UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica
Más que un estado sólido
https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRONICA
A Research Vision

Preliminary biodigestor design from swine manure generated in San Andrés island

Dimensionamiento preliminar de un biodigestor a partir de porcinaza generada en San Andrés isla

Luisa Marina Gómez-Torres[1], German Arturo López-Martínez[2]
Carlos Julio Lozano-Piedrahita[3]

INFORMACIÓN DEL ARTICULO

Historia del articulo
Enviado: 28/11/2018
Recibido: 03/12/2018
Aceptado: 25/12/2018

Keywords:
Anaerobic digestion,
Biodigestor,
Electric generation,
Methane.

Palabras clave:
Digestión anaeróbica,
Biodigestor,
Generación eléctrica,
Metano.

ABSTRACT

Livestock production in San Andrés is subsistence, there are 2,223 pigs, in 205 farms. This technology generates serious contamination problems. The results of the dimensioning a biodigester are presented, with the BioDigestor© software, from swine manure, with the objective of observing the technical-economic feasibility for the implementation of this technology. The capacity of the biodigester allows the processing of 12.31 t/d of manure, generating 276 MWh/year of electrical energy through the operation of a generator engine that works with biogas. The dimensioning of the biodigester included the calculation of the volume of the feed tank, biodigester, discharge tank, biogas storage, sludge drying bed, collection and conduction systems, heating and biogas utilization. An economic study was carried out which allowed to conclude on the viability of the project. The total cost of the digester amounts to 723,986,263 COP, which is equivalent to 21,925 COP/kW installed.

RESUMEN:

La producción pecuaria en San Andrés es de subsistencia, hay 2,223 porcinos, en 205 predios. Esta tecnología genera serios problemas de contaminación. Se presentan los resultados del dimensionamiento de un biodigestor, con el programa BioDigestor©, a partir de porcinaza, con el objetivo de observar la factibilidad técnico-económica para la implementación de esta tecnología. La capacidad del biodigestor permite procesar 12.31 t/d de estiércol, generando 276 MWh/año de energía eléctrica mediante la operación de un motor generador que funciona con biogás. El dimensionamiento del biodigestor comprendió el cálculo del volumen del tanque de alimentación, biodigestor, tanque de descarga, almacenamiento de biogás, lecho de secado de lodos, sistemas de captación y conducción, calefacción y aprovechamiento del biogás. Se llevó a cabo un estudio económico el cual permitió concluir sobre la viabilidad del proyecto. El costo total del digestor asciende a 723,986, 263 COP, lo que equivale a 21,925 COP/kW instalado.

1 BSc. In Chemical engineering, Universidad Nacional de Colombia, Colombia. MSc In Environmental engineering, Universidad Nacional de Colombia, Colombia. PhD. In Chemical engineering, Universidad Nacional de Colombia, Colombia. Current position: Interdisciplinary Group of Environmental Studies, GEA: Escuela Tecnológica Instituto Técnico Central, Colombia. E-mail: lmgomezt@gmail.com lmgomezt@itc.edu.co ORCID: https://orcid.org/0000-0002-4700-5939
2 BSc. In Mechanical engineering, Universidad de América, Colombia. MSc. In Mechanical engineering, Universidad de los Andes, Colombia. Current position: Interdisciplinary Group of Environmental Studies, GEA: Escuela Tecnológica Instituto Técnico Central. Research Group on Alternative Energies, GIEA-UD: Universidad Distrital Francisco José de Caldas, Colombia. E-mail: germanlopezm@yahoo.es galopezm@udistrital.edu.co germanlopezm@itc.edu.co ORCID: https://orcid.org/0000-0003-3280-9026
3 BSc. In Electomechanical engineering, Universidad Antonio Nariño, Colombia. MSc. In Health and Safety at Work, Universidad Nacional de Colombia, Colombia. Current position: Department of Systems and Industrial Engineering: Faculty of Engineering, Universidad Nacional de Colombia, Colombia. E-mail: cjlozanop@gmail.com cjlozanop@unal.edu.co ORCID: https://orcid.org/0000-0002-7322-5046
Cite this article as: L. M. Gómez-Torres, G. A. López-Martínez and C. J. Lozano-Piedrahita, "Preliminary biodigestor design from swine manure generated in San Andrés island", Visión electrónica, algo más que un estado sólido, vol. 1, no. 2, Special edition, july-december 2018. DOI revista: https://doi.org/10.14483/issn.2248-4728

