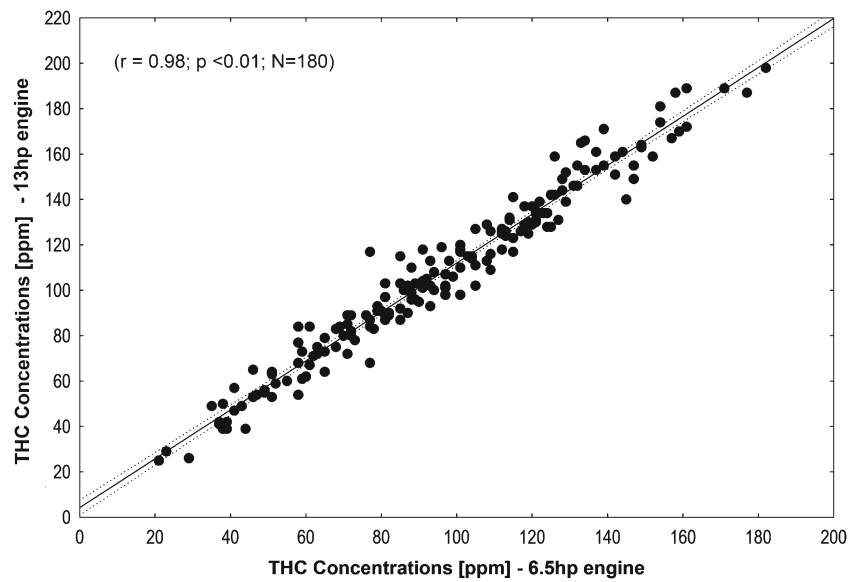


Fig. 3 CO concentrations varying the content of AEA in the gasoline and the load applied to the system, for conditions of $\lambda > 1$ (a), $\lambda = 1$ (b), and $\lambda < 1$ (c)

Fig. 4 Correlation of THC concentrations between the 13 and 6.5 hp engines



composition, while gasoline is predominantly composed of hydrocarbons (Koç et al. 2009). In this case, a greater oxygen mass content in the fuel contributes to the oxidation of the HC into CO₂.

In addition to the pre-mixed oxygen effect, the addition of ethanol to gasoline is also associated with other effects that justify reduced emitted THC and CO concentrations: reduced ignition time and improved combustion stability due to higher laminar flame speeds and higher internal pressures in the engine cylinder; improvement in the equilibrium and combustion efficiency due to reduced HC heavy fractions and better evaporation of AEA-gasoline blends (latent heat of evaporation and octane number in AEA-gasoline blends are higher

than in pure gasoline) (Turner et al. 2011). Other studies have also found a reduction in THC and CO concentrations (in Otto cycle engines) by adding oxygenated fuels to gasoline (Balki, Sayin and Canakci 2014; Gravalos et al. 2013; Koç et al. 2009; Masum et al. 2015; Thangavel et al. 2016; Yao, Tsai and Wang 2013; Zhu et al. 2017).

Regarding the behavior of THC and CO concentrations as a function of the load variation, an increase in the load applied to the engine leads to admitting higher fuel content per unit of time in the engine cylinder (increase in the mass consumption of fuel), supplying the demand for higher engine axis rotations and higher magnetic field intensities of the generator (Barakat, Awad and Ibrahim 2016; Olanyk 2013). In the present study,

