Numerical study of energetic, exergetic and ecological efficiency in the use of biogas in cogeneration systems

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Abstract. *This paper presents a numerical study based on energy analysis, exergy and ecological efficiency of a cogeneration power system (generator - chiller - heat exchanger) that uses biogas as energy input. The use of biogas in cogeneration units of energy must be preceded by a study of technical and economic viability, indicating the potential for generating energy from biogas. The study also sees the importance of quantifying the actual losses of the system identifying the equipment with the largest irreversibilities. Knowing the elemental composition and having as parameter the equivalence ratio was possible to determine the final composition of combustion products through a system of nonlinear equations resulting from the combustion reaction during the process of combustion. The study of combustion of biogas, combined with the concepts of energy, exergy and ecological efficiency provide technical information on the advantages and disadvantages of using biogas in cogeneration systems for energy. The study allowed to quantify the energy accumulated in the combustion gases, rejected by the microturbine, when it is operated on natural gas and biogas, and the results revealed too, the fact that it is a renewable fuel source, showing the viability in the use of biogas as an alternative fuel of the natural gas, to reduction of methane in the atmosphere, and also to reduce the emission of greenhouse gases.*

Keywords*: Cogeneration, Biogas, Ecological Efficiency*

1. INTRODUCTION

In Brazil, there is a significant potential of varied raw materials used in energy production from biomass, renewable energy source. A simple approach reveals the economic and social importance of these raw materials, processed into biofuels used to obtain thermal and electrical energy, serving as alternatives to lessen dependence on the use of fossil fuels, not renewable, seeking solutions to reduce global impacts as well as contribute to the country's energy matrix.

In this context, Brazil has a large supply of biogas because of its diversity of sources. Among other, include waste in rural areas, waste from cattle, swine and poultry in slaughterhouses, urban waste in landfills, waste treatment systems in urban sewage, crude glycerin as a byproduct in the production of biodiesel, vinasse in ethanol distilleries, etc. Biogas is a gas composed of different proportions of ammonia, carbon dioxide, hydrogen, methane, carbon monoxide, nitrogen and hydrogen sulfide. The presence of non-combustible substances in the biogas, such as water and carbon dioxide affect the firing process, making it less efficient. These substances absorb part of energy generated. Besides these, there is also the presence of hydrogen sulfide (H_2S) which can cause corrosion, reducing both the yield and the lifetime of the thermal engine used. For this reason, it is recommended the pre-cleaning before any of biogas use in thermal machines.

The energy potential of biogas is based on the quantity of methane contained in gas that determines its calorific value, and can be used as fuel instead of natural gas extracted from mineral reserves.

The use of biogas as an energy source fits into distributed generation in Brazil. About 81% of the total supply of electricity in Brazil is held by large hydroelectric plants far from major consumption centers. There is the need to implement new alternatives for electricity generation and it should consider issues as diverse as geographic distribution of production, reliability and flexibility of operation, availability of fuel prices, etc. Electricity generation from organic waste could emerge, particularly in smaller scale, associated with the consumer, who will certainly have an important role, since it is probably the only way to ensure the implementation of additional capacity in the short term.

Thus, the distributed generation should suit the needs of the Brazilian energy market always looking for improvements and increasing the efficiency of available energy resources, and reducing the environmental impacts of your process (Salomon, 2007).

The use of a gas of low calorific value, such as biogas in microturbines requires two considerations: the redevelopment of a microturbine for burn gas poor, specifically the combustion chamber, and a clean gas before the burns.

Among the main advantages of using biogas microturbine are: the ability to operate using a low gas content of methane ($CH_4 > 35\%$) without affecting its efficiency, good performance at temperatures between -10 °C to 45 °C, good efficiency between 30 and 33% (*based on LHV*) Low emissions (< 10 *ppm* NO_x) Possibility of cogeneration and, excellent modularity. However, among the disadvantages, we can mention: the efficiency at partial loads is low, limited experience of use, the use of air bearings to reduce maintenance costs, but it is essential to the use of air filters (Salomon, 2007).

The process of power generation is started by burning fuel, natural gas or biogas, the raw material of microturbine for generating electricity. The flue gases can be exploited in this way, the importance of quantification of this energy for reuse.

