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GAS EMISSION AND EFFICIENCY OF AN ENGINE-GENERATOR SET RUNNING ON BIOGAS

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ABSTRACT: In Brazil there is a wide availability of residues, which have been used in the production of biogas and biofertilizers. The engine-generator by biogas is grid connected, and produce electricity for self-consumption and the surplus is inserted into the grid. The aim of the present study was to evaluate energetic efficiency and exhaust gas emission of two cases: two engine-generators sets of 100 kVA running on biogas, produced from residues of a poultry slaughterhouse unit (PSU) and swine fattening unit (SFU). Load variation in the engine-generator set was evaluated in the *SMCP* (system of protection and synchronism). There was an increase in the emission of nitrogen oxide, sulfur dioxide and exhaust gas temperature, in both cases. The elevation in the load of the engine-generator increased its global efficiency (mechanical plus electric), with levels between 6.12% with load of 10 kW and 20.91% with 70 kW. The average specific consumption of biogas in the load of 70 kW was 0.76 m^3 kWh^{-1} in the swine fattening unit and 0.80 m^3 kWh^{-1} in the slaughterhouse unit with load of 70 kW. The last results show an engine-generator on biogas of 100 kVA (load of 70 kW), spent an average of 1.4 m^3 of biogas to produce 1.0 kWh of electricity.

KEY WORDS: biofuel, energy efficiency, organic waste, gas emission.

INTRODUCTION

Even though the Brazilian energy supply is dependent from non-renewable energy sources, such as oil, natural gas and mineral charcoal, renewable sources as biomass, hydraulics, firewood, vegetal charcoal, lixivium and other sources, are responsible for 39.4% of the internal energy supply (MME, 2015). Biomass is an abundant renewable source of energy that may be derived from all organic matters produced by human and natural activities, including industrial residues, as well as urban, forest, agricultural and animal solid residues (IVES et al., 2013; KOHL et al., 2014; KYLILI; FOKAIDES, 2014; WYMYSLOWSKI et al., 2010).

In Brazil, the PROINFA (Program of Incentive to Alternative Sources of Energy) aims to stimulate the production of decentralized electric energy by independent and self-producers. The extension of thermoelectric generation with biomass is one of the PROINFA's goals. In that sense, it came up an opportunity for systems of electric energy generation that use biogas as primary energy source to be implemented in rural properties and agro industries, for self-consumption and grid connection (SOUZA et al., 2013).

Organic waste from livestock and slaughterhouses can be treated in anaerobic digestion systems, resulting in by-products of biogas and biofertilizers. MARCOS et al. (2012) emphasize that organic wastes from livestock and slaughterhouses of poultry are among the most contaminating products in the meat industry. According to LI et al, (2014) the manure of swine production has an elevated polluting potential, and it needs to be treated before being disposed in the environment, soil and water. The best treatment of then is the anaerobic digestion, that reduces the organic loads of these animal polluting residues, producing the gaseous biofuel, biogas, and an

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effluent that can be used as biofertilizer in crops, where allows the cycling of nutrients, such as nitrogen, phosphorus and potassium (NUNES et al., 2011; MIAO et al., 2013; CHERUBINI et al., 2015).

The main gas component in biogas is methane (CH_4), which presents global warming potential around 21 times stronger than carbon dioxide (CO_2). Electricity generation with engine-generator, using biogas as fuel, has been one of the best forms of mitigating the emission of methane and promoting the reduction of the greenhouse effect (WHITING & AZAPAGIC, 2014; YASAR et al., 2014), and has been widely identified as an efficient mechanism to generate electrical power based on renewable energy sources. The biogas consists of a mix of gases at different concentrations, as shown in Table 1. The type of feedstock influences in the concentration and quantity of gases generated (JÚNIOR et al., 2010).

TABLE 1. Components and percentage of gases on biogas.