Fig. 5 Correlation of CO concentrations between the 13 and 6.5 hp engines

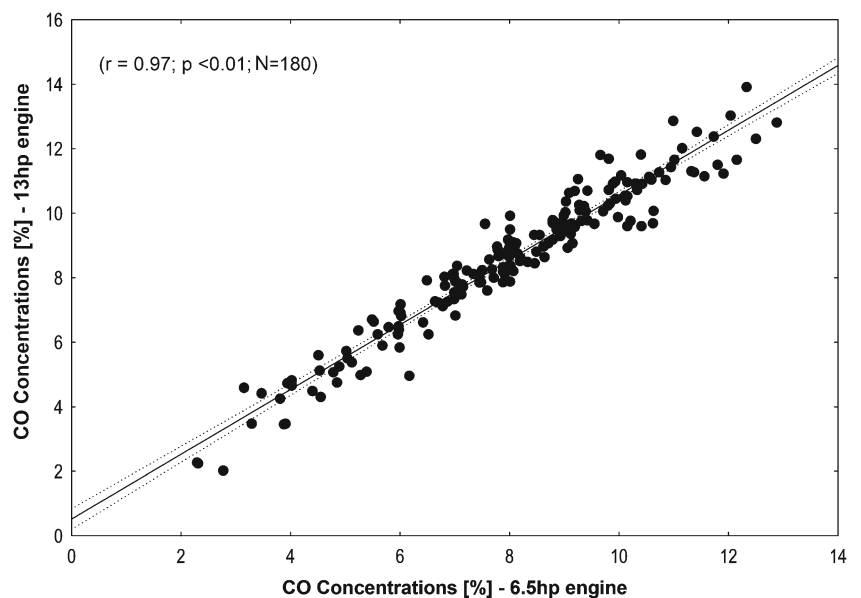


Table 2 Mass, specific and energy consumption and system efficiency for gasoline and AEA blends as a function of load variation

Parameters	Load (W)	Blends			
		E0	E10	E20	E27
C_m^a (g/min)	260	10.35 ± 0.24	11.90 ± 0.01	12.57 ± 0.26	13.76 ± 0.13
	810	12.70 ± 0.20	14.33 ± 0.12	15.39 ± 0.37	16.58 ± 0.04
	1350	15.43 ± 0.24	16.37 ± 0.25	17.30 ± 0.19	18.59 ± 0.25
	2000	17.77 ± 0.04	19.22 ± 0.21	20.88 ± 0.12	21.99 ± 0.01
$bsfc^b$ (g/kWh)	260	2.39 10 ² ± 55.5	2.74 10 ² ± 3.5	2.90 10 ² ± 60.0	3.18 10 ² ± 31.0
	810	94.10 ± 15	1.06 10 ² ± 8.5	1.14 10 ² ± 31	1.30 10 ² ± 2.5
	1350	68.57 ± 14.5	73.70 ± 11.5	76.89 ± 8.0	82.62 ± 11.0
	2000	53.31 ± 1.5	57.66 ± 6.0	62.64 ± 3.5	65.97 ± 0.0
C_{en}^c (cal/min)	260	9.14 10 ⁴ ± 2118.95	9.32 10 ⁴ ± 117.60	9.49 10 ⁴ ± 1963.38	10.64 10 ⁴ ± 1043.96
	810	11.21 10 ⁴ ± 1765.79	11.23 10 ⁴ ± 901.57	11.62 10 ⁴ ± 2831.81	12.82 10 ⁴ ± 270.65
	1350	13.62 10 ⁴ ± 2118.95	12.99 10 ⁴ ± 1999.12	13.06 10 ⁴ ± 1434.78	14.37 10 ⁴ ± 1894.59
	2000	15.67 10 ⁴ ± 441.45	15.05 10 ⁴ ± 1567.94	15.76 10 ⁴ ± 868.42	17.01 10 ⁴ ± 38.67
η^d (%)	260	4.51 ± 0.44	4.48 ± 0.48	4.03 ± 0.10	4.19 ± 0.69
	810	10.19 ± 0.17	10.68 ± 0.34	10.27 ± 0.29	8.79 ± 0.24
	1350	14.60 ± 0.40	14.99 ± 0.11	15.06 ± 0.25	13.84 ± 0.38
	2000	18.43 ± 0.16	19.45 ± 0.43	18.48 ± 0.31	17.33 ± 0.48

^(a) No statistically significant difference was found between the mass consumption data varying the blends ($F = 1.93$; $p = 0.14$); a statistically significant difference was found varying the loads ($F = 51.60$; $p < 0.01$)

^(b) No statistically significant difference was found between $bsfc$ data varying the blends ($F = 0.18$; $p = 0.91$); a statistically significant difference was found varying the loads ($F = 289.04$; $p < 0.01$)

^(c) No statistically significant difference was found between energy consumption data varying the blends ($F = 0.64$; $p = 0.59$); a statistically significant difference was found varying the loads ($F = 75.86$; $p < 0.01$)

^(d) No statistically significant difference was found between system efficiency data by varying the blends ($F = 0.08$; $p = 0.97$); a statistically significant difference was found varying the loads ($F = 298.46$; $p < 0.01$)

the higher the fuel consumption (due to the increase of the applied load), the higher the CO and THC (unburned or partially burnt) concentrations.

Correlation between gaseous emissions and the engine-generator system (13 and 6.5 hp)

The graphical representation of the correlation analyses between the THC and CO concentrations emitted by both engine-generators for the same factors and the same response-variables are shown in Fig. 4 (THC emissions) and Fig. 5 (CO emissions).

