USE OF BIOGAS IN A SINGLE CYLINDER AIR-COOLED ENGINE POWER GENERATION UNIT

Olavo Miranda Martins, olavomm@gmail.com
Fabrício José Pacheco Pujatti, pujatti@demec.ufmg.br
Ítalo Lopes da Rocha, italolopesdarocha@yahoo.com.br
Ana Luísa Evaristo Rocha Petrini ,alpetrini@ufmg.br
Lívia Cristina Silva Lobato, lsilvalobato@yahoo.com.br
Carlos Augusto de Lemos Chernicharo, calemos@desa.ufmg.br
Universidade Federal de Minas Gerais - UFMG

Abstract.*The search for alternative energy sources that allows the reduction of Global Warming Gases emissions is becoming an important international market, for both carbon credits sales and renewable cheap power generation. On the other hand, the use of these sources often requires high investments and expensive technologies that still need a huge development. This work shows the results of a study which the main purpose is reduce the operational costs from the Research and Training in Sanitation Centre (CePTS), which treats domestic wastewater by biological and anaerobic ways, through the power generation. For this purpose, it was used a commercial power generation unit adapted to operate with biogas at atmospheric pressure. To improve the power generator performance, it was installed an electronic air/fuel mixture control unit, capable to vary the biogas flow according to the oxygen concentration on the exhaust manifold. The results shows a reduce of 13% on the fuel consumption compared with the original engine with biogas, for the same electrical power of 3,2 kW. It were also analyzed electrical power quality factors, such as frequency, mean voltage and harmonics, but both systems have presented similar oscillations on the frequency and the mean voltage.*

Keywords*: Biogas; Alternative Energy; Power Generation, Power Unit.*

1. INTRODUCTION

The biogas from biomass decompositionit is not largely used in power units, given that this fuel has low Lower Heating Value (LHV) compared with another fuels, is produced and available in lower pressures and there is no commercial small power units able to operate with this fuel in a optimized way.

On the other hand, biogas is a huge pollutant agent when untreated thrown at the atmosphere, once that its Global Warming Potential (GWP) is 21 times higher than the CO_2, making its treatment indispensible.

At brazilian wastewater treatment plants, the biogas is burned and the combustions products are thrown directly at the atmosphere. The energy generated is wasted, due to the high cost to build and operate a power cogeneration station and the economic return is limited. This situation have been improved along the years thank to the international carbon credit market and government incentives to reuse this energy.

This paper shows the results done at the Research and Training in Sanitation Centre (*CePTS*) to reuse the biogas in a power generator unit in order to obtain the best performance in terms of gas consumption and efficiency.

2. METHODOLOGY

For this work, a single cylinder power generator unit was used, which was designed to operate with gasoline and already adapted to work with biogas non-pressured. The power unit principals' mechanical and electrical parameters are shown in Tab 1. The daily biogas production in *CePTS* is around 8 m^3 which would limit the working hours for the experiments. Therefore, a compress system was developed, compressing biogas until 8 bar, and filtering it, reducing the H_2S concentration and humidity.

Table 1.Principals features of the power unit.

Stroke	4
Engine size	389 cm^3
Nominal speed	3600 rpm
Output voltage	110/220 V
Mechanical power with gasoline	9.70 kW
Electrical Power with biogas	3.60 kVA
Electrical power with gasoline	5.00 kVA

The experiments were divided in the following steps: power unit characterisation working with biogas, installation of an electronic flow control and performance evaluation, power unit characterisation working with gasoline, and comparison of the three cases. These steps are further described in the following topics.

2.1. Measurements

To evaluate the power generated by the engine, it was used a bank of electrical resistance to dissipate the electrical power. The resistances were mounted in the way shown in Fig.1, so it was possible to vary the electrical power dissipated, covert a wide range of the engine throttle position, and simulates load applied on the shaft. It was used a *Minipa electronic multimeter* to measure the voltage and current. The electrical power quality generated was evaluated in terms of the line frequency, measured with the electronic multimeter and harmonics at the maximum power, measured with a *Fluke Power quality analyzer* model 434.