Knowing the composition of combustion products allows to evaluate the efficiency and availability of combustion energy, and environmental efficiency. The ecological theories that incorporate the knowledge of thermodynamic provide sorted into different aspects of the impact of the efficiency of ecosystems, and can lead to conclusions about how the activities can be organized in a more environmentally efficient and most economical way.

This paper presents a theoretical study involving combustion reactions, including chemical equilibrium, to determine the formation of compounds such as NO_x, CO_2, among others, applying the definition of ecological efficiency. To Knowing the elemental composition was determined the final composition of the products of combustion, stoichiometric, through a system of nonlinear equations resulting from the combustion reaction and the dissociation reactions during the combustion process.

The main idea of the study is to examine the sensitivity of microturbine energy production, by varying the load, and its influence on irreversibility, verifying the total energy efficiency, rate of recovery of the gases of combustion, the exergy and environmental efficiency of the equipment. Often a given objective can be achieved with lower cost when the irreversibility is smaller. For less irreversibility is associated with a given change of state, more work will be done or less work is required. Therefore, this study determines the effects of energy production (electric and thermal), compared to burning natural gas and biogas in a microturbine, by estimating an ecological efficiency as a function of the pollutants produced in the process of complete combustion..

2. ANALYSIS METHODOLOGY

To evaluate, energy, exergy and ecologically to microturbine, it was required to include the curves of the *Capstone microturbine ® brand model 330* with a nominal capacity of 30 kW power (*ISO conditions*). The first part of the work is devoted to studying the reuse of energy rejected to the environment by the microturbine using combustion gases, which are the input energy that could be used for other specific process. The second part is the exergy analysis by quantifying the exergy efficiency of the microturbine operating on natural gas and biogas, to verify the irreversibilities, and finally, the ecological part.

To determine the thermodynamic properties and the relevant calculations. It was used the *EES* program (Engineering Equation Solver).

2.1. Energy analysis

For the analysis of energy-generating system were applied balance equations of mass and energy, as shown in Eq. (1) and (2).

$$\left(\frac{\partial m}{\partial t}\right)_{vc} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out} \quad (1)$$

$$\left(\frac{\partial E}{\partial t}\right)_{vc} = \sum_{j} \dot{Q}_j - \sum_{vc} \dot{W}_{vc} + \sum_{in} \dot{m}_{in} h_{in} - \sum_{out} \dot{m}_{out} h_{out} \quad (2)$$

Where, $\left(\frac{\partial m}{\partial t}\right)_{vc}$ is the mass change in time for the volume control, and $\sum_{in} \dot{m}_{in}$ and $\sum_{out} \dot{m}_{out}$ are the mass flows entering and leaving the control volume, $\left(\frac{\partial E}{\partial t}\right)_{vc}$ the energy variation in time to control volume, $\sum_{j} \dot{Q}_j$ the sum of heat flows through the control volume, $\sum_{vc} \dot{W}_{vc}$ the sum of workflows, and $\sum_{in} \dot{m}_{in} h_{in}$ e $\sum_{out} \dot{m}_{out} h_{out}$ are the energy flows entering and leaving the volume.

To determine the flow of natural gas and biogas from the power flow and exhaust gas was considered the Law of Conservation of Species, taking into account a reaction for each hydrocarbon in the fuel, according to the composition of natural gas supplied by Copergás and biogas in the literature (Campos *et al*., 2010). These turbines work by assuming the complete combustion with excess air (between 450 and 500%) for the process.

To determine the specific heat (cp_p), molar mass of the exhaust gas (PM_p) was considered the partial fraction of products as follows (y_i):

$$cp_p = \sum_i y_i cp_i \quad (3)$$

$$PM_p = \sum_i y_i PM_i \quad (4)$$

Being,

$$y_i = \frac{n_i}{n_{total}}. \quad (5)$$

Where, y_i it is the molar partial fraction of the component *i*.