1. Introduction

One of the main problems of the swine activity is the handling of excreta, since they are produced in large quantities and must be removed from the place where the pigs are housed. The accumulation of this waste contaminates the aquifers, rivers and lakes due to the leachate generated, as well as the bad odors and associated vectors. Pig manure is seen as an important environmental pollutant, but during its treatment it generates very valuable byproducts, such as methane and organic fertilizer, which can make pig production sustainable in San Andres Island [1].

The livestock sector in the island represents 30% of the agricultural activity, being the pig production the most representative with 2,223 animals, distributed in 205 piggeries [2], established all over the island, including on strategic ecosystems such as mangroves and Beaches. This sector, due to the way in which it has been handled, generates negative impacts to the environment, mainly due to the inefficient collection and final disposal of liquid and solid waste, which, paradoxically, is an excellent potential raw material for the preparation of fertilizers [1].

The main problems of the sector in the Island include inadequate management practices, nutritional limitations, precarious sanitation protocols, improvised constructions, inefficient management system and continuous generation of negative environmental impacts by the final disposal of waste in the adjacent areas to the spaces of stabling, especially in pig and poultry activities [1, 3]. Due to this, the environmental authorities demand the implementation of cleaner production systems, which is why the search and the formulation of viable alternatives for the treatment of waste from livestock production is justified [4].

Pig farming has a number of weaknesses, mainly related to the inadequate integral management of its wastes, a limited architecture of the pigsties, which does not allow in most cases, the implementation of technologies for the treatment of organic wastes, and the need to complement concepts, skills and abilities of agricultural producers. In this context, anaerobic digestion is a technology with minimal economic investment, increases water savings, prevents pollution, generates inputs used for agricultural production and is available to small producers [1].

Additionally, the energy demand in San Andres Island is 158 GWh / year, a relatively high value compared to its size. The main reason for this consumption is the high population density. Electricity is generated by a 55 MW power plant, which has diesel generators and consume more than 40 million liters of fuel per year [5]. For this reason, the use of different renewable energy sources is justified, among them residual agricultural and livestock biomass, to help replace the generation of electric energy with fossil fuels.

The main purpose of this article is to propose a preliminary dimensioning of an anaerobic digestion system for the generation of biogas, taking advantage of all residual livestock biomass produced, for the generation of electricity on the island.

2. Materials and methods

From the national swine census [2], it was determined that on the island of San Andrés there are 2,223 pigs, from piglets from 1 to 60 days of age to Sows of more than 240 days, and Boars of more than 180 days, distributed in 205 properties, all in the form of exploitation in backyard.

According to the swine census and the type of exploitation carried out on the Island, there is an average of 10.8 pigs per farm, a low value, when compared to technified farms that exist in the continental zone of the country; However, due to the relatively small size of the Island (25 km2), a concentration of 8.2 properties per km2 is obtained, and about 89 pigs per km2, relatively high values, which allow us to think about some energy exploitation project, through a network of distribution of biogas, or biomethane, which could supply an electric power generation plant in some strategic location, taking into account that the production of electric energy is approximately 6.8 kWh / m3 of biogas [6].

The BIOdigestor PRO Version 3.5 software was used to perform the biodigester calculations using porcine residual biomass. This program considers the production of excreta (feces + urine + water) as 8.4%, which is a value similar to those reported by the literature where it is mentioned that the average production of excreta in fattening can be one tenth of the live weight per day (solid and liquid), with a content of 10% dry matter [7]. It was taken into account that the average temperature on the Island is 27 ° C, and according to the amount and type of swine, the average live weight of the animal was considered to estimate the amount of manure produced that will be fed of the biodigestion system (Table 1).

