Agrisost|2016, Vol.22, No.3: pages: 51-59 **ISSN 1025-0247**
Available at: http://www.agrisost.reduc.edu.cu

Efficiency of Livestock Residue Treatment in Geomembrane Digesters

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Received: June 3, 2016
Accepted: November 17, 2016

ABSTRACT

The efficiency of twelve 10 m^3 geomembrane biodigesters to treat swine and cattle residuals was assessed. The study took place at the Cooperative of Credits and Services (CCS) of the municipality of Cumanayagua, Cienfuegos, Cuba. Its goal was to evaluate feasibility of technology implementation in Cuba. The effluent physical and chemical indicators were determined at entry and exit from biodigesters. The biodigesters charged with pig manure were able to remove 75.88% COD, and up to 66-44% SS. Besides, 64.79% of the contaminating organic load was converted into volatile products during biofermentation. Meanwhile, the biodigesters charged with cattle manure removed 60.42% of COD, and up to 67.67% of SS; 61.51% of the organic contaminating load was converted in volatile products. It was concluded that the biodigesters had acceptable efficiency values, and that the technology can be applied in Cuba.

Key words/: renewable energy, livestock, methane, biogas

INTRODUCTION

The search for sustainable alternatives of intensive animal manure treatment is a top priority internationally (IEA, 2013) Fernández *et al.*, 2014 considered that digester technology offers simple solutions to the final stage of livestock excreta.

Several designs and technologies have been used in digesters. According to Hilbert (2003), Ramón *et al.* (2006), Olaya and González (2009), Oviedo (2011), Guardado (2013), Guzmán (2014) and Blanco (2015), are the ones with fixed dome, removable cover, and geomembrane base (PVC), all are useful and differ from one another, but they have the common disadvantage of not being effective to cope with large volumes. However, many private producers using relative small masses, located in fragile ecosystems (mountains), need small and practical biodigesters.

To address that problem, tests have been made with horizontal tubular geomembrane biodigesters (Díaz and Vega, 2013, and Blanco *et al.*, 2015). The type of building material is a key factor. Poggio *et al.* (2009) and Blanco *et al.* (2015), noted that between 2007 and 2008, thirteen tubular family biodigesters

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were installed (11 made of polyethylene and 2 made of PVC), at the Japon Mayo basin, in Perú. In the late 2008, the state of biodigesters was assessed (30% were useless, all polyethylene).

Another important factor to consider in biogas manufacturing is the organic material, since several types of residues and sub products of agriculture, forestry, industry, excreta from animals (cattle, pigs and buffalos) and humans, meat processing residuals, and even water hyacinth have been used for commercial production of methane in developing and industrial countries (Krishna *et al.*, 1991).

Anaerobic digestion is a widely spread small-scale technology in India, China and Nepal. In China and India, there were more than 44.5 million biodigesters by 2011 (Martí, 2015). In the European Union countries there are more than 4 000 biogas plants (Kumar *et al.*, 2000). Countries in Latin America are also developing industrial projects to make biogas from organic waste.

In 2006, Bolivia implemented a housing project that included self-powered homes (250 polyethylene tubular biodigesters were installed), in rural areas to treat organic wastes from small, mid and large farms (Campero, 2008).

In 2003, Mexico started the first electric power generation project using biogas from anaerobic fermentation of the municipal organic solid residues, in Salinas Victoria, Nuevo León. Since the first biodigester, several biogas plant models have been developed and passed, in order to increase efficiency and lower their costs (Kaiser *et al.*, 2002).

The pilot project presented has contributed with the installation of 47 family biodigesters, in rural communities in Cumanayagua. The aim of this study was to assess the efficiency of twelve geomembrane biodigesters on small-scale farms, and feasibility of the technology in Cuba.

MATERIALS AND METHODS

A non-experimental study was made, in a population comprising 47 small-scale farms, on mountains or nearby areas, and in the plains, in the mid-east Cumanayagua. The sample included 12 cases chosen at random, between 2013 and December 2015.

In 2013, twelve 10m^3 PVC geomembrane biodigesters were installed. Two samples (entry and exit) were collected from each biodigester during operation.

Sampling and physical and chemical assay to residues

Residue sample taking was made according to Bartram and Rees (2000). The samples were collected between 8:00 A.M., in 1.5 mL capped plastic containers, previously washed and labeled, and dried in the sun. The samples remained in ice boxes in the dark, until they were taken to the lab.

The tests were made at the National Institute of Water Resources (INRH), in Cienfuegos, following the Standards Methods for the Examination of Water and Wastewater (APHA, 1995), and sanctioned by the National Accredited Body of the Republic of Cuba (ONARC). The values achieved were compared to the standard in NC 27:1999, that regulates wastewater discharges to Class A receptors.

Evaluation of efficiency in geomembrane biodigesters

To evaluate the efficiency of biodigesters during operation, several indicators were calculated; such as removal percent, solid percent in the mixture (Sm), Total Volatile Solid percent (TVS), daily gas production (Gp), and methane production (Mp).