2.1.1. Energy efficiency

The efficiency (η) based on the first law of thermodynamics is the ratio between the desired energy and energy consumed by the component under study, defined by Eq. (6) (Moran and Shapiro, 2006).

$$\eta = \frac{Energy\_out}{Energy\_Input} \quad (6)$$

2.1.2. Ratio energy recovery from exhaust gases

The ratio of energy recovery from exhausted gas (R_{rec}) was calculated by Eq. (7), and is the ratio between the energy accumulated in exhaust gases ($\dot{Q}_p$) and the energy provided by fuel ($\dot{Q}_{fuel}$).

$$R_{rec} = \frac{\dot{Q}_p}{\dot{Q}_{fuel}} \quad (7)$$

2.2. Exergy Analysis

Exergy (ex_{tot}) is the maximum capacity of a flow of energy for produce work. The study of exergy has its foundation in a useful amount of energy used in thermal processes (Moran and Shapiro, 2006 and Kotas, 1995), which is commonly, divided into four parts: physical (ex_{ph}), chemical (ex_{ch}), kinetic and potential.

The exergy analysis is a useful tool for analyzing the operation of thermal systems, enabling the identification of areas of greatest irreversibilities, and identifies/quantify flows of energy that could be reused.

2.2.1. Total system exergy

The Fig. 1 represents schematically the process of exergy for any state.

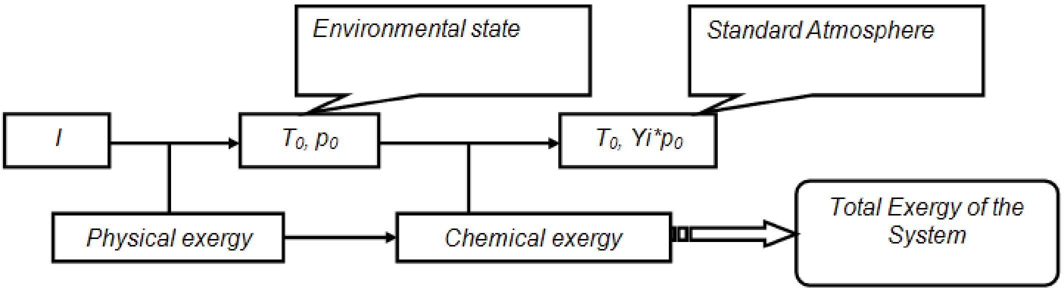

Figure 1. Representation of the total exergy of the process.

The Exergy represents the sum of physical and chemical exergy of the state, calculated by Eq. (8).

$$ex_{tot} = ex_{ph} + ex_{ch} \quad (8)$$

2.2.2. Physical exergy

Kotas (1995) defines the physical exergy (ex_{ph}) (thermomechanical) as the maximum work that can be obtained when a quantity of material is taken from the initial state to states of equilibrium pressure and temperature (T_o, P_o) of the environment of reference, physical processes involving only pressure and temperature interactions with the environment.

$$ex_{ph} = \left\{cp\left[T - T_0 - T_0 \cdot Ln\left(\frac{T}{T_0}\right)\right] + \frac{\bar{R}}{M} T_0 \cdot Ln\left(\frac{p}{p_0}\right)\right\} \quad (9)$$

Where (T) and (p) it are the temperature and the pressure, ($\bar{R}$) is the constant gas, and (M) the molar mass of the flux.

2.2.3. Chemical exergy

According to Kotas (1995), the chemical exergy (ex_{ch}) is defined as the maximum work obtained when the substance is brought into account from the environmental state to complete the thermodynamic equilibrium with the reference state, by using processes involving heat transfer (reactive systems) and exchange substances with the environment (non-reactive systems). Thus, the chemical exergy is calculated with the chemical potential difference between the two states, calculated by Eq. (10).

$$ex_{ch} = \left[\frac{\sum(y_i \cdot \tilde{\varepsilon}_i^{pa}) + \bar{R} \cdot T_0 \cdot \sum y_i Ln(y_i)}{M}\right] \tag{10}$$

2.2.4. Exergy destruction or irreversibility in microturbine

This concept gives us a quantitative assessment of degradation of energy caused by the irreversibilities. To determine the exergy destruction ($\dot{I}_d$) of the microturbine, they were determined the exergy flows of the different states of the cycle ($\sum_{in} \dot{Ex}_{\text{tot,in}} - \sum_{out} \dot{Ex}_{\text{tot,out}}$), following the procedure mentioned above. Applying the combination of first and second law of thermodynamics it has that:

$$\left(\frac{\partial Ex}{\partial t}\right)_{vc} = \sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j - \left(\dot{W}_{vc} - p_0 \cdot \frac{\partial V}{\partial t}\right) + \sum_{in} \dot{Ex}_{\text{tot,in}} - \sum_{out} \dot{Ex}_{\text{tot,out}} - \dot{I}_d \tag{11}$$