Gas component	IGONI et al., (2008)	SALOMON & LORA (2009)	HUANG & CROOKES (1998)	MACIEL (2003)
Methane (CH_4)	55-75%	40-75%	50-70%	45-60%
Carbon dioxide (CO_2)	30-45%	25-40%	25-50%	35-50%
Hydrogen sulphide (H_2S)	1-2%	Traces	Traces	-
Nitrogen (N_2)	0-1%	Traces	0.3-3%	0-10%
Hydrogen (H_2)	0-1%	Traces	1-5%	<0,1%%
Carbon monoxide (CO)	Traces	Traces	-	<0.1%
Oxygen (O_2)	Traces	Traces	-	0-4%

The exploitation of biogas may occur as direct burning for thermal energy production or in electricity generating engines. In that sense, hydrogen sulfide must be removed from the biogas to avoid the corrosion of the energy generation system. Its purification might be obtained by processes of dry oxidation, adsorption, biotreatment and chemical absorption. Carbon dioxide is an inert gas in biogas, and as high its concentration as small the lower heating value (LHV) of biogas (SUN et al., 2015).

In the processes of biogas burning, pollutant gases are generated, such as nitrogen oxide, mainly when the mixture air-fuel has little oxygen or when high temperature peaks occur during the process of burning. Nitrogen oxide reacts with the oxygen in the air and results in nitrogen dioxide; such reaction is initiated by the sunlight (SHALAJ et al., 2015). INATOMI & UDAETA (2007) report that this gas is one of the responsible for the greenhouse effect, and also that it may be carried by the wind to distances up to one 1000 km away from the transmitter, causing acid rains in places that are distant from the source.

The present study aimed to evaluate the efficiency of electric energy generation and gas emission in two engine-generator sets of 100 kVA, running on biogas produced by the anaerobic digestion of biomass from swine effluents (case 1) and poultry slaughterhouses (case 2), with electric load variation in the engine-generator.

MATERIAL AND METHODS

The study was performed at a Swine Fattening Unit (SFU) and at a Poultry Slaughterhouse Unit (PSU), both located in the west region of the State of Paraná – Brazil. The SFU is located in São Miguel do Iguaçú, Paraná, Brazil, and presents an average of 5,000 confined animals and the manure is treated in two biodigesters model plug flow of 925 m^3 and 231 m^3, which produce biofertilizers and biogas. The PSU (Poultry Slaughterhouse Unit) is located in Matelândia, Paraná, Brazil, and presents an operational capacity of 280,000 poultry/day and the residual biomass is processed by means of one plug flow biodigester of 28,000 m^3, producing biogas and liquid effluent treated.

The SFU and PSU units have an engine-generator each one, of 100 kVA (see Figure 1), producing self-electricity connected in grid, using biogas as fuel. The biogas produced in the biodigesters of each unit flows by pipe to feed the two engine-generators. Both units are composed by a gas engine Otto cycle MWM, 6 cylinders, cubic capacity 7.2 liters, running at 1800 RPM of angular velocity. The relation biogas/air mixture is electronically controlled by a sensor of oxygen produced in the gas emission that allows a better efficiency of the engine. The engine is linked with an electric generator model Gramaco/G2R 200 MB, 4 poles, with nominal rotation of 1800 RPM, with power of 100 kVA, frequency of 60 Hz, tension 220 V with three-phases and current of 270 A.

In this study were obtained parameters of performance and emission pollutant for both cases: Case 1, with the engine-generator operating in the SFU unit; Case 2, the engine-generator operating in the PSU unit.

The performance parameters evaluated were the specific consumption (SC) of biogas (m^3) per electricity (kWh) produced, rate m^3 kWh^{-1}, and the global efficiency (mechanical plus electrical) of the biogas engine-generators for both cases (case 1 and case2). The engine must be prepared according to the fuel, compression rate, air-fuel relation and ignition point. Such variables influence the total yield, effective power and specific consumption (SC). The SC (m^3 kWh^{-1}) of the engine-generator can be obtained with [eq. (1)]:

$$SC = \frac{Ch}{Ne} \qquad (1)$$

where,

Ch - consumption per hour of biogas by the engine, m^3 h^{-1};

Ne - effective electric load in the engine-generator, kW.