From Figs. 4 and 5, a correlation ($r_{THCconcentrations} = 0.98$) ($r_{COconcentrations} = 0.97$) between the gaseous emission data obtained for both engines (13 and 6.5 hp) using the same factors (lambda, blend and load) and the same response-variables (THC and CO concentrations) can be observed; therefore, there was no statistical difference. In summary, the gaseous emissions from the exhaust system of both engines presented the following tendencies: significant reduction in THC and CO concentrations as the AEA content in gasoline increased; significant increase in THC and CO concentrations with enrichment λ and load increase up to 2000 W.

Performance evaluation of the engine-generator set

Mass, specific and energy consumption and system efficiency—13 hp engine

Table 2 shows the performance parameters for the engine-generator system for the E0, E10, E20 and E27 blends, varying the load applied to the engine.

In general, the addition of AEA to the blend did not imply in a statistically significant variation in fuel consumption and system efficiency for all loads applied to the engine-generator. Nevertheless, a slight tendency of increase for mass, specific and energetic consumption and reduced efficiency of the system was observed when AEA is added to the blend; this effect is due to the lower LCV of oxygen compounds in relation to HC (Gibbs et al. 2009; Wu et al. 2004). According to Channiwala and Parikh (2002), the LCV of liquid fuels directly depends on its elemental base (chemical composition), in which carbon and hydrogen are the largest contributors to heat generation in combustion.

The trend of a significant increase in mass and energy consumptions with the increase of the load applied to the engine for all analyzed blends can be justified by the

demand for higher torques in the engine axis and higher magnetic field intensities of the generator under conditions of higher loads (Barakat, Awad and Ibrahim 2016; Olanyk 2013). Also (according to Table 2), a significant reduction of the *bsfc* and a significant increase in the system efficiency were observed with the increase of the load applied to the engine for all analyzed blends; approximately 20% (conversion of chemical energy into electricity) was reached at the load of 2000 W, regardless of the fuel blend used. This behavior shows that the system efficiency was more sensitive to load variation compared to the blend variation. The variation in the system efficiency regarding the applied load is justified by the better thermodynamic utilization of fuel under conditions of higher loads. This means higher torques in the engine axis increase inertial tension and mechanical efficiency of the rotor; this behavior is related to the smaller efforts to pump the gases from inside the combustion chamber, as well as lower attrition forces of the internal moving parts of the engine (Heywood 1988).

Correlation between performance data of 13 and 6.5 hp engines

The correlation between the performance data obtained for the two engines (13 and 6.5 hp) was verified, adopting the same factors (blend and load) and the same response-variables (mass consumption ($r = 0.96$), specific consumption ($r = 0.99$), energy consumption ($r = 0.96$), and system efficiency ($r = 0.98$)). In summary, the performance data of both engine-generator sets presented the following trends: a slight increase in the mass, specific and energetic consumptions and a slight reduction in the system efficiency as the AEA content in the gasoline increased; a significant increase in mass and energy consumption and system efficiency, and a significant reduction in the *bsfc* with an applied load increase to the engine up to 2000 W.

Overall, the conditions for emission and performance testing required lower torques on the 13 hp engine axis compared to the 6.5 hp engine due to the larger capacity to perform work per unit of time (higher power) in the more powerful engine. However, this difference in power and capacity did not imply in statistically significant variations between the emissions data and the performance of the two engines. According to Brunetti (2012), the exhaust gas concentrations, as well as the efficiency of Otto cycle engines, mainly depend on the quality of the A/F blend, the type of fuel and the engine operating conditions. In the present study the A/F blends, the loads applied to the engines and the fuels used were the same for both the single cylinder and the fuel intake system, resulting in similar trends in THC and CO concentrations and performance in both engines, regardless of their power.

Conclusions

The addition of AEA to gasoline increases the concentrations of oxygenates in the chemical composition of the blends; this behavior implied in higher quality combustion reactions and significant reductions in THC and CO emissions, as well as a slight increase in mass, specific and energetic fuel consumptions and reduced systems efficiency; nonetheless, the statistical analyses showed that this trend of variation in fuel consumption and engine-generator efficiency was not significant.

For both engine-generators, the depletion of the A/F blend (increase in lambda value) resulted in statistically significant reductions in the emitted THC and CO concentrations. In addition, the increased load applied to engine-generators led to a significant increase in THC and CO concentrations and in mass and energy consumptions.

No statistical difference was observed between the emission data and engine-generators performance, adopting the same factors and variables-responses. These results indicate that even under conditions of minor rotation intensities applied to the axis of the 13 hp engine (when compared to the 6.5 hp engine) for any operational condition of the engine-generators, the conversion of chemical energy into electricity was very similar between the engines, regardless of their power.

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