Where, $\left(\frac{\partial Ex}{\partial t}\right)_{vc}$ is the exergy change in time, $\sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j$ is the exergetic flow due to heat transfer, $\left(\dot{W}_{vc} - p_0 \cdot \frac{\partial V}{\partial t}\right)$ is the exergetic flow due to heat transfer.

$$\dot{Ex}_{tot} = \dot{m} \cdot ex_{tot} \tag{12}$$

To determine the exergy efficiency (Ψ_{ex}) of the microturbine will be selected the theory of rational efficiency of the system (Kotas, 1995), expressed as:

$$\Psi_{ex} = \frac{Exergy\_out}{Exergy\_input} \tag{13}$$

This concept involves comparing the desired result or product of the system with the resources consumed to produce the product, measuring the relationship between what was required exergy and exergy advantage added to the system.

2.3. Ecological analysis

The combustion process can be analyzed theoretically by modeling the reaction of oxidation of fuel components in chemical equilibrium. The equilibrium equations are related to the dissociation of chemical compounds found in combustion products. According to the definition of chemical equilibrium constant, which is written in terms of the mole fractions of components of chemical equation and is dependent on temperature and pressure will be formed a system of nonlinear equations which once solved would provide the composition of mixtures of gases of combustion products for a given equilibrium condition, determined precisely by the thermodynamic conditions of pressure and reaction temperature (Campos *et al*., 2010).

In the present study was considered that the reaction is performed at atmospheric pressure in adiabatic conditions of the combustion chamber. Therefore, the value of the temperature, which affects the equilibrium constant, is also an unknown of the problem and asks for one more equation. The resolution of this system was obtained through an open computer code developed by Oliker and Borman (1975) and delivered by Turns (2000). With the model were determined the concentrations of combustion products under conditions of chemical equilibrium.

The ecological efficiency (ε) is a dimensionless indicator for assessing the environmental impact of gaseous emissions by comparing emissions in CO_2 equivalent emissions, with the existing standards for air quality. The ecological efficiency is determined by Eq. (14) (Costa et al, 2009).

$$\varepsilon = \left[\frac{0{,}204\eta}{\eta + \Pi_g} \ln\left(135 - \Pi_g\right)\right] \tag{14}$$

The value of ε is a function of efficiency (η) of the equipment or process responsible for emission and pollution indicator (Π_g). From an ecological standpoint, a minimum acceptable value for the ecological efficiency would be equal to 0.5 would be called "*Critical Value of Ecological Efficiency*" and that when $\varepsilon = 0$, it is considered unsatisfactory, but $\varepsilon = 1$ indicates a situation ideal (Costa *et al.*, 2009).

The best fuel from ecological point of view is one that has a minimal amount of Carbon Dioxide Equivalent obtained from burn it. To quantify this environmental impact, we define the "*pollution indicator*" Π_g (Costa *et al*., 2009).

$$\Pi_g = \frac{(CO_2)_e}{LHV_{fuel}} \tag{15}$$

Where, $(CO_2)_e$ is expressed in kg/kg$_C$ (kg per kg of fuel), end *LHV* (*Low Heat Value*) is expressed in MJ/kg. So, Π_g is expressed in kg/MJ.

The coefficient for the carbon dioxide equivalent $(CO_2)_e$, is a hypothetical factor of the pollutant concentration and it is calculated by Eq. (16) (Costa *et al.*, 2009).

$$(CO_2)_e = (CO_2) + 80(SO_2)_e + 50(NO_x) + 67(MP) \tag{16}$$

Where, $80(SO_2)$ is sulfur dioxide equivalent in CO_2, $(SO_2)_e$, $50(NO_x)$ is nitrogen oxide equivalent in CO_2, $(NO_X)_e$, e $67(MP)$ is the equivalent of the particulate matter in CO_2.

3. RESULTS AND DISCUSSION

Knowing the composition of biogas (Faria and Rodrigues, 2001), the higher and lower calorific value of biogas it was calculated using the first law of thermodynamics, enthalpy of formation from its component gases, found in literature. The values of heat capacities and enthalpies of formation of natural gas were found in the literature (Garcia, 2002). Table 1 shows the elemental composition, enthalpy of formation, the lower and the higher calorific value and the molecular weight of natural gas and biogas.