Figure 1 shows the general measuring scheme in both cases. In order to measure the consumption per hour of biogas by the engine, a thermal dispersion mass flow meter was used, model Thermatel TA2 Enhanced, with measurement band between 0.51 and 85 m^3 h^{-1}; by means of the SMCP (system of protection and synchronism) of the engine-generators, the electric load was varied and the C_h measured. In Case 1, SFU unit, the electric load was changed from 10 to 70 kW (10, 20, 30, 40, 50, 60, and 70 kW). In Case 2, PSU (Poultry Slaughterhouse Unit), the electric load was varied from 10 to 80 kW (10, 20, 30, 40, 50, 60, 70 and 80 kW). The SC of the engine-generator was obtained for each load. The measurements were performed within the period from 19 to 25 of April 2011, with four daily replications.

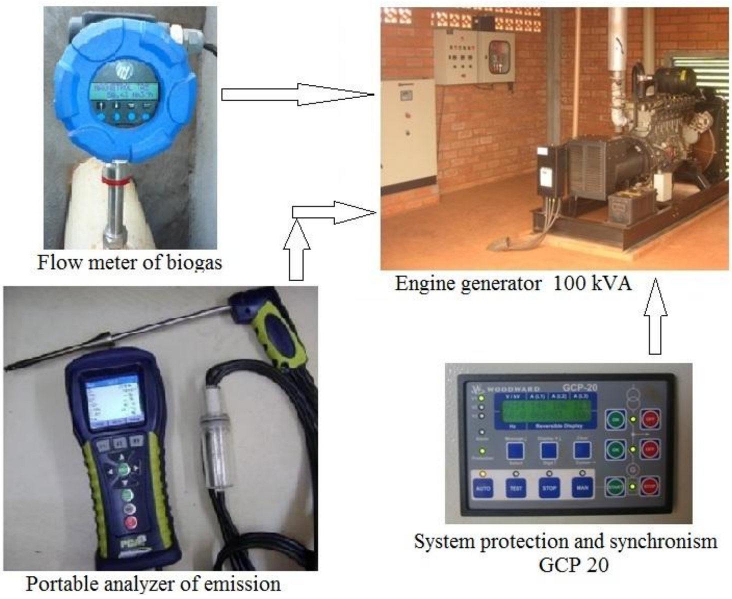

FIGURE 1. General measuring scheme of emission, consumption of biogas and electricity production in an engine generator of 100 kVA.

The global efficiency η_t (%) was obtained by [eq. (2)]:

$$\eta_t = \frac{100}{SC.\text{LHV}} \tag{2}$$

where,

LHV - biogas lower heating value, kWh m^{-3};

SC - specific consumption obtained by [eq. (1)], m³ kWh^{-1}.

Biogas, for being a mix of several gases, but mainly methane and carbon dioxide, has its heating value determined by the percentage of methane present. The lower heating value ($LHV_{Methane}$) of 1 m^3 of methane is 9.95 kWh m^{-3} (SOUZA et al, 2013). Then the LHV of the biogas (kWh m^{-3}) can be obtained by [eq. (3)]:

$$\text{LHV}_{\text{Biogas}} = \text{Percentage Methane} * \text{LHV}_{\text{Methane}} \tag{3}$$

where,

Percentage Methane - percentage of methane in biogas, % / 100;

$LHV_{Methane}$ - lower heating value of methane, kWh m^{-3}.

The percentage of methane was obtained with the Drager X-am 7000 gas analyzer, with simultaneous and continuous detection of up to five gases, and infra-red sensors for detecting carbon dioxide and hydrocarbons.

The pollutants measured in the exhaust gases, were nitrogen oxide (NO) and sulphur dioxide (SO_2), the concentration of them were obtained by means of a portable analyzer (*Bacharach PCA 3*), see Figure 1. The measurements were performed for different electric loads, as was done for performance.

A part of the hydrogen sulfide (H_2S) in biogas was removed using swarf filters installed in the inlet of the engine, which reacts with the iron forming iron sulfide. The concentration of H_2S in biogas will influence in the concentration of sulfur dioxide (SO_2) released by the engine.

