USE OF BIOGAS ON SMALL POWER GENERATORS

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Abstract*. A dual feeding system of biogas/gasoline to a low-power spark ignition engine is proposed. Design aspects, construction and tests of the feeding system appear, including the mechanisms and accessories of regulation in different operation regimes. A mathematical model has been used for the design of the carburetor-mixer in order to optimize its geometry, diminish the losses of pressure and maintain the adequate air/fuel ratio. The results of the tests made at the Internal Combustion Engines Institute of UNI on a single cylinder stationary 6 kW gasoline motor are included.*

Key words: *biogas, feeding system, renewable energies.*

1. Introduction

Clear and sustainable tendency, in Peru and the world, is the increasing use of clean technologies and renewable energies, although it is still either far from the wished levels or without the necessary diffusion. The main reasons that have originated this change are the drastic diminution of proven petroleum reserves, with the consequent increase of price of their derivatives, and the increase of the concentrations of toxic substances in the urban atmospheric air. Other serious collateral problem is the enormous amount of remainders generated by the high industrial and technological development of the present societies, and which the nature is incapable to recycle rapidly. The degree of sufficiency of a country to satisfy its necessities with energy is moderate by means of the index of power that in Peru is of 80,8%, which indicates that there is a 19,2% of deficit and imposes the necessity to concern energy. Another worrisome data is that in our country there are more than a million families which don't have access to the electricity and to the advantages that this one brings. In this scheme, the use of the biomass for energy generation appears like an interesting alternative to cover partially this deficit. As it is known, biomass that comes mainly from the farming, domestic and/or industrial organic remainders, can be processed to obtain important products like biogas and fertilizers. The generation of electrical energy from use of biogas in internal combustion engines has been the central subject of several projects developed in the National University of Engineering (UNI, Lima-Peru) in order to offer a viable energetic electrical alternative for devoid places of energy. The aim of these projects and this paper was to develop an elemental carburetor in order to operate a spark ignition engine with biogas. It is important to indicate, that in our case, the adaptation was characterizes by the simplicity of the modifications, use of simple technology and the economy of its accomplishment.

Biogas is a gas mixture originated from decomposition of organic matter made by bacterial action in anaerobic conditions (in oxygen absence). This process can happen in natural form, like in the marshes, sanitary fillings, etc., or in a controlled environment, as in main the component biodigestors. The main components of biogas are methane (CH_4) and carbon dioxide (CO_2), but also are small amounts of sulphydric acid (H_2S), hydrogen (H_2), nitrogen (N_2), oxygen (O_2), argon (Ar), carbon monoxide (CO) and ammonia traces (NH_3). Low heating values and other biogas properties depend on the amount of methane in biogas, which it depends as well on the process of obtaining and the used material. In our case, biogas is obtained in an ascending flow anaerobic reactor (RAFA), of 6 m. of depth, which has a retention time of 7 hours and produces an average of 10 m^3 of biogas with a content of 80% of CH_4.

2. Considerations for the design of the biogas carburetor-mixer and mathematical modeling.

The carburetor-mixer of biogas is the most important component of the feeding system and is the element in charge to mix biogas with the air in the suitable proportion, in any charging load. The used mixer is of the type venturi and has been designed on the basis of a mathematical model. This mixer consists basically of two parts: a housing and a nozzle

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(venturi), this last one is interchangeable. The mixer has the same fluid-dynamic principle that a conventional carburetor, that is, the air flow enters the motor due to the suction caused by the downstroke of the piston during the admission process. The air flow begins to be developed from its entrance to the mixer; the greater speed of the air in the throat of venturi originates a depression in the holes of biogas what causes the flow of the mixture to the motor. The depression in the venturi throat varies based on the position of the valve of butterfly of the gasoline carburetor. Biogas enters to the airflow in the mixer in radial form, mixing itself gradually with the air throughout the admission duct before entering the motor.