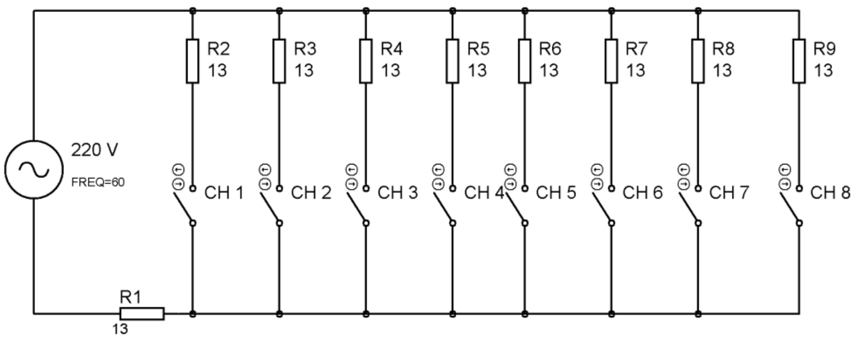


Figure 1. Resistive circuit used to dissipate the electrical power generated

The power dissipated was calculated according to Eq. (1) for a resistive circuit.

$$P = V.i \qquad (1)$$

where:

P is the electrical power dissipated in Watts; V is voltage in Volts and i is electrical current in Amperes.

The biogas consumption was measured with a diaphragm gas meter, connected at the admission manifold. In order to accurate the results, it was measured the time to flow $1m^3$ through the gas meter and the results were converted to normal cubic meter (Nm^3/h). To evaluate the gasoline consumption it was used the gravimetric method, measuring the time for 100g been consummated.

2.2. Power unit with biogas non-pressured

On the power unit used, the engine has been modified from factory, to work with non-pressured biogas.This modification added to it a diffuser to smooth the biogas admission, an H_2S filter and a balancing chamber to stabilize the flow. In this system, the biogas flow is regulated with the help of a manually valve, and is not possible to control the A/F ratio precisely. In Fig 2 is shown the modifications in the engine.

(a) (b)

Figure 2. H_2S and balancing chamber (a) and gas diffuser at the engine admission (b)

To evaluate this system performance, all the manufacturer recommendations were followed precisely and the gas meter installed after the balancing chamber to reduce any possible interference. Although this care, it was not possible to keep the engine working smoothly and continuous, possibly because the non-pressured biogas bag is smaller than those ones witch this system was developed for. Therefore, with this system the biogas is stored at lower pressure and the flow is more likely to climate variable, such as winds. For this reason, the evaluation of the engine working with biogas non-pressured was aborted and the focus was directed to the electronic flow control system.

2.3. Electronic flow control system

The electronic flow control system is responsible for change the biogas flow according to the O_2 concentration at the exhaust manifold. This control system was programmed to keep the lambda factor around 1, once this is the optimum value to burn the methane.

To allow the electronic control system work properly, the biogas was used under the pressure of 1.5 bar, sustained by an automotive pressure regulator. In order to enable the engine to work uninterrupted, the biogas compressed until 8 bar and stored in a proper cylinder.

(a)

(b)

Figure 3. Overview of the electronic flow control system

This system was assumed the reference for the biogas, since it has operated more stable and presents more repetitive results. It can be easily started, only with biogas can automatic adapt the biogas flow according with the power demand, thank to the electronic control system.

2.4. Atmospheric Parameters

As a thermal machine, the engine's performance can be influenced for atmospheric parameters, such as pressure and temperature, which has to be taken into account in the results. These variation, affects especially the biogas, causing a difference at his density, LHV and sometimes the methane concentration. At Tab. 2 is presented some important parameters to better evaluate the engine performance with the two fuels.

Table 2.Atmospheric parameters and fuels properties

Experiment	k	Methane Concentration(%)	LHV	α_c	P_{atm}(hPa)	T_{atm} (ºC)	Relative Humidity (%)
Biogas - 07/02/2011	1,33	60	19632(kJ/m^3)	1,118	928,2	31,1	37,1
Biogas - 19/03/2012	1,33	60	19643 (kJ/m3)	1,118	928,1	30,9	50,0
Gasoline - 10/02/2013	--	--	42500 (kJ/kg)	1,161	925,2	30,3	43,5
Gasoline - 17/02/2014	--	--	42500 (kJ/kg)	1,154	929,7	30,3	43,0

3. RESULTS

To compare the performance of the three systems, it is necessary to evaluate the fuel consumption, since the power dissipated in resistance bank is nearly the same. With the electrical power measured, it is possible to estimate the power developed by the engine, knowing that the electrical generator efficiency is around 80%, and correcting it with the ABNT atmospheric factor to obtain the effective power. The effective power is represented by Eq. (2). And the atmospheric factor can be calculated with Eq. (3).

$$P_{ref} = \alpha_c \times P_\gamma \tag{2}$$

where:

P_{ref} is the effective power; P_γ is the measured power and α_c, atmospheric factor.

$$\alpha_c = \left(\frac{P_{so}}{P_s}\right)^{1,2} \times \left(\frac{T_{ar}}{T_0}\right)^{0,6} \tag{3}$$

where:

P_{so} is the dry ambient pressure (kPa); $T_{ar}$is the ambient temperature (K) and P_s e $T_0$is the reference pressure and temperature in the same units.

Since the engine works with liquid and gaseous fuels, it is better to evaluate the consumption in terms of specific fuel consumption – SFC, given by Eq. (4). This is an indication of engine efficiency, but this parameter can more precisely evaluated with the ratio between the power developed by engine and the power that enters on it, expressed in Eq. (5).

$$SFC = \frac{\dot{m}_f}{P_{ef}} \tag{4}$$

where:

SFC is the specific fuel consumption; $\dot{m}_f$is the fuel flow and P_{ef} is the effective power.

$$\eta_{eng} = \frac{\dot{m} \times LHV}{P_{ef}} \tag{5}$$

where:

η_{eng} is the engine efficient; *LHV* is the Lower Heating Value; $\dot{m}_f$is the fuel flow and P_{ef} is the effective Power .

As the electronic control system demands pressured biogas to operate, it is necessary to take into account the energy to compress the biogas and discount from the total electrical energy generated. The power to compress the biogas can be calculated with Eq. (6), and the temperature variation during the isentropic compression is given by Eq. (7).

$$\dot{w} = \frac{\dot{m}(h_1 - h_0)}{\eta_{comp}} \tag{6}$$

where:

$\dot{w}$ is the power required by the compressor (kW); $\dot{m}$ is the gas flow (kg/s); h_1 e h_0 are the biogas enthalpy before and after the compression respectively (kJ/kg) and $\eta_{comp}$is the compressor efficiency.

$$\frac{T_0}{T_1} = \left(\frac{P_0}{P_1}\right)^{\frac{k-1}{k}} \tag{7}$$

where:

$T_0$and T_1 are the biogas temperature after and before the compression respectively; P_0 e $P_1$are the biogas pressure after and before the compression respectively and k is the ratio between specific heats (C_p/C_v).

The quality of electrical energy generated can be measured in terms of the frequency oscillation, since this is important parameters for both, selling this energy and using on electrical machines. The power unit was prepared in idle mode to generate electrical energy in 60 Hz, and left the self speed control actuate as the power dissipated increased.

3.1. Engine efficiency

The graphic on Fig 4 shows a comparative of the engine global efficiency operating with biogas and gasoline, for the four operating points analyzed.