RESULTS AND DISCUSSION

Figure 2 shows the concentration (ppm) of nitrogen oxide (NO) released in the exhaust gases from the engine-generators in different electric loads for both units: the slaughterhouse unit (SPU) and the SFU. Nitrogen oxide emission measured was 1023 ppm by the engine of slaughterhouse and 487 ppm in SFU engine, with 70 kW of load. Even though the emission was higher in the slaughterhouse, both sets elevated the emission of NO with load increase, which is related to the elevation of the average output temperature of the exhaust gases in the engine-generator sets (Figure 3), because it is formed in temperature peaks during the explosion in the natural cycle of internal combustion engines. The temperature the exhaust gases was measured with the probe temperature of the portable analyzer (Bacharach P*CA 3)* of emission.

The increasing load causes increases in the average temperature and its peaks, favoring its formation. LEE et al. (2010) when assessing generation efficiency and emissions of both nitrogen oxide and dioxide in an engine-generator set running on gasoline and operating with biogas at 60% methane, verified that the temperature increase leads to an elevation of nitrogen oxide emissions, and that by elevating the recirculation of exhaust gases, there is a decrease in the emissions of nitrogen oxide and dioxide as well as in mechanical energy generation.

HUANG & CROOKES (1998) carried out tests to improve generation efficiency and reduce emissions of nitrogen oxide and dioxide, by using ideal ignition intervals based on maximum generation efficiency with different recirculation rates of exhaust gases. The results showed that both NO_x emissions and generation efficiency decrease when the recirculation rate is increased.

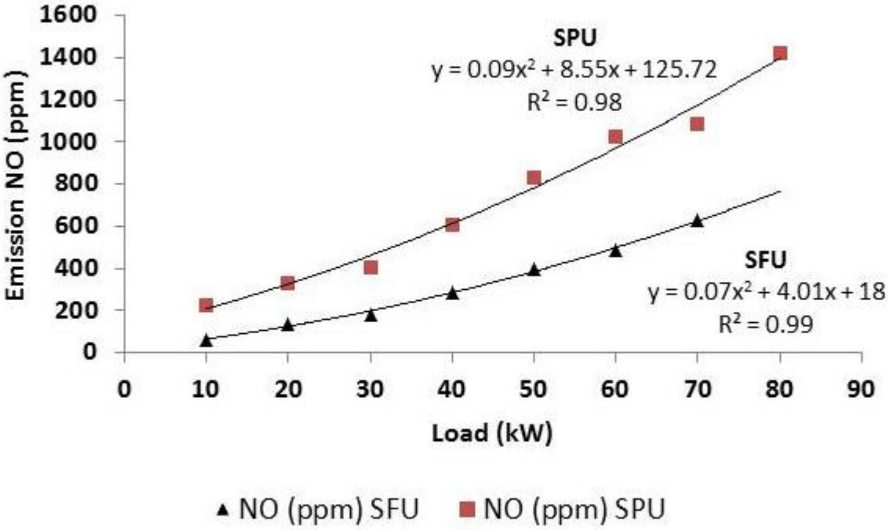

FIGURE 2. Nitrogen oxide (NO) emission in relation to load variation on the engine-generator sets at SPU and at SFU.

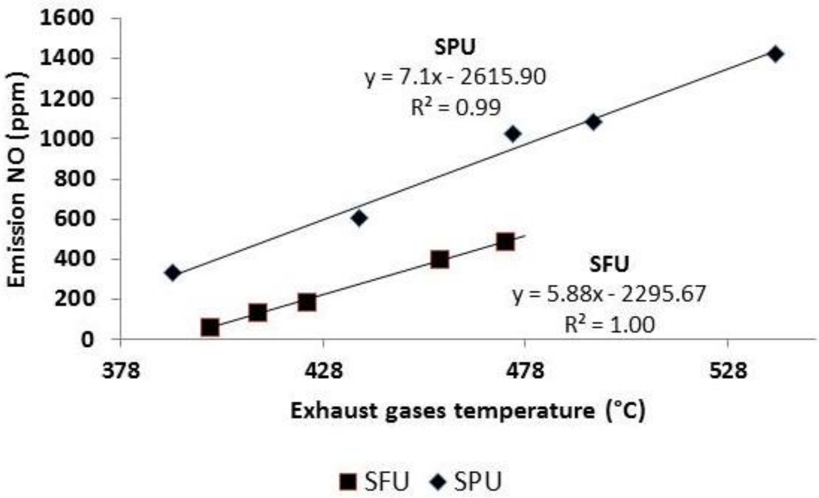

FIGURE 3. Variation of nitrogen oxide emissions with output temperature increase in the exhaust gases on the engine-generator sets at SPU and at SFU.

The figure 4 shows the emission of sulfur dioxide (SO_2), which is directly related to the quantity of hydrogen sulfide (H_2S) in the biogas used in the engine-generator. The emission of the engine at SFU was 1029 ppm, while the PSU engine indicated 265 ppm, with the same load, 70 kW. Such large difference is related to the amount of hydrogen sulfide in the biogas, given that one way of reducing sulfur dioxide emissions is by decreasing the concentration of hydrogen sulfide in the biogas used in the engine-generators.

During measurements of hydrogen sulfide (H_2S) concentrations performed at the SFU, it was possible to verify that the average concentration was 3258 ppm before the filter with crushed iron and 2712 ppm after the filtering process, what results in a reduction of 16.75% in the concentration of H_2S. At the SPU, the initial average concentration of H_2S was 1406 ppm before the biogas went through the filtering process and 483 after being filtered, presenting a reduction of 65% in the concentration of H_2S. The filters of the SPU and SFU have the same volume, but the amount (mass) of iron in the filter of the SFU was smaller, reducing its efficiency of remotion. In addition, the high concentration of hydrogen sulfide can damage the engine; the main problem could be the corrosion of internal components. According to WALSH et al. (1988) the higher concentration of H_2S will increase the emission of SO_2, and the maximum concentration of hydrogen sulfide in biogas that feed the engine with lower damage is 10 ppm (WALSH et al., 1988).

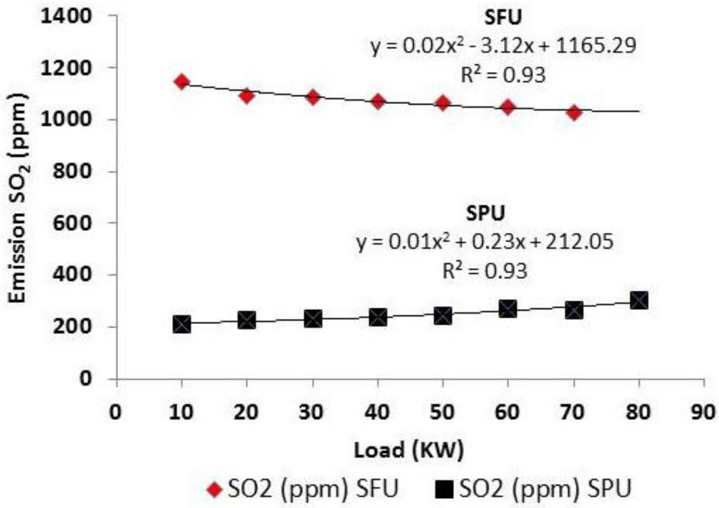

FIGURE 4. Emission of sulfur dioxide (SO_2) in relation to the load variation of the engine-generator set at both the SFU and the SPU biodigesters.

The average percentage of methane measured in biogas was 60% in the SFU and 70% in the SPU biodigester. Thus, applying equation 3, the lower heating value (LHV) of each biogas is 5.97 kWh m^{-3} at the SFU, and 6.97 kWh m^{-3} at the SPU. Under a load of 70 kW, the set at the SFU consumed 0.76 m^3 kWh^{-1} (specific consumption of biogas, SC) and the one at the slaughterhouse consumed 0.80 m^3 kWh^{-1} (see Figure 5), obtained by [eq. (1)]. Electric load variation led to a reduction in specific consumption of biogas in both cases (SC).