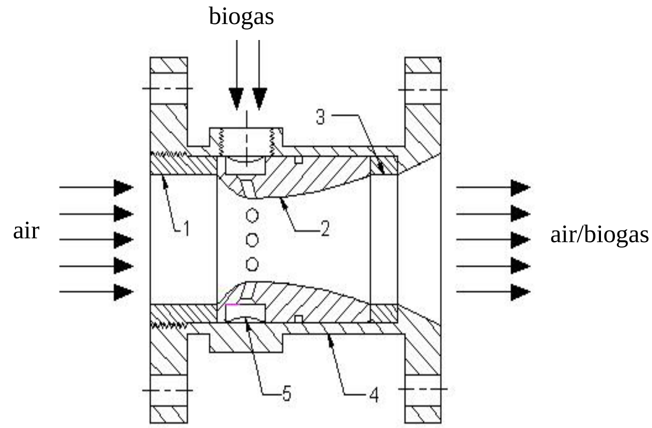

Figure1. Scheme of the biogas mixer. 1- Centring device, 2 - Nozzle, 3 - Adjusting ring, 4 - Housing, 5 - Ring of feeding of biogas.

The mathematical modeling of the mixer allowed us to obtain the main measures of this one, such as: the diameters at the entrance and exit of the nozzle, the diameter of the throat, the optimal length and the nozzle profile. The profile of the nozzle must be in such way that it produces the smaller losses of pressure in the flow. The modeling also allowed to determine the number and the diameter of the biogas feeding holes, under that homogenous mixes with a suitable coefficient of excess of air is obtained. Also the inclination of the perpendicular axis of the holes of biogas with respect to the plane to the axis of the nozzle was considered (see figure 1), in such a way that it increases the unloading coefficient values of them. The main dimensions of the used biogas mixer appear in figure 2.

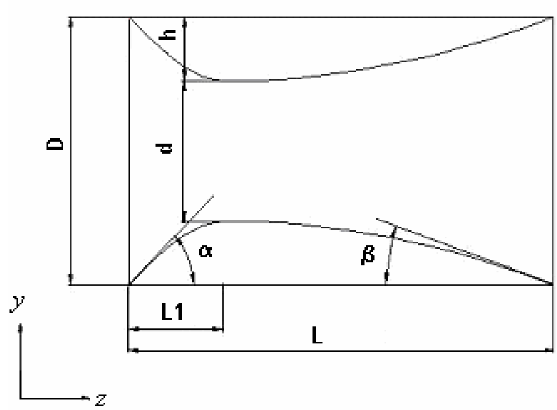

Figure 2. Main dimensions of the used nozzle.

To obtain the profile of the mixer nozzle, two polynomial curves of third degree were used according to the recommendations of Trelles (2001):

$$y = a_0 + a_1 z + a_2 z^2 + a_3 z^3 \tag{1}$$

The numerical values of the coefficients of the polynomials are obtained from the boundary conditions of the profile and some geometrical recommendations of Trelles (2001):

$$z = 0 \;\; at \;\; y = 0 \;\; and \;\; y = L \tag{2}$$

$$\left.\frac{dy}{dz}\right|_{z=0} = tg\alpha; \quad \left.\frac{dy}{dz}\right|_{z=L} = -tg\beta; \quad \left.\frac{dy}{dz}\right|_{z=L1} = 0 \tag{3}$$

$$h = \frac{D-d}{2}\;; \qquad \frac{L_1}{L} \approx 0{,}20-0{,}25; \qquad \frac{L}{h} \approx 6{,}5-7{,}5\;; \tag{4}$$

$$\alpha \approx 40-50^{\circ}; \quad \beta \approx 15-25^{\circ}$$

Known the profile and the dimensions of the nozzle, continuity and energy equations, and the equation for an adiabatic compression process (isentropic) for two points of the nozzle (separated a differential *dz*) can be raised. Using the equation of Darcy (for this same differential *dz*) and the diagram of Moody, finally, average values of pressure and speed throughout the nozzle are possible to be calculated, they are showed in Figure 3.