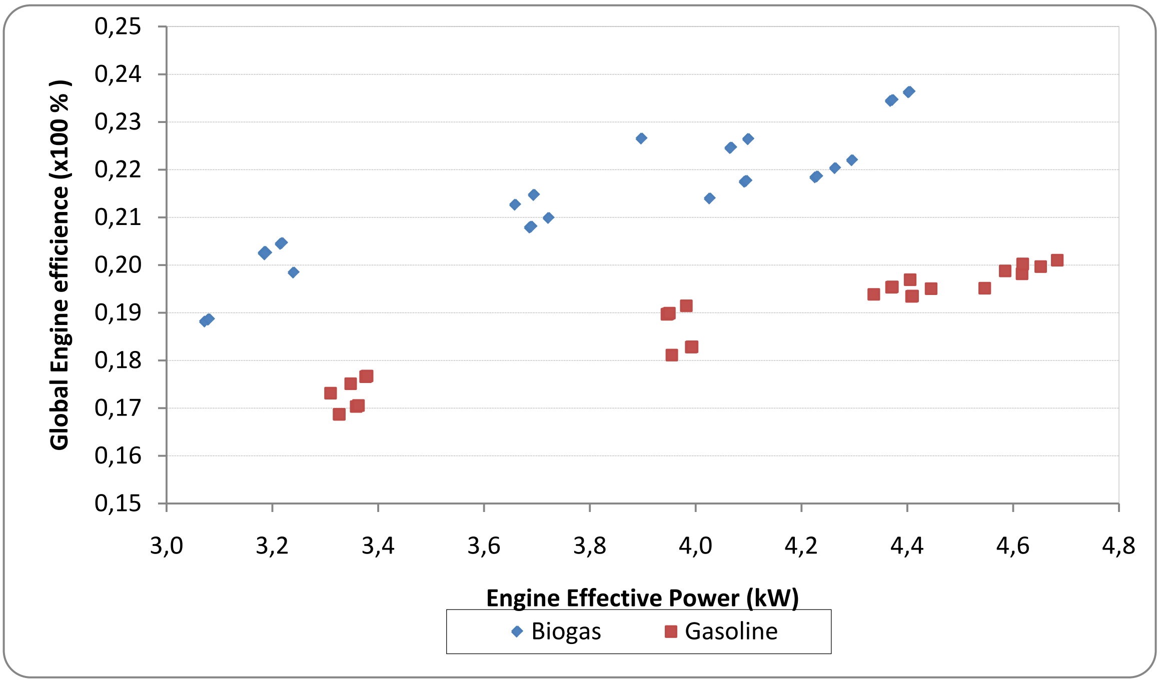


Figure 4. Comparative graphic Engine Effective Power X Global engine Efficiency

It can be seen that with biogas, the engine efficiency has increased 11% in average. These results shows that for the same input power, the engine working with biogas can deliver more power than the gasoline fueled engine. The increase can be directly associated with the flow control installed in the biogas system, which allows the engine to work in the stoichiometric condition for the methane and automatically adapt the fuel flow rate when load is applied on it.

Fig. 5 shows the electrical power available for both systems and the electrical power for the biogas discounting the power necessary to compress it.

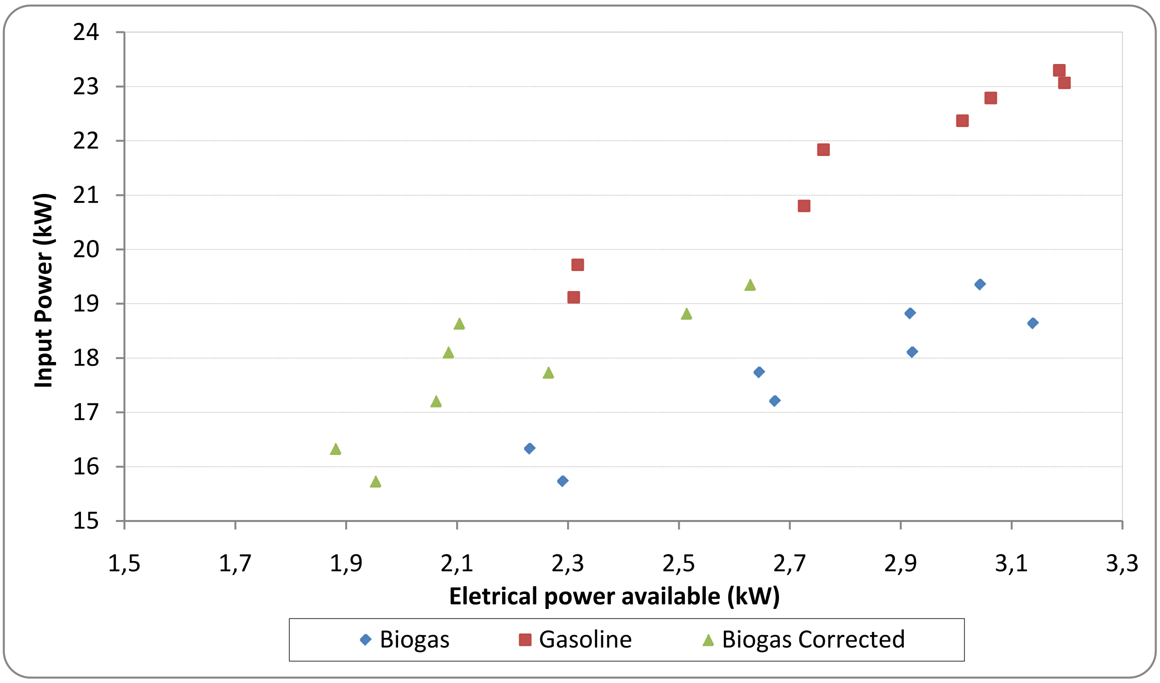


Figure 5. Comparative graphic Electrical Power Available X Power Input

Comparing the electrical power available (discounting the power to compress the biogas), the engine working with biogas demand less input power when compared with gasoline. Analyzing the points for the biogas system, there is a reduction on the power available that comes for the same input power. However, this reduction, around 0,2 kW, do not turn the use of compressed biogas unfeasible, since for the points measured, this system demands less input power to deliver the electrical power.

3.2. Specific Fuel Consumption

The Specific Fuel Consumption is the most convenient way to compare the fuel consumption for the two systems and is shown in Fig 6.

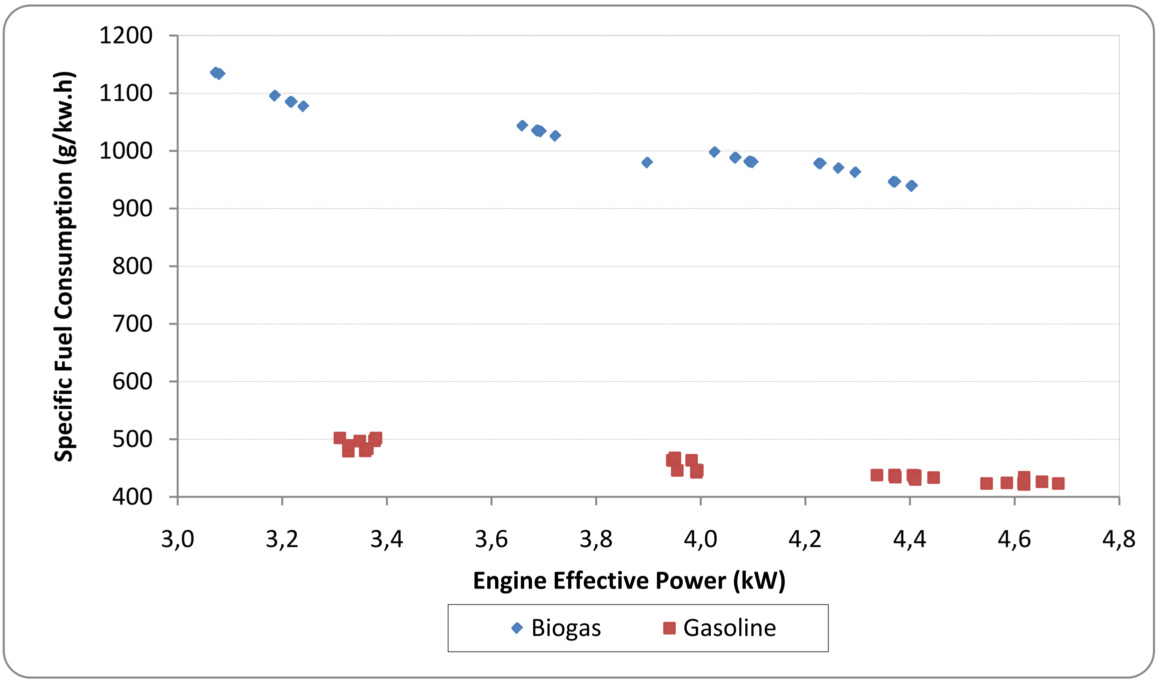
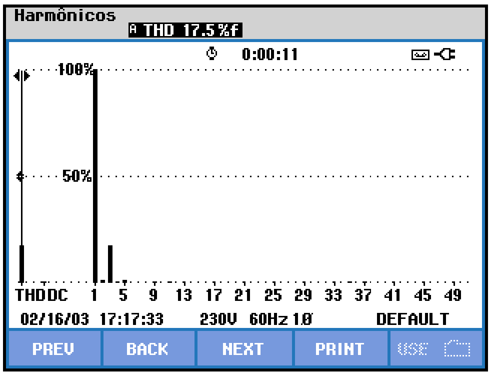