Statistical analysis

The data were processed using IBM. SPSS v15. A mean comparison was made for two independent samples, from a t test, significance 0.05. The percent data were changed according to function $2*\sin^{-1}\sqrt{x}$ for analysis.

RESULTS AND DISCUSSION

Residue alkalization was produced in the evaluated systems during the process, with pH increase, without statistical differences between the two. This change owed, partly, to the hardness of the local water, but also to the generation of carbonates during anaerobic digestion of organic matter (Rendón, 2007).

The values found in the test coincided with the values achieved by Ruiz (2010) and Blanco *et al.* (2015), who pointed out that when anaerobic digestion is made in a biodigester, several phases occur. In each phase, microorganisms expressed their maximum activity within a distinct pH range, with a methanogenic phase between 6.5 and 7.5. Furthermore, Stams (2004) noted that a pH increase at the end of the process indicates that the reactor converts organic matter into volatile fatty acids and carbonates, efficiently.

According to the lab results, the indicators related to organic load experimented a marked decline when the residues had already gone through the biodigester. The biodigesters charged with swine manure (7), 75.8% of COD, and up to 66.44% of SS, on average, were removed. It also made possible that 64.79% of the organic contaminating load is converted into volatile products during biofermentation. In the biodigesters that used cattle manure (5), 60.42 % COD, and up to 67.67 % SS, were removed. Additionally, 61.51% of the contaminating organic load was converted into volatile products.

A central logarithmic trend analysis (Fig. 1 and 2) revealed that the former group of biodigesters kept VTS removal levels within 53% and 69%; COD oscillated between 37% and 99%. The latter experimented lower VTS motility (55%, 68%), with higher COD fluctuation (11%, 78%). However, there are still problems with some reactors (1 and 5), which was reflected in the low removal percent observed.

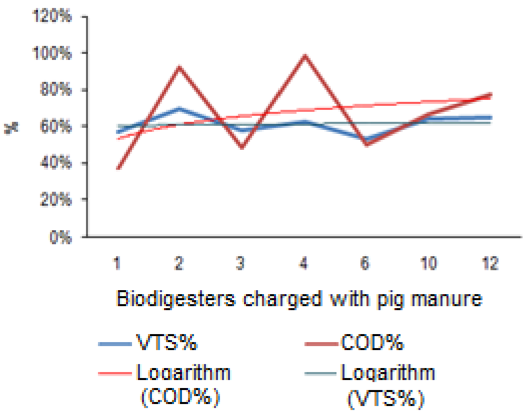

Figure 1: VTS and COD removal from swine manure-fed biodigesters. Source: Report from INRH, Cienfuegos.

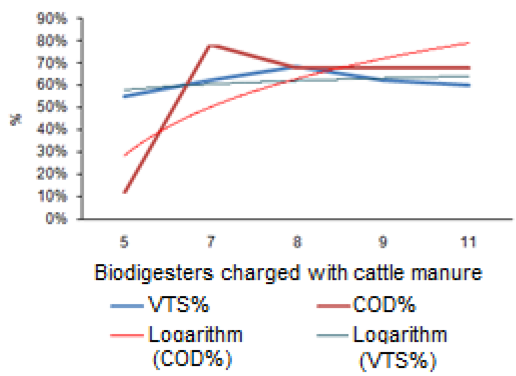

Figure 2: VTS and COD removal from cattle manure-fed biodigesters. Source: Report from INRH, Cienfuegos.

The systems revealed acceptable results in general terms, though studies made by Guzmán (2013a, 2013b and 2013c) showed that in similar systems the COD removal values could be above 60%; VTS, between 55% and 85%, which are favorable efficiency values, both for biogas generation and removal of the contaminating load from the digesters in the study.

Moreover, when comparing the results achieved to the standard values (NC 27/99) set by the National Standardization Office in Cuba for wastewater discharges to class A receptors, values went beyond the maximum permissible limits, except for the pH. It corroborated the fact that the effluent cannot be discharged or poured into courses or receptors containing natural water, or sewage systems, because the quality demands were not met, or because organic matter removal was not achieved. It coincided with regulations made by the Unit of Mining and Energy Planning, (tables 1 and 2).

Table 1: Values of the main variables evaluated on exit from swine substrate-fed biodigesters

Biodigester	pH	CE	DQO	DBO	ST	STF	STV	SS
1	7.11	4320	5392	237	20076	480	2671	45
2	7.00	3240	285	69	1464	480	2111	5
3	6.24	5390	21068	900	22198	6012	2881	300
4	7.95	4490	405	100	1894	1020	2581	0.9
6	6.99	3730	2214	1307	1000	480	3171	12
10	7.20	6000	1578	1050	1500	490	2471	40
12	7.19	2262	329	72	1440	265	6381	5
NC 27/99	(6.5 - 8.5)	1400	70	30	-	-	-	1

Source: Report from INRH, Cienfuegos.