Table 1. Elemental's composition, molecular weight, calorific value and enthalpy of formation of gases.

Fuel	C, *%*	H, *%*	O, *%*	S, *%*	N, *%*	LHV, *MJ/kg*	HHV, *MJ/kg*	h_f, *kJ/mol*	MM, *kg/kmol*
Natural Gas	70,23	21,47	5,16	0,00	3,14	44,38	49,09	-45,15	18,81
Biogas	38,93	7,63	42,75	0,00	10,69	14,77	16,45	-15,17	26,35

Table 2 presents the composition of products of combustion of fuels in this study. By Tab. 2 we make a quantitative comparison of the products of combustion of fuel in kg/kg$_{fuel}$ (kg per kg of fuel).

Table 2. Products of combustion of fuel, kg/kg$_{fuel}$.

Fuel	H	H_2	NO	CO_2	O	OH	O_2	N_2	N	CO	H_2O	Total
Natural Gas	0,000	0,004	0,038	2,316	0,002	0,031	0,095	11,660	0,000	0,164	1,876	16,185
Biogas	0,000	0,001	0,008	1,348	0,000	0,005	0,022	4,034	0,000	0,040	0,669	6,128

From Tab. 2 it could it see that among the studied fuels, biogas it is the biofuels that releases less mass of pollutant per mass of fuel, and the natural gas releases more pollutants per mass of fuel mass.

Table 3 shows the values calculated using Eq. (15) and (16), referring to the concepts of indicator of pollution and carbon dioxide equivalent, respectively.

Table 3. Comparison of results between the fuel emissions.

Fuel	$(CO_2)_e$, kg/kg$_C$	Π_g, kg/MJ
GLP	4,896	0,100
Natural Gas	4,214	0,095
Biogas	1,726	0,117

From Tab. 3, we observed that biogas is the fuel that has a greater indicator of pollution, while natural gas has the lowest indicator of pollution. As shown in Eq. (15), the indicator of pollution of a fuel is inversely proportional to its lower calorific value. So even the biogas has the lowest value of $(CO_2)_e$, the fact that the biogas present the lower calorific value it was the predominant feature to submit a higher indicator of pollution. That is, to generate the same amount of energy that other fuels in its burning, it must use an amount three times more biogas, thus generating a greater amount of pollutant (Campos *et al.*, 2010).

The use of gaseous fuels generates an insignificant amount of particulate matter that is disregarded for purposes of calculations. As mentioned earlier, to validate the computer model data taken from the microturbine manufacturer *Capstone® model 330*, and it was simulated for different parameters such as: energy efficiency, exergy, ecological ratio for the recovery of the gases combustion, and others depending on load, using natural gas and biogas as fuel.

Table 4. Shows some important parameters in the simulation with 100% load applied to the microturbine using natural gas and biogas.

Parameters with 100% load	**Natural Gas**	**Biogas**
Fuel Flow (kg/s)	0.0026	0.00856
Temperature of exhaust (ºC)	254.8	251
Ratio for the recovery of the gases combustion (%)	16,98	12,44
Exergy Efficiency (%)	22,98	15,64
Destruction of Exergy (kW)	80.17	135.1
Ecological Efficiency (%)	85,41	83,178

Figure 1 shows the variation of the energy efficiency of the microturbine **(**η**)** according to load. It can be observed that the efficiency increases with load the microturbine, but this fact also depends on the temperature of air entering the combustion chamber, a parameter which directly influences the behavior of the apparatus. According to the manufacturer's data, the behavior of the energy efficiency of the microturbine is the same as operating with natural gas as with biogas. The maximum efficiency for the case study was 25.92% for an ambient temperature of 25 °C.