Figure 6. Comparative graphic Engine Effective Power X Specific Fuel Consumption

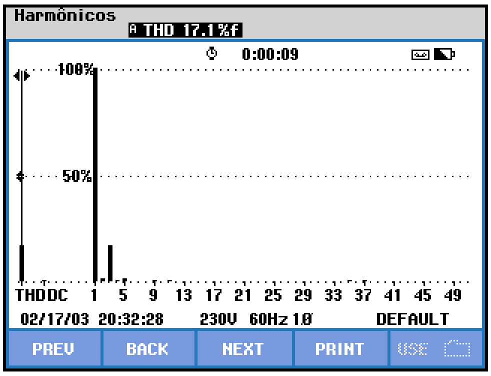
The Specific Fuel Consumption for the Gasoline was around 500 g/kW.h lower than Biogas, which was an expected result since these fuels are in different physical conditions, has different densities and different Heat Value. It is important to remember that the biogas is a sub product from wastewater treatment, and the price per gram of these fuelis lower than the gasoline. Assuming that biogas is generated in large scale, at big wastewater treatment stations, it is interesting to use it instead of the gasoline.

3.3. Quality of the generated energy

The line frequency in Brazil is 60 Hz, therefore the power unit has a mechanical device at the engine to keep the engine speed at around 3600 RPM in order to keep the line frequency constant when more power is required from the engine. Fig 7 shows the harmonics generated and Fig 8 shows the line frequency for the power generated.



(a)



(b)