Production stage	Pigs	Average Weight kg	Excreta Production t/d	Dry mass kg/d	Volatile mass kg/d
Piglets 1-60 days	819	15	1.03	103.2	82.56
Porker s 61-120 days	622	50	2.61	261.2	208.99
Butcher hog 121-180 d ays	335	106	2.98	298.2	238.56
S ows 120-240 days	194	135	2.20	220.0	176.00
Sows more 240 days	205	160	2.76	275.5	220.42
Boar s + Butcher hog 180 days	48	180	0.73	72.6	58.06
Total	2,223		12.31	1,230.7	984.59

Table 1. Summary of the substrate for the feeding of the biodigester in San Andrés, 2016. Source: own.

2.1. Dimensioning of biodigesters

The biodigesters are sized according to the type of biogas storage, geometry, type of construction materials and according to their position with respect to the surface [6]. Using the Biodigestor © software, a general scheme of the layout and dimensioning of the equipment was generated, all this depending on the volume of biomass feeding. The structures that were dimensioned were the feed tank, the feeding system, the biodigester, the discharge tank, the drying bed, the biogas collection and conduction pipes, the biogas purification system, the generation system of electric and calorific energy and torches, which correspond to the typical structures that make up a power generation plant through the use of available biomass.

2.2. Application of the Biodigestor Software.

The requested information was introduced related to the project data and the biomass source. The waste option was selected based on the average weight and number of animals. Subsequently, the data were entered according to the source of manure production, the software calculated the biogas and energy production, the geometry, and the dimensions of the biodigester, as well as the costs for its implementation.

3. Results and discussion

The dimensions of the elements that make up the proposed system and the technical characteristics of the sections required by the power generation plant were calculated

3.1. Structures and supply pipes

The feed tank was sized for the daily supply volume of the biodigester. The mixture is made once a day and is programmed so that all this load is fed to the biodigester at intervals of 24 hours, automatically or manually. This volume includes the volume of biomass and water that is used for dilution. The proposed design for the tank then has two inputs for manure (collected and mixed), along with an outlet to the digester. The volume of manure production is 12.31 t / d, with an assumed total solids percentage of 10 %. Table 2 presents a summary of the sizing of the main structures of the biodigestion system, including the feed tank.

Description	**Diameter (m)**	**Height (m)**	**Long (m)**	**Width (m)**	**Volume (m^3)**
Feeding tank	3.61	1.2	–	-	12.31
Biodigester	-	4	9.30	13.95	213.00
Discharge tank	-	1.2	6.79	4.53	36.93
Sludge drying bed	-	0.5	5.23	3.48	9.10 (m^2)

Table 2. Summary of the sizing of the structures. Source: own.

The feed pipes conduct the biomass from the mixing or feeding tank to the bottom of the biodigester. These pipes discharge about 50-100 cm from the bottom of the biodigester. They should be straight and as far as possible should not be installed with elbows pipes to facilitate cleaning. The recommended diameter of the pipe (Figure 1) is maximum 100 mm (PVC pipe 4").

The main objective for the construction of a biodigester, is to obtain a high production of biogas and a high reduction of organic matter per unit volume of the biodigester. The project must be designed based on the biomass available and based on the biogas and / or energy requirements of the installation. The required volume of the biodigester depends on the type and amount of substrate, the operating temperature, the agitation system, and the volumetric organic load applied [8].

The dimensioned digester is of the lagoon type, where a semi-buried or underground lagoon and a perimeter wall are built, where a membrane is fastened (Figure 1) The bottom of the lagoon is covered with a waterproof material and a flexible membrane that stores the biogas is placed on the lagoon cover [9]. The volume of mixture collected daily, multiplied by the number of days that the load will be in the digester (17 d), allows knowing the necessary volume of the digester, which for the case is 213 m3 of capacity (Table 2).