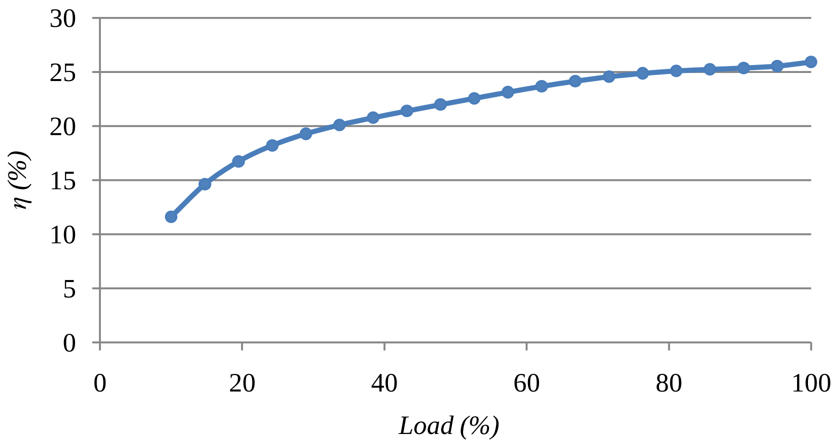

Figure 1. Graph of the energy efficiency of the microturbine **(**η**)** operating with natural gas and biogas as a function of load.

Figure 2 shows the graph of the temperature of the exhaust turbine by operating on natural gas and biogas varying the load. It can be observed that the difference between the exhaust temperature by using natural gas and biogas as fuel is almost insignificant, with a range of 3 ºC approximately. This is related to the total power output that is the same for the fuels contained in the study. The big difference is the flow of fuel, since the calorific value of biogas is approximately three times lower than that of natural gas. The maximum values of exhaust temperature were 167.2 °C and 164.2 °C for natural gas and biogas, respectively.

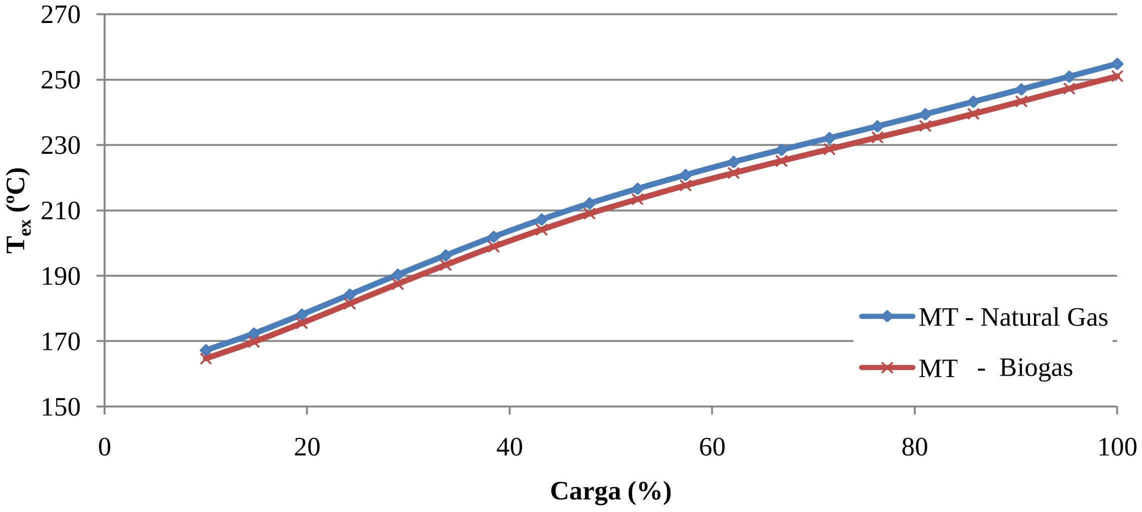

Figure 2. Graph comparing of the exhaust gas temperature (T_{ex}) as a function of load, operating on natural gas and biogas.

Another important parameter to quantify is the energy contained in exhaust gases, which it could be used in a cogeneration process. This analysis was performed using the ratio of energy recovery from flue gas, defined by Eq. (7). Figure 3 shows the graph of the ratio of energy recovery from flue gas (R_{eg}) in the microturbine as a function of load, operating on natural gas and biogas. It can be observed that this energy ratio increases as the load increases, and the same behavior for both fuels. This is due to higher energy capacity of natural gas, represented by the same calorific value, driving this increase. The maximum amount is for 100% load with a value of 0.1698 when the microturbine operates natural gas and biogas to 0.1244, which represents 26% more power for the use of cogeneration.