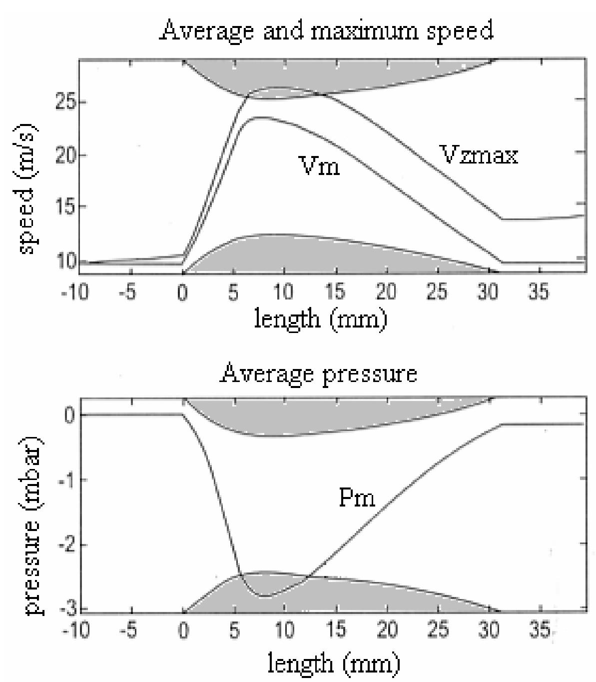

Figure 3. Speed and average pressure variation throughout the nozzle (Trelles, 2001)

In order to calculate the total area of holes for biogas provision, the stoichiometric air/fuel (biogas) ratio has being previously calculated from the following chemical equation of the biogas burnup:

$$CH_4 + \frac{b}{a}CO_2 + 2(O_2 + 3{,}76N_2) \rightarrow (1+\frac{b}{a})CO_2 + 2H_2O + 7{,}52N_2 \tag{5}$$

where: *a* and *b* are the volume fractions of CH_4 and CO_2, respectively. From the tests, the determined values were *a* = 0,2 and *b* = 0,8. Then, in this case, the stoichiometric relation air-biogas is approximately 10,2 kg air/kg biogas. In our case, the conditions of maximum provision of biogas and maximum power are obtained when the butterfly valve is completely open and the coefficient of excess of air is equal to 0,9 (nominal conditions).

The air excess coefficient (λ) is defined as:

$$\lambda = \frac{G_a}{(l_0 \cdot G_c)} \tag{6}$$

where: G_a and G_c are the air and fuel mass flows, respectively. Taking into account the well-known formula of the flow through holes, we obtain:

$$\lambda = \frac{1}{l_0} \cdot \frac{A_d \cdot C_d}{A_c \cdot C_c} \cdot \sqrt{\frac{\rho_0}{\rho_c}} \cdot \sqrt{\frac{\Delta P_d}{\Delta P_d + \Delta P_c}} \tag{7}$$

where: A_d and A_c are the areas of the throat of the diffuser and the holes for the passage of biogas, respectively; C_d and C_c are the unloading coefficients of the indicated areas; ρ_o and ρ_c are the fuel and air densities. ΔP_d and ΔP_c are the depression at the venturi throat of the mixer and at the biogas pressure gauge, respectively (in mbar). From the results of the mathematical model, we obtain the value of the maximum depression in the throat of the nozzle (ΔP_d = 4,5 mbar) for the experimental engine at nominal operation conditions. Knowing the air flow and the value of the air excess coefficient (λ= 0,9), the fuel flow can be calculated.

Assuming that the conditions of temperature for the gas and the air are equal (atmospheric temperature T_0), then:

$$\frac{\rho_0}{\rho_c} = \frac{\mu_0 P_0}{\mu_c P_c}; \qquad \mu_c = a\mu_{CH_4} + b\mu_{CO_2} \tag{8}$$

where: μ_o and μ_c, P_o and P_c are the molecular masses and the absolute pressures of the air and the fuel, respectively. From these equations, the total area of the holes for the provision of biogas to the motor can be obtained:

$$A_c = \frac{1}{\lambda \cdot l_0} \cdot \frac{A_d C_d}{C_c} \cdot \sqrt{\frac{\mu_0}{a \cdot \mu_{CH_4} + b \cdot \mu_{CO_2}}} \cdot \sqrt{\frac{P_0}{P_0 + \Delta P_c}} \cdot \sqrt{\frac{\Delta P_d}{\Delta P_d + \Delta P_c}} \tag{9}$$

The variations of λ and the relative biogas mass flow $G_c/G_{c,0}$ based on the relative air mass flow $Ga/Ga_{air,0}$ are showed in Figure 4, where it has been assumed that the values of A_c, A_d, ΔP_c, a, b, C_d and C_c stay close to constant. Note that the curve of the air excess coefficient (λ), can be moved to a higher (or lower) position, so it means that the mixture can be impoverished or enriched when diminishing or increasing the biogas flow, which can be obtained, for example, by diminishing or increasing the passage area of the biogas hole (A_c). It is also possible to appreciate how the mixture is impoverished when the butterfly valve is opened (or, which is the same, increasing the load). Because of these facts, after some testing, the diameter of the holes of feeding of biogas was increased in gradual form (one by one), with the intention of increasing the flow of fuel and, consequently, the engine power. This modification was made knowing that it would increase the specific consumption of fuel, mainly at low loads, but allowed to obtain a greater power.

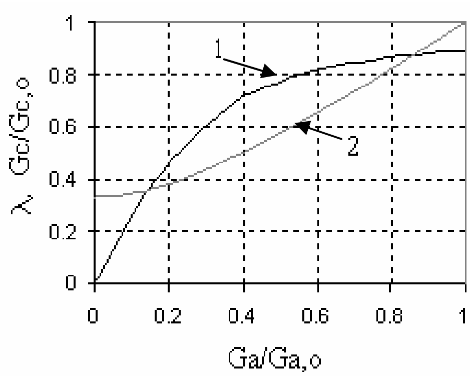

Figure 4. Variation of the air excess coefficient λ (1) and of relative mass flow of biogas $G_c/G_{c,0}$ (2) based on flow relative the air mass flow $Ga/G_{a,0}$.

It is interesting to indicate that the tendency of this curve, that is, the mixture becomes rich as diminishing the air flow when the butterfly valve is closed meanwhile diminishing the load, makes unnecessary the installation of a special system for the slow motion regimes and load losses. The nozzle of the mixer must be made treating that the inner surface be as smooth as possible. The bridles of the housing of the mixer are made according to the size of the bridle of the gasoline carburetor and of the air cleaner, respectively. The biogas entrance to the mixer is through a step valve, which regulates the main flow of combustible.

3. Other modifications.

3.1. Biogas filter. With the purpose of eliminating or diminishing the percentage of H_2S, filters are commonly made with substances quicklime, particles of iron or certain types of land known as hematite, brown or limonite, which are rich in ferrous substances, that when reacting with the H_2S form iron sulfide. The used filter was settled in the biogas conduction line to the motor, approximately to 4 m. of the entrance of this one. A tube of PVC of 30 cm. of diameter and 1 m of height were used as a filter, which was filled up with particles of iron in three compartments.

3.2. The slow motion system. It is possible to mention that the system does not count on a special device for the operation of the motor at low or non-load, since the biogas mixer allows a stable operation of the motor in these regimens by itself.

3.3. The motor itself. Due to the biogas has an octane number greater than any commercial gasoline, the motor could work with a greater compression ratio, thus, the base of the butt was rectified, increasing the compression ratio from 8/1 to 10,5/1, better results were obtained, mainly in the referring to the specific consumption of biogas. Should be mentioned that this modification was only made for experimental study and is not advisable to make in other cases, since this one is a permanent modification and could prevent the good operation of the motor with gasoline (detonation could appear) during a possible shortage of the biogas.

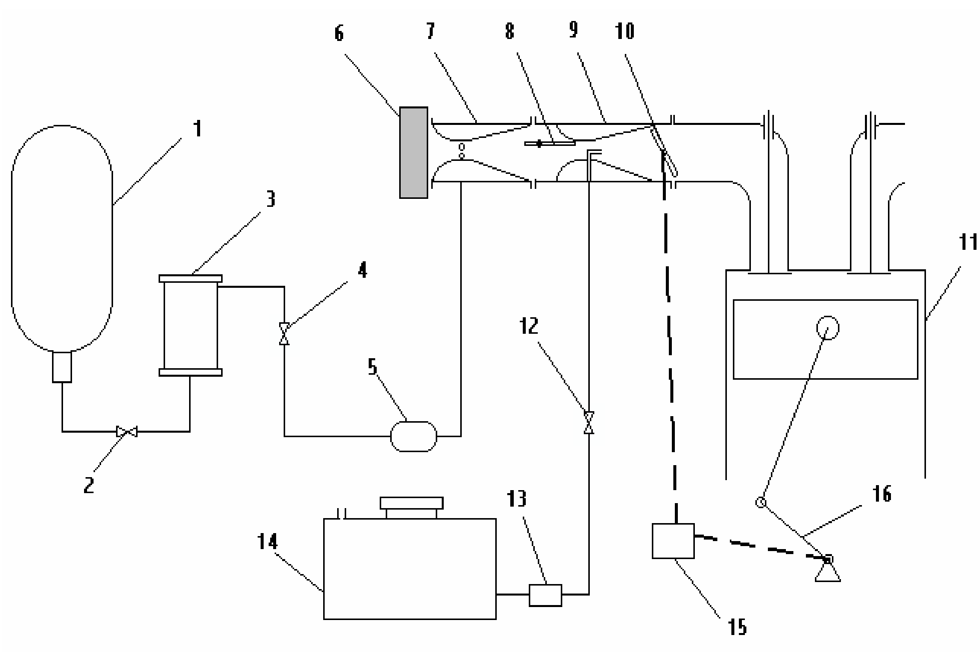

Figure5. Sketch of the installation of the biogas engine: 1- Biogas storage, 2- Closing valve, 3- Filter of H_2S, 4- Step valve, 5- Regulation gasoline valve, 6- Air filter, 7- Biogas-mixer, 8- Choke, 9- Carburetor, 10- Butterfly valve, 11- Motor, 12- Gasoline closing valve, 13- Gasoline filter, 14- Tank, 15- Speed regulator, 16- crankshaft.

3.4. Starting system. The starting system of the original motor was stayed, since due to the low calorific power by unit of volume of mixture of biogas with the air compared with the one of the gasoline (from 10 to 20% minor), the motor continued starting with gasoline.

3.5. The speed regulator. There was necessity neither to make modifications nor to change the original regulator of the motor. It is possible to indicate that the presence of the regulator is essential in order to maintain the voltage and the frequency of the current of group constants.

The set of the components of the feeding and speed regulation systems of a biogas motor appear in Figure 5.

4. Experimental results

To demonstrate the functionality and trustworthiness of the feeding system of biogas, as well as to obtain the load characteristic curves of a motor with this fuel, tests were made in a proving stand, specially designed and constructed for this aim. A series of tests were carried out in order to observe the influences of the modifications made to the original motor. The load was simulated utilizing a bank of 40 light bulbs of 100 W each one, turning on five by five. The modifications were oriented to substitute the gasoline for biogas trying to take advantage of the design characteristics of the original motor, first to start the motor and then to operate it. After introduce the carburetor-mixer of biogas and operating in permanent regime, the several operational parameters were measured.

The Technical specifications of the motor were: Mark: HONDA, GX-240; type of motor: Spark ignition, of carburetor, 4 times, valve in head, one-cylinder; compression ratio: 8/1; piston displacement: 242 cm^3; diameter x displacement: 73x58mm; maximum power: 5,97 kW to 3600 rpm.

For the experimental conditions of operation of the motor (3600 rpm and variable load) was verified that the voltage dependent of the power, working with biogas, varies slightly from 235 V (6,8% greater than the nominal voltage) for the work at no load to 225 V (2,3% greater than the noun) for the motor working with a completely opened butterfly valve, which indicates a reliable work of the motor in any charging load. It is possible to mention that to obtain electrical energy of quality a variation of up to ±5% of the nominal tension (220V) is admitted at the most (Peruvian Ministry of Energy and Mines, 1999). As far as the frequency of the current, this one undergoes smaller fluctuations to 2%.

Figure 6 shows the variation of the fuel specific consumption based on the power generated for two tests varying the biogas feeding. Both curves have coincident tendencies. The smaller value of the specific consumption of the motor is of 0,65-0,70 m^3/(kW.h) for a power of 4,25 kW. This value is in the rank that indicates Mitzlaff (1988) (0,65 – 1,0 m3/(kW.h)) for spark ignition motors of modified Otto cycle, although it is possible to mention that this rank has been obtained for biogas with a composition average of 60% of CH_4, whereas in our case the composition of biogas reaches a value of 80%. Also it's observed that the tendency of the curves is still decreasing, indicating that it is possible that the motor develops more power.

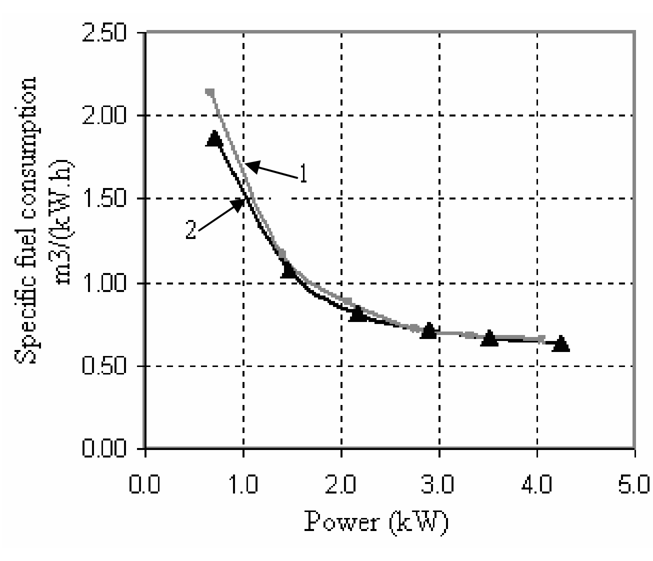

Figure 6. Variation of the specific consumption of biogas (m^3/(kW.h)) based on the generated power (kW). 1- with 10 holes of ϕ2 mm., 2- with 2 holes of ϕ2,2 mm and 8 of ϕ2mm.

The hourly consumption of biogas was 2,6 m^3/h at 4,25 kW (full load). The determination of the hourly consumption of biogas is important for the sizing of the plants of biogas, the mixer and other accessories. The effective thermal efficiency of the motor is of 18,7% at 3,1 kW. This relatively low thermal efficiency, in spite of the assumed low efficiency of the generator (80%), might be due to the small size of the motor. The coefficient of air excess, in all the rank of variation of the load, was lower than 1, it means, the motor always worked with rich mixtures, obtaining values that go from 0,72 for the work without load to 0,9 for the maximum loads of the motor. Worked with rich mixtures in all the rank of loads didn't allow to obtain greater thermal efficiencies.