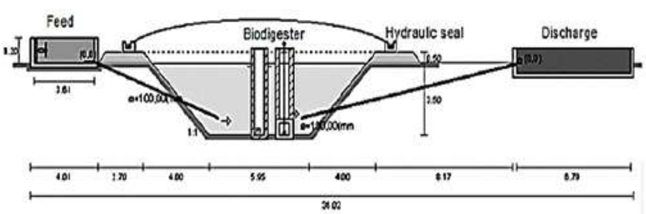

Figure 1. Dimensions of the biodigester. Source: own.

Likewise, the calculation of biogas production is approximately 393.17 Nm3/day. The digester has the following dimensions: length 9.30 m, width 13.95 m and height 4 m (Table 2), and the characteristics of the electromechanical equipment necessary for the operation of the biodigester are presented (Table 3).

Description	Quantity	Capacity	Units
H_2S removal filter	1	16	m^3/h
Generator	1	31	kW
Biogas burner	1	16	m^3/h
Agitators for biodigester	2	2.1	kW
Heating system	1	3.1	kW
Feed tank mixer	1	0.5	kW

Table 3. Characteristics of electromechanical equipment. Source: own.

3.2. Discharge piping

The discharge pipes extract the degraded liquid component of the biodigester and that can later be used as fertilizer material. At least two discharge pipes with a minimum diameter of 100 mm must always be installed. It is recommended to use PVC pipe (SR17) as it is more resistant to aggressive water. The same recommendation is valid for the supply pipes. The discharge tank has an inlet and an outlet, and its dimensions are: 6.79 m, 4.53 m and 1.2 m (Table 2). A pump is used to discharge the contents of the tank and take it to the sludge drying bed, to later use it as fertilizer. The availability of nutrients is 22.89 kg / day of nitrogen, 8.86 kg / day of phosphorus and 6.17 kg / day of potassium. Table 4 shows the daily and annual production of organic fertilizer.

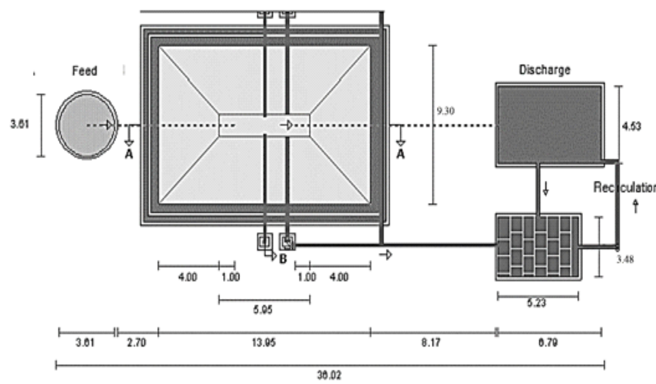

Figure 2. Dimensions of the biodigester, including the area of agricultural use and marketing. Source: own.

3.3. Production of biogas, electric power and energy equivalences.

The production of biogas and methane is 143,507 m3 / year (393.17 m3 / d) and 93,279 m3/year (255.56 m3/d), respectively. Table 5 shows the production of electrical energy with their respective carbon dioxide equivalents. In Table 6 the results obtained referring to the specific productions of biogas and methane respectively.

Tons equivalent CO_2	1,386	(t/y)
Power to install	31	(kW)
Heat power	58	(kW)
Electricity production	275,812	(kWh/y)

Table 5. CO2 equivalences, power to install and electricity production. Source: own.

Unit	Biogas	Methane
Per m^3 of biodigester	1.84 (Nm^3/d)	1.20 (Nm^3/d)
Per m^3 of biomass	31.94 (Nm^3/m^3)	20.76 (Nm^3/m^3)
Per kg dry mass	0.32 (Nm^3/kg MS)	0.21 (Nm^3/kg MS)
Per kg volatile mass	0.40 (Nm^3/kg MV)	0,26 (Nm^3/kg MV)

Table 6. Specific production of biogas and methane. Source: own.

3.4. *Biogas collection pipes*

It is recommended that the collection of biogas be made in the perimeter wall that serves to hold the cover membrane. For the dimensioning of the biogas collection pipes, the biogas production volume of the biodigester must first be determined. Based on this production volume, the number of collection pipes is determined. The diameter of each pipeline is determined based on the maximum conduction velocities of each pipeline and the volume of biogas that each pipeline must capture. Pipes with diameters greater than 75 mm should preferably be installed for biodigesters with a volume ≥ 100 m3 [9].