Figure 7. Harmonics generated at maximum Power (a) Biogas and (b) Gasoline

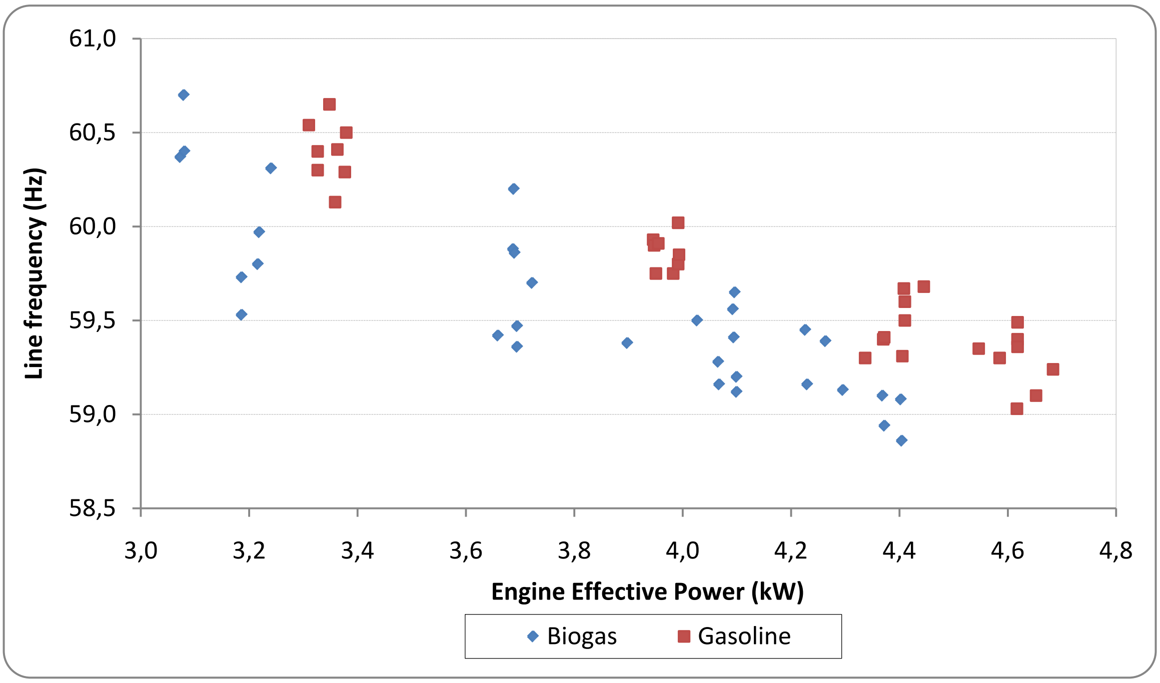


Figure 8. Comparative graphic Engine Effective Power X Line Frequency

It can be seen that for both fuels, the line frequency decrease when the power generated increase and the minimum value is around 59 Hz. In general, when working with biogas, the power unit generates line frequency under the gasoline, which can be associated with the lower Biogas' Heat Value. This variation is not considerable for general use but it can be a limiting point to integrate this generator on the official network.The harmonics generated are approximately the same for both fuels at the same load condition, what lead the conclusion the fuel does not influence at the harmonics generated.

4. CONCLUSION

Looking to all results, it can seen that installing the electronic flow control system has improved the engine's performance when compared with the gasoline, since the global efficiency with this fuel has increased around 11%. Although the Specific Fuel consumption with the biogas was greater than the gasoline, their use on this engine is still feasible, because of the better energy conversion efficiency, making Biogas more interesting than gasoline when this fuel is largely available.

Discounting the power to compress the biogas, the engine with this fuel is still more efficiency than with gasoline. Therefore, it is possible to conclude that, both the possibility to work with gas at pressures higher than the atmospheric and the more precisely Air/Fuel ratio control brings performance gains that make viable the use of biogas on this power unit.

The power quality was not satisfactory to integrate this power unit to official network, because of the oscillation on the frequency and the harmonics generated. For these reason, it is necessary to develop a speed control more precise or implement an electronic wave modulator, able to control the line frequency with more accuracy, and create capacitive filters to eliminate the harmonic presence.

Finally, it is possible to conclude that the use of biogas in internal combustion engines is economical and functional viable, especially when working at pressures higher than the atmospheric and associated with mixture control devices. However, it is necessary to develop more dedicated systems for biogas, in different engines' size, as well as investigate the most suitable parameters for this fuel.

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6. RESPONSIBILITY NOTICE

The authors, Olavo Miranda Martins, Fabrício José Pacheco Pujatti, Ítalo Lopes da Rocha,Ana Luísa Evaristo Rocha Petrini ,Lívia Cristina Silva Lobato and Carlos Augusto de Lemos Chernicharo, are the only responsible for the printed material included in this paper.