Figures 7 and 8 show the levels of CO (%) and hydrocarbons HC (ppm) versus the coefficient of excess of air for the tests made with gasoline and with biogas. As in the case of other gaseous fuels, with biogas verifies that there is a significant diminution of the toxic emissions with respect to the work of the motor with gasoline. The CO is reduced approximately in 90% in slow motion, whereas the hydrocarbons are reduced until in 65% in this same regime.

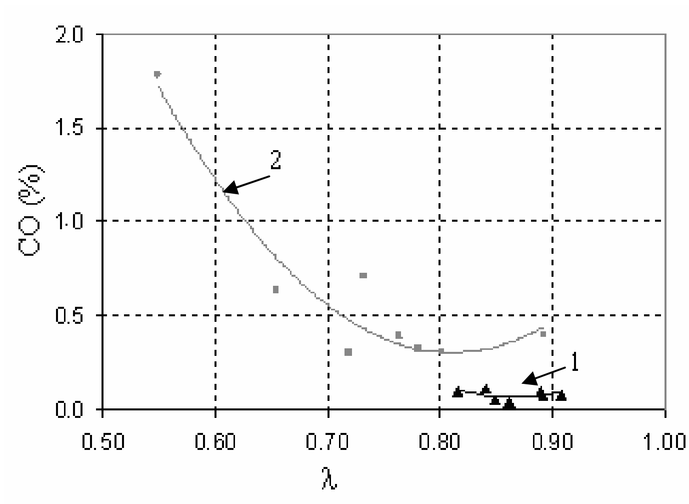

Figure7. Percentage of CO in exhaust gases based on the coefficient of excess of air (λ).1-with biogas, 2-with gasoline.

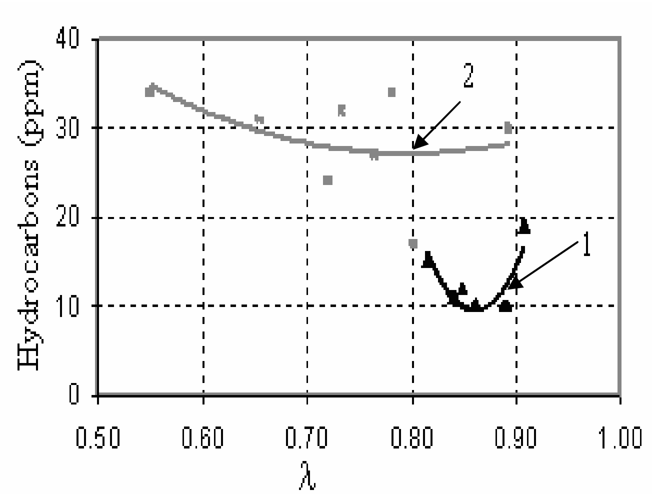

Figure 8. Hydrocarbon emissions (ppm) based on the air excess coefficient (λ). 1- with biogas, 2- with gasoline.

5. Conclusions.

It was implemented a system that allows an easy start-up of the motor and a reliable and safe feeding of biogas, using a simple and low-cost technology. These modifications allowed us to operate a stationary motor at suitable way with a fuel no specified by the manufacturer. This is very important because it's a way to help to the electrification of many rural and urban marginal communities which do not have access to the electrical energy. The system proposed requires any modification neither in the supplying fuel system nor in the speed regulator of the used motor.

The maximum power developed by the motor working with biogas is 4,25 kW, which is approximately 29% lower than nominal power of the motor (5,97 kW) working with gasoline. The test using biogas shows a specific consumption close to 0,65-0,70 m^3/(kW.h) at full load. The motor worked at stable manner in slow motion, in spite of not counting on a subsystem of feeding of biogas for low loads. The toxic emissions of exhaust gases are clearly smaller using biogas as fuel, which is very important from the ecological point of view.

6. Acknowledgement

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