3.5. *Safety valves*

A safety valve must always be installed to control the maximum and minimum pressure. The minimum pressure prevents the digester from handling negative pressures and from entering the air in an excessive way, inhibiting the anaerobic digestion process or promoting the formation of explosive atmospheres by the mixture of biogas with oxygen. And the maximum pressure prevents the biodigester from becoming too full of gas and the membrane to burst or come loose from the ties [9].

3.6. *Sizing of biogas generators*

Biogas can be used as fuel in generators for the production of electricity or in fossil fuel replacement boilers. It can also be used to produce heat. The biogas has a calorific power of 6.25 kW / m3 and the methane of 10 kWh / m3. In order to dimension a generator, it is necessary to consider the degree of efficiency of all the units that make up the generator and the energy losses due to the mechanical movement of the motor and alternator [9]. It can be assumed that 1 m3 of biogas with 65% methane can produce approximately 1.92 kWh of electricity. Table 7 shows the production of biogas and the equivalence of electrical energy. It is recommended to install a generating unit with a power of 10% greater than the nominal one in this case 31 (kW).

	Per day	**Per year**
Biogas production: (Nm^3)	393.17	143,507
MWhe	0.755	276

Table 7. Energy equivalences of the biogas generated. Source: own.

3.7. *Economic study*

For the economic study, an initial investment for the plant was calculated equal to approximately 718,484,514 COP. Annual expenditures were calculated as follows: depreciation costs (COP 84,781,455), operation and maintenance costs (COP 9,498,837), labor cost (COP 79,658,527), and other costs (COP 107,772,677). On the other hand, the annual income that the plant receives are for: electricity produced (97,647,193 COP), commercialization of organic fertilizer (305,676,323) and marketing of carbon CERs (53,976, 618 COP). With these values the project presents an annual income-expenditure performance is 135,164,589 and an internal rate of return (IRR) is 0.19.

These values do not include the costs of harvesting the biomass produced in each farm, nor the transportation of it to the biodigestion plant, actions that must also be adjusted to the respective regulations in force.

4. Conclusions

The methodology for the design of a biodigester that produces 393.17 m3 of biogas per day was presented, which allows the generation of 276 MWh / year of electrical energy, from the organic waste of 2,223 porcines. The design included the collection tank, biodigester effluent tank, control systems. The BIOdigestor PRO version 3.5 software was used to generate the simulation of the preliminary biodigester design.

The financial analysis of the project concludes that an investment of close to COP 719,000,000 is required. The income associated with the operation of the plant is related to the electricity produced, the sale of organic fertilizer and emission reduction certificates (CERs) to projects whose activity reduces the amount of Greenhouse Gases (GHG). It is noteworthy that the values considered for this income were calculated conservatively and the IRR of 0.19 indicates that the investment can be recovered before the expected period.

In conclusion, it can be said that the construction of a biodigester for the management of swine manure in San

Andrés Isla is feasible technically and economically. The proposed procedure conceives in its stages the identification of occupational hazards and to face them the realization of plans prevention, as well as the evaluation of occupational safety and health management.

Acknowledgments

The authors express their gratitude to the Escuela Tecnológica Instituto Técnico Central, (ETITC), for their support in the development of the project approved by act No. 02 of February 8, 2016, whose partial results obtained so far have allowed the culmination of this Article.

References

[1] J. Toro-Calderón, "Generación de Opciones Tecnológicas para la Producción Agropecuaria en San Andrés Isla", Cuadernos del Caribe, vol. 7, no. 1, 2006, pp. 117-124.

[2] Instituto Colombiano Agropecuario – ICA, "Tabla de Población Porcina por Municipio y Departamento", 2016. [Online]. Available at: http://www.ica.gov.co/getdoc/8232c0e5-be97-42bd-b07b-9cdbfb07fcac/Censos-2008.aspx

[3] J. