Technical Note

Experience of biogas supply in a rural community, in Cuba♦

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Abstract

The objective of this paper is to present the experience of distribution of biogas generated in a pig production center (Pig Production UEBP El Colorado, Cabaiguán municipality, Sancti Spiritus province, Cuba) to a rural community in Cuba, to be used in food cooking and other domestic purposes. The biogas was obtained from the process of anaerobic digestion of the excreta of the animals, through two digesters which were part of the treatment system. The study evaluated the supply, consumption and utilization of the biogas produced in a pig production farm and 31 houses of the nearby rural community, with the installation of the biogas distribution network and applications in food cooking, water heating, lighting and refrigeration. Among the benefits, 11 t per year of firewood ceased being used for cooking in the kitchen of the UEB and the houses, the work was humanized and the workers were benefitted in the dining hall; in the houses electricity consumption decreased between 40 and 60 % as average; while 18,3 MW h/year of electricity from the National Grid (where 1 MW = 1 000 KW) were not consumed. In addition, the use of biogas for cooking contributed to improve the quality of life of 110 inhabitants and allows a fast recovery of the investment.

Keywords: energy source, excreta, pig

Introduction

Renewable sources of energy represent a feasible economic and environmental alternative for its supply to productive units and population settlements. Likewise, animal husbandry and agri-food waste constitute one of these renewable sources to obtain energy (Mofokeng *et al*., 2016), by utilizing the biochemical characteristics of biomass and the metabolic action of microorganisms to produce the gaseous fuel called biogas, through anaerobic digestion (Rota and Sehgal, 2015).

The technology of anaerobic biodigestion for biogas production contributes to decrease environmental contamination, reduce the emission of greenhouse gases, and save fossil fuels and chemical fertilizers; as well as improves the quality of life of people in rural and suburban zones (Vidal, 2013).

The main components of biogas are methane (CH_4) and carbon dioxide (CO_2), although the biogas composition varies according to the biomass used, its approximate composition is shown in table 1. Methane, main biogas component, is the gas that confers the fuel characteristics to it, while its energy value is determined by the concentration of this gas (around 20-25 MJ/m^3, compared with 33-38 MJ/m^3 in natural gas), according to Werner *et al*. (1989).

Generally, in most Latin American countries biogas has had limited use for food cooking and heating of farm animals (Carreras, 2013). However, the use of biogas in internal combustion engines for substituting fossil fuels has gained importance in recent years (IRENA, 2017).

Biogas can be used to replace gasoline up to 100 %, while in diesel engines only a maximum of 80 % is achieved, because the low ignition of biogas does not allow explosion to occur in this type of engines that lack a spark plug (Zapata, 2002). According to Marchaim (1992), for the use of biogas in engines it is essential to eliminate sulfhydric acid (H_2S), because it, when reacting with water, forms sulfuric acid (H_2SO_4) which is highly corrosive and can cause serious internal damage to the engine.

Nevertheless, unlike the existing international experience with natural or liquefied gas from oil, the experience related to biogas distribution to be consumed in houses is very scarce. Literature only reports the injection of biogas to natural gas networks in Sweden (Forsberg, 2014), Luxembourg

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Table 1. Average chemical composition of biogas.

Gas	Percentage of the total volume
Methane, CH_4	54-70
Carbon dioxide, CO_2	27-45
Hydrogen sulfur, H_2S	0-0,1
Hydrogen, H_2	1-10
Nitrogen, N_2	0,5-3,0

Source: Guerrero (2012)

(Jury *et al.*, 2010) and Spain (Hernández *et al.*, 2015).

The objective of this paper is to present the experience of distribution of biogas generated in a pig production center to a rural community in Cuba, for its utilization in food cooking and other domestic uses.

Materials and Methods

The pig production entrepreneurial unit (UEBP, for its initials in Spanish) El Colorado, located in the Cabaiguán municipality –Sancti Spiritus, Cuba–, has a rural community nearby, of the same name, with 80 houses and 250 inhabitants; the UEBP and the community are located at latitude 29° 05' 00" N and longitude 79° 30' 00" W, at a height of 101 m.a.s.l. The mean annual temperature is 26 ºC, with mean annual rainfall of 1 270 mm and relative humidity of 79 %.

The UEBP has two fixed-dome biodigesters (modified Chinese model), with 45 and 50 m^3 of digestion, respectively, constructed in the framework of the international project BIOMAS-CUBA, (photographs 1 and 2); both biodigesters treat the excreta of 600 pigs (50 % of the animal stock of the UEBP).

The two biodigesters, altogether, produce daily 90 m^3 of biogas, because of their high efficiency – due to improvements in their design, the discipline of operation of the system and to the diet supplied to the pigs (concentrate feeds)–; nevertheless, the productive facility only consumes daily between 15 and 17 m^3, for which there is a surplus of 73-75 m^3/day.

This situation demanded to search for an alternative use for the unutilized biogas and the decision was to distribute it to the adjacent community, where the house closest to the UEBP was 100 m away and the farthest one, 270 m away; in order to achieve higher energy utilization, improve the living conditions of women and men, as well as to eliminate the environmental contamination that would be generated if it is burned in a torch (because of the emissions of CO_2).

The biogas availability did not allow to supply it to all the houses, for which the selection criteria were the following: i) to prioritize the houses where workers of the UEBP lived; and ii) the houses in which the most vulnerable people lived, such as physically handicapped or blind people, elders, little children, which were completed with the closest houses.

Photograph 1. Biodigester of 45 m^3.

Photograph 2. Biodigester of 50 m^3.

Considering the geographical distribution of the 31 selected houses a distribution network was designed, which was constructed from a central line with an 18-mm high-density polyethylene (HDPE) pipe, which feeds the UEBP, and from which three branch lines of the same material start out supplying biogas to the houses, through rubber diverting pipes of 12 mm; such network has a total length of 2 150 m.

In order to know the biogas volume that enters the network, proportional to the consumption by the houses and the UEBP, two biogas meters were installed: meter 1 for the community and meter 2 for the productive facility, and weekly readings were performed.

The biogas cleaning was performed through an innovative system, with two filters that contain 25 kg of iron filings each and water up to a height of 15 cm, which allow to decrease the content of hydrogen sulfide –a corrosive gas–. The iron filings were washed every 25 days, adding water through the valve installed on the top, and after six months the filters were ready to reintroduce the iron filings; the residues of the filters were collected and deposited in the aerobic lagoon.

The filters were elaborated with two plastic 200-liter tanks; for draining them an 18-mm stopcock was placed on the lower part, and the reposition of the iron filings and water was carried out through the top part. The filters were evaluated through samples with three repetitions, in two measurement points (one before the gas entered the filters and the other after the biogas left them), using a portable LANTEC model GEM 2000 gas analyzer, made in the United States.

The expense of electricity in the houses was determined by processing the data provided by the Electrical Enterprise, and the historical consumption from 2008 to 2015 was analyzed. Through this analysis the consumption of each house before and after having the biogas service could be determined; in addition, the electricity saving in each house was calculated.

Results and Discussion

During the implementation of the biogas distribution system, the main challenge was the training and advisory of the community in the installation and utilization of this new energy source. Likewise, in order to make the system monitoring work more viable three responsible persons were selected by the community, one per each branch line, who monthly met with the specialists.

The installation of the pipes was carried out by the community members with the advisory of experts on the topic, and they were distributed according to the position of the houses. The location of the two biodigesters, the biogas distribution network and the 31 benefitted houses are shown in figure 1.

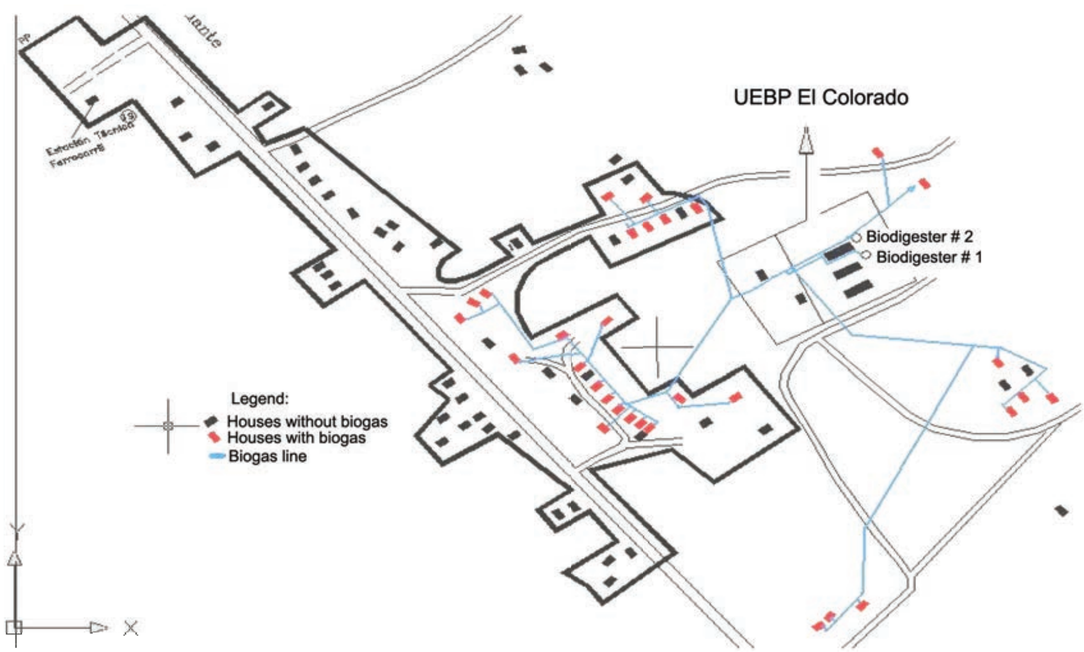

Figure 1. Location of the two biodigesters, the biogas distribution network and the 31 benefitted houses in the UEBP and El Colorado community.

To consume the biogas, three domestic cookers of two burners, an industrial stove of two burners, a rice cooker, five lamps and one refrigerator, which work with this gas, were delivered to the UEBP; as well as domestic cookers of two burners and a rice cooker to the 31 houses. After the installation of the two meters, the biogas consumption was measured through periodic reading, which is shown in table 2.

According to the measurements the following results could be obtained:

- Average biogas consumption per house: 1,5-1,7 m^3/day
- Average biogas consumption in the UEBP: 15-17 m^3/day
- Average consumption in the 31 houses: 60 m^3/day
- Average consumption per person: 0,5 m^3/day

Evaluation of the filters

The average content of sulfhydric acid (hydrogen sulfide) in the biogas produced in the biodigesters was 1 990 ppm before passing through the filters and 950 ppm after going through them. This reduction of 48 % is considered acceptable, but it is necessary to increase the filters as well as to improve the contact surface of the biogas inside the filter, and increase its circulation time within the system through the installation of serial filters.

Zapata (2002) indicated a content of sulfhydric acid between 0,125 and 0,176 % (1 250-1 760 ppm) in the biogas produced in biodigesters fed with pig excreta, similar to the 0,1 % reported by Tornero-Araujo and Ramírez-Vázquez (2015); likewise, Víquez-Arias (2010) reported a content higher than 0,2 % (2 000 ppm) of hydrogen sulfide in piggeries that used concentrate feeds, and less than 0,02 % (200 ppm) in non-traditional ones with diets of kitchen waste and forages. Sosa *et al*. (2014) reported higher concentrations.

The installation of the biogas distribution network generated diverse impacts, on the reduction of electricity consumption and the improvement of people's standard of living, as well as on the environment.

Before using biogas, the most used energy sources for cooking in the productive unit and the community, were electricity, diesel –costly– and firewood –difficult to be accessed due to its scarcity.

With regards to electricity consumption in the houses, before and after the installation of the biogas distribution network, it was determined with the information provided by the Municipal Electrical Enterprise. This information comprised a background of the electricity consumption in each house in the selected time period, from January, 2008, to December, 2014. It could be observed that after the installation of the biogas network installation, the electricity consumption in all the served houses decreased between 30 and 60 % (fig. 2).

After doing the evaluations the following results were obtained:

- Average electricity consumption before using biogas in the houses: 80,3 MW.h/year.
- Average electricity consumption after using biogas in the houses: 62 MW.h/year.
- Decrease of the electricity consumption: 18,3 MW.h/year.

It was observed that in several houses the consumption reduction was not noticeable, because they did most of the food cooking with firewood, to save electricity; that is why, the biogas supply has had a positive impact on the standard of living.

On the other hand, the daily cooking of food for 25 workers in the UEBP was carried out using firewood, whose combustion generated smoke that remarkably affected the working conditions. Likewise, the expenses for the search, preparation and transportation of firewood were high, due to the

Table 2. Reading of the biogas meters.

Meter 1. Houses		Meter 2. UEBP	
Reading number	Value (m^3)	Reading number	Value (m^3)
1	0	1	0
2	13 096,336	2	2 563,125
3	21 739,465	3	3 071,562
4	23 596,212	4	3 526,984
5	52 276,869	5	4 041,436
6	54 141,756	6	4 534,652

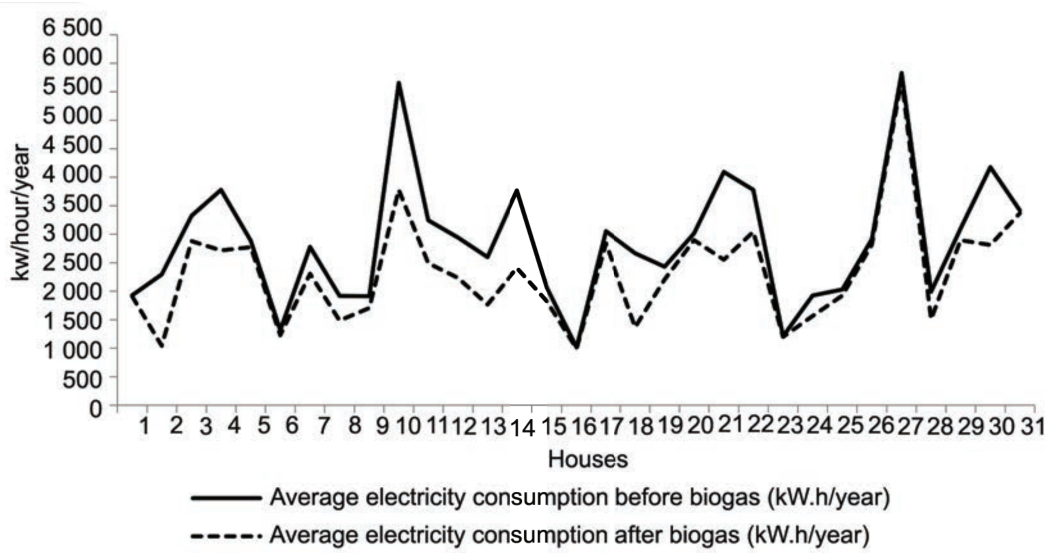

Figure 2. Performance of electricity consumption in the houses.

workers' salaries and the cost of diesel for the transportation –$ 3 500 CUP (Cuban peso) in salaries and $ 26 940 CUP in diesel, annually.

With the construction of the biodigesters 11 annual tons of firewood ceased being used for cooking, the smoke emissions were eliminated and the working conditions of the cooks were remarkably improved, who were also favored by the domestic equipment that consumes biogas. In addition, in the houses 3 380 liters of diesel stopped being consumed annually.

Other evaluated impacts were:

- The daily consumption of 90 m^3 of biogas allows to avoid cutting down 24 ha/year.
- The emission of 59,8 t CO_{2eq}/year, that is 1 255 t of methane, was avoided (calculations made from the methodology of GEF, 2008).
- 4 t/year of effluents were produced, which are used as biofertilizers to ameliorate the soils.
- The hygienic-sanitary conditions of the kitchen of the UEBP and the 31 houses were improved.
- The work of 15 people (men and women) who worked in the UEBP was humanized with the substitution of firewood by biogas, as well as the work of women in the 31 houses.
- 25 people were directly benefitted in the dining hall of the UEBP, and the standard of living of 110 inhabitants (65 % of the total population) in the El Colorado community was improved.

The total cost of the investment, including the two biodigesters, was 121 213 CUP; while the total saving per year of exploitation of the biogas distribution network reached 63 310 CUP; likewise, it was calculated that the investment is recovered at the end of the second year of exploitation and the net present value (NPV) is higher than zero, for which the investment is justified from the economic point of view (table 3).

Conclusions

The experience of biogas production from the excreta of animals and its distribution for domestic use, developed in El Colorado UEBP and rural community, showed its pertinence and feasibility, and becomes a reference of the promotion of agroenergy.

The biogas distribution network generated, in the UEBP as well as in the houses, a positive effect on the saving of firewood, electricity and diesel; on the improvement of the standard of living and working, as well as on the environment. In addition, the investment of the whole system, including the two biodigesters, is recovered at the end of the second year of exploitation.

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Table 3. Economic analysis of the investment.

Indicator Calculation basis used: 1 USD = 1 CUC; 1 CUC = 10 CUP (value used by the MEP)	Currency	Year 1	Year 2	Year 3	Year 4	Year 5
Cost of biodigester 1	CUC	4 570				
Cost of biodigester 2	CUC	4 715				
Cost of installation in UEBP	CUC	428				
Cost of installation in houses	CUC	2 500				
Cost of total investment	CUC	12 213				
	CUP	121 213				
Useful life (years)	25					
Incomes (%)		0	0	0	0	0
Interest rate (%)		0	0	0	0	0
Cost of electricity	0,21 USD/kW.h					
Energy not consumed from the National Grid	MW.h/year	18,3	18,3	18,3	18,3	18,3
Saving for the Basic Electrical Organization (MW.h/year x 210 $/MW.h)	USD/year (= CUC/year)	3 843	3 843	3 843	3 843	3 843
	CUP/year	38 430	38 430	38 430	38 430	38 430
Saving in the houses	CUP/year	2 338	2 338	2 338	2 338	2 338
Saving for firewood substitution	CUP/year	428	428	428	428	428
Saving for diesel substitution	CUC/year	2 694	2 694	2 694	2 694	2 694
	CUP/year	26 940	26 940	26 940	26 940	26 940
Total saving	CUP/year	68 140	68 140	68 140	68 140	68 140
Depreciation	CUP/year	4 830	4 830	4 830	4 830	4 830
Saving-depreciation (cash flow)	CUP/year	63 310	63 310	63 310	63 310	63 310
Accumulated cash flow	CUP/year	- 57 903	5 407	68 717	132 027	195 337
Period of investment recovery			1,91			
Net present value > 0	118 950					

CUC: Cuban convertible peso, MEP: Cuban Ministry of Economy and Planning.

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