Table 2: Values of the main variables evaluated on exit from cattle substrate-fed biodigesters

Biodigester	pH	CE	DQO	DBO	ST	STF	STV	SS
5	7.15	4470	8008	2135	8542	480	3111	42
7	6.99	1852	306	114	1000	480	2571	4
8	7.76	6460	8058	145	7288	265	5850	10
9	7.19	2512	331	77	1400	270	6645	5
11	6.99	2790	1417	670	4180.00	280	2571	40
NC 27/99	(6.5 - 8.5)	1400	70	30	-	-	-	1

Source: Report from INRH, Cienfuegos.

Quality of bio. generated in each biodigester

Biol quality in the systems assessed resulted negative for use in 58% of the samples, according to the evaluation criteria by Guzmán (2913a); the key factor effecting on the results is the retention time (short), that blocks digestion of all organic matter in the anaerobial process.

Usage under such conditions is detrimental, as it affects organic matter retention and the destruction of the edaphic micro fauna (Technical Department, PRONACA, 2016). Based on reports by the Unit of Mining and Energy Planning (2003), and Guzmán (2013a), effluents require proper facility and storage. Depending on its quality, they can be kept for 5.15 days. After that, and due to environmental action, they are no risk to health.

In these conditions, biogas daily production is approximately 0.2 m3 biogas/m^3 digester/day, within the range described in the literature for anaerobic digestion (Kashyap *et al.*, 2003). It can be used as fuel, only when methane is in concentrations 50% or higher (Rodríguez, 2012). The values achieved were between 62% and 64%, and always above the set standards, depending on the groups studied (table 3).

Table 3: Evaluation of methane emission decline in the biodigesters

Producer	Methane (%)	Carbon dioxide (%)	Methane values			
			Minimum	Maximum	Mean	Mid
Results for digesters using swine residues						
P1	57	38	53	91	64	69
P2	69	26				
P3	58	37				
P4	91	4				
P6	53	42				
P10	64	31				
P12	90	5				
Results for digesters using cattle residues						
P5	55	40	55	90	62	66
P7	62	33				
P8	62	33				
P9	90	5				
P11	60	35				

Source: Report from INRH, Cienfuegos.

Another analysis has to do with the amount of methane that was not emitted, as a benefit produced by the technology installed, accounting for 9414 m3/year, in 300 days of operation, where 72% corresponds to biodigesters using swine residues, and 28% to digesters using cattle substrate. The rest is dumped into the atmosphere (17202 m^3/year).

There is also a potential capacity for biogas generation, which is related to the amount of excreta produced (1.76 m^3/day; 20.9 m^3/day) for biodigesters charged with pig manure, and (2.7 m^3/day; 22.5 m^3/day) for the rest. The limits are will depend on the size of the biodigester (2.7 m^3/day). As a result, annual biogas production was 11058 m^3.

The values observed coincided with the values achieved by Rodríguez (2015), who noted that a 10m^3 geomembrane biodigester, located in the province of Ciego de Avila, Cuba, using residues from 40 pigs produced 756 m^3 of biogas, annually. Besides, it could reduce methane emissions in 630 m^3 a year. On Hervedro farm, in Cumanayagua (biodigester No. 12), operating on similar conditions, 810 m^3 of biogas are produced yearly, producing a reduction in methane emissions of 729 m^3. Both examples are part of a project directed by ANAP, Program for Small Donations by UNDP.

The results of efficiency indicators evaluated (Table 4) evidenced that the highest percent was observed in biodigesters charged with pig manure. In other words, they removed a larger quantity of organic matter during operation.

However, Ms and VTS had significant differences ($p<0.05$) toward systems charged with cattle manure, thus making possible that a larger organic load could be turned into volatile products.

Table 4: Efficiency indicators for biodigesters according to livestock type

Livestock	Removal	Sm	STV
Swine	1.99 ± 0.21	0.58 ± 0.07	1.79 ± 0.04
Cattle	1.77 ± 0.27	0.60 ± 0.05	1.80 ± 0.04
ES ±	0.542	0.881	0.958

$P<0.005$ (Duncan, 1955)

CONCLUSIONS

Anaerobic fermentation made in twelve 10m^3 PVC geomembrane tubular biodigesters, in Cumanayagua, has the potential to generate 9414 m^3/year of methane gas (CH_4), during 300 days of operation. Digesters using pig residues accounted for 72%; whereas, only 28% was generated by digesters using the cattle substrate. The rest goes into the atmosphere (17202 m3/year).

Considering the short time of retention and the inter-daily load (0.5 m^3 of excreta), non-usable organic fertilizer (biol) was generated in 58% of the cases studied. Its use is detrimental, and produces nutrient unbalances in the soil, that affect organic matter, and destroy the edaphic micro fauna.

The mid-eastern region of Cumanayagua has a potential for renewable energy from available biomass. It reduces the appearance of wastewater that may cause environmental problems, along with a decline in greenhouse gas emissions. Additionally, acceptable operational levels -biogas production and removal of the contaminating load. Therefore, the adoption of small-scale technology can be implemented by local farm owners.

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