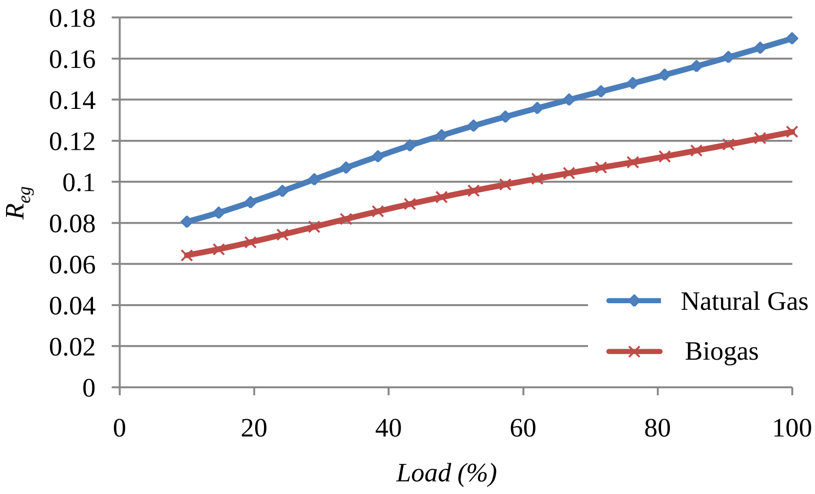

Figure 3. Graph of the ratio of energy recovery from flue gases of the microturbine (R_{eg}) as function of the load, operating on natural gas and biogas.

The graph in Fig. 4 shows the variations of the exergetic efficiency of the microturbine (Ψ_{MT}), working with both fuels, being higher with natural gas as 32% above the equipment supplied by using biogas. This is due by the partial proportions of combustion products, dissociation of the products and the flow of these gases, since it required a three times greater supply of biogas to achieve the required power for the equipment. In addition, the inlet pressure of biogas is 7.5% higher than the natural gas directly affects the energy losses of the system due to its chemical composition.

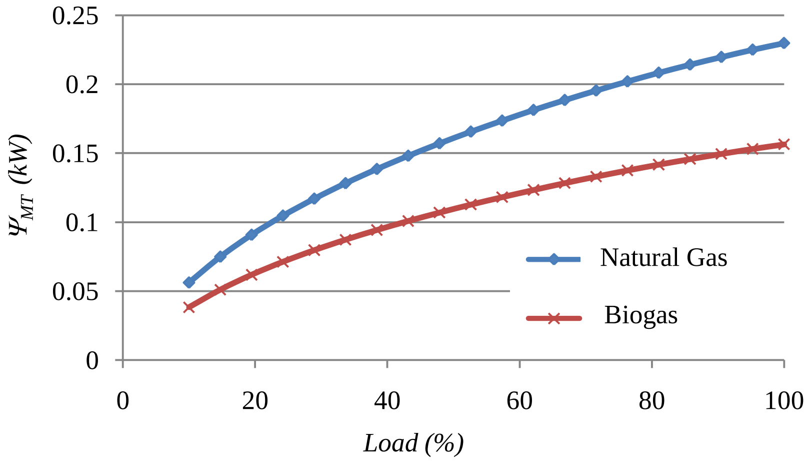

Figure 4. Graph of the exergetic efficiency of the microturbine as a function of load, operating on natural gas and biogas.

The graph in Fig. 5 shows the variation of exergy destruction in the microturbine operating on natural gas and biogas varying the load. It can be observed that as the load increases the exergy destruction too, compromising the performance of the equipment, since the availability (exergy) is smaller, either using natural gas or biogas. However, the exergy destruction of the equipment using biogas is 40% using natural gas. This fact is merely related to the losses of exergy efficiency, because the values of pressure, temperature, flow rate and composition. This behavior confirms the fact of lower exergy efficiency of the microturbine operating on biogas, as most of exergy destruction less the availability and therefore lowers the exergy efficiency.

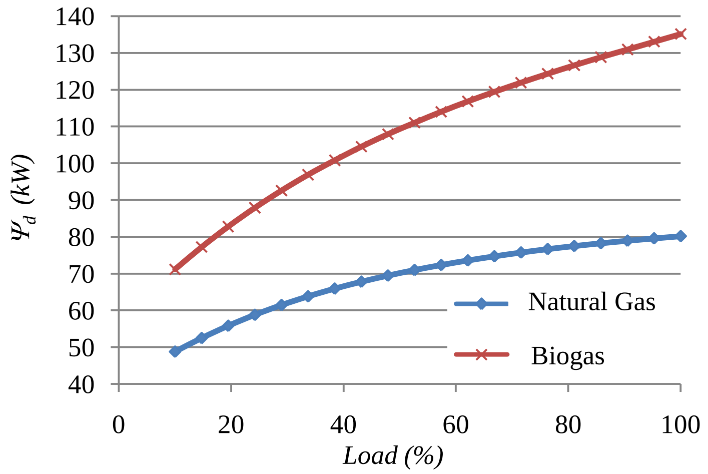

Figure 5. Graph of the exergy destruction of the microturbine (Ψ_d) as the function of the load in the microturbine operating on natural gas and biogas.

Finally, the graph of Fig. 6 shows the behavior of ecological efficiency (ε) of microturbine by varying the load. It can be observed that as the load increases this ecological efficiency also increases, even when operating by natural gas or biogas, the tendency is the same, but the microturbine operating on biogas tends to be less polluting than when operating with natural gas with a percentage difference of approximately 3%. The graph shows that the values of ecological efficiencies for the fuels studied were very close.

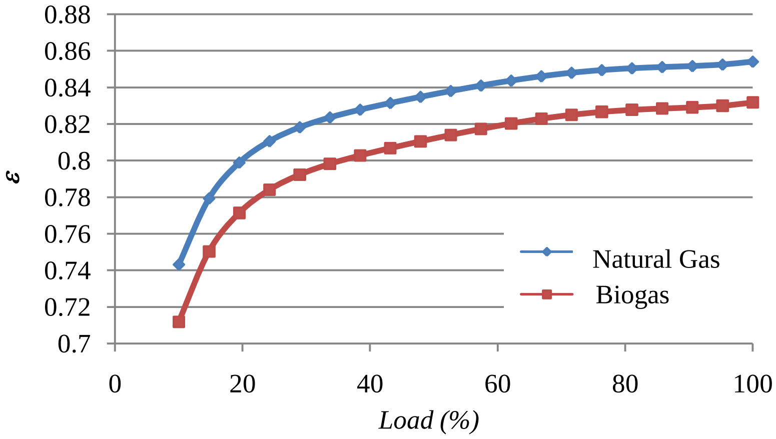

Figure 6. Graph of the microturbine efficiencies ecological as function of load, operating on natural gas and biogas.

4. CONCLUSIONS

In flaring of CO, CO_2 and NO_X there is less release. From the ecological point of view is the best fuel (lower value of $(CO_2)_e$), despite having an indicator of pollution a little higher than natural gas, due to the low value of the *LHV*.

The study allowed to quantify the energy accumulated in the combustion gases, rejected by the microturbine, when it is operated on natural gas and biogas. It is important that the exergetic assessment confirmed the potential available energy of the system through gas rejected to the environment.

In function of the temperature of exhaust gases when the microturbine operates with natural gas gives a value of 254.8 °C and biogas with a value of 251 °C, with a minimum difference of 3 °C.

The rate energy recovery from exhaust gases showed that the microturbine energy provides a higher rate of 16.8% with natural gas that by using biogas, 12.4%, as fuel.

The maximum amount is for 100% load with a value of 0.1698 when the microturbine operates natural gas and biogas to 0.1244, which represents 26% more power for the use of cogeneration.

It can be observed that as the load increases the exergy destruction too, compromising the performance of the equipment, since the availability (exergy) is smaller, either using natural gas or biogas. However, the exergy destruction of the equipment using biogas is 40% using natural gas.

In reference to the exergy efficiency of the system, the microturbine operating with natural gas provided 32% more energy than operating on biogas, due to the destruction of exergy provided by this fuel through the high flow used by the microturbine to the combustion process.

Finally, in reference to the environment, and according to the ecological analysis, the use of biogas system provides a better ecological efficient of 85.4%, against 81.2% when using natural gas as fuel, operating at 100% load equipment.

It can be observed that as the load increases this ecological efficiency also increases, even when operating by natural gas or biogas, the tendency is the same, but the microturbine operating on biogas tends to be less polluting than when operating with natural gas with a percentage difference of approximately 3%.

From the results shown and the fact that it is a renewable fuel source, shows the viability in the use of biogas as an alternative fuel of the natural gas, to reduction of methane in the atmosphere, and also, to reduce the emission of greenhouse gases. The reuse of energy for energy cogeneration has increased over recent years due to optimization of energy resources. Therefore, this numerical study, demonstrated this energy fact.

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