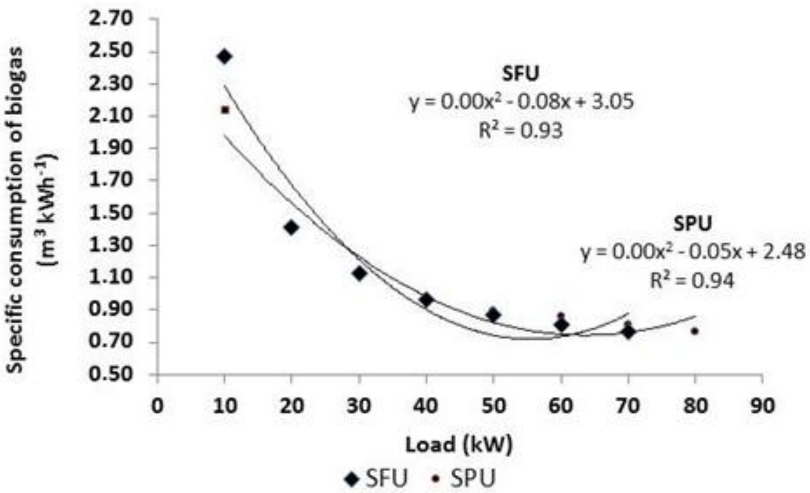

FIGURE 5. Specific consumption (m^3 kWh^{-1}) in relation to load variation on the engine-generator sets at the SPU and SFU biodigesters.

At lower loads the engine at SFU presented a higher specific consumption than the engine at SPU. However, at high loads the specific consumption was lower at the SPU when compared to the SFU. Figure 6 shows the global efficiency of both engine-generator sets, obtained by [eq. (2)]. When the load is increased, so is the electric energy generation efficiency of both sets. Generation efficiency at the SFU was 21.84 %, and 17.10% at the SPU with 70 kW of load.

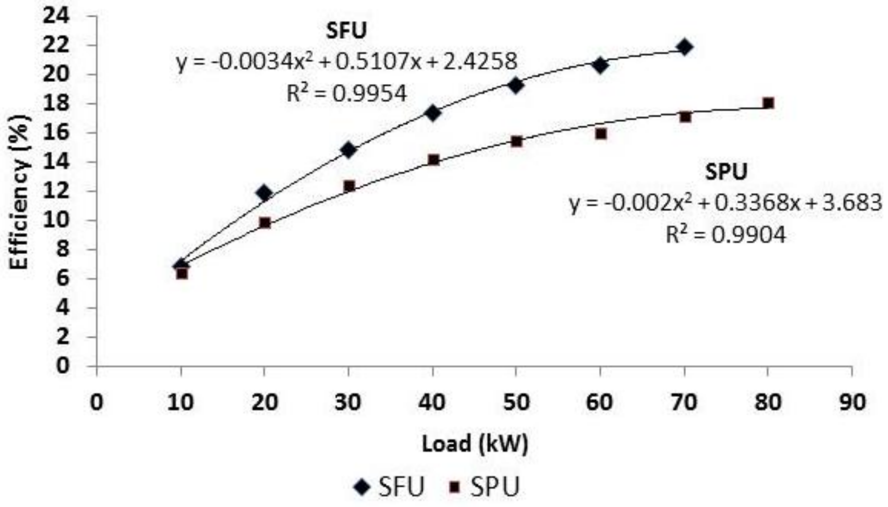

FIGURE 6. Electric energy generation efficiency with load variation at the SPU and SFU biodigesters.

CHANDRA et al, (2011), when assessing the specific consumption of biogas in internal combustion engines obtained similar results by using load variation and combustion angle variation. With load elevation there was a significant increase in engine performance. JEONG et al. (2009) found efficiency up to 26% in tests with internal combustion engines.

CONCLUSIONS

The emission of NO depends on the average output temperature of the exhaust gases, and increased with the load of the engine in both cases (SFU and SPU). Emission of sulfur dioxide depends on biogas quality. In the SFU, where the concentration of H_2S in biogas is higher the emission of SO_2 reached 1029 ppm at load of 70 kW, while the SPU engine indicated 265 ppm.

The importance of the study has been identifying the performance the generator engine during the biogas consumption. At full load, 70 kW, the engine generator of SFU unit consumed 0.76 m^3 kWh^{-1} (specific consumption of biogas, SC) and the one at SPU unit consumed 0.80 m^3 kWh^{-1}. With those results it is possible to conclude that the medium consumption of biogas by an engine generator can achieve 0.8 m^3 of biogas to produce 1.0 kWh of electricity, or 1.25 kWh produced for 1.0 m^3 of biogas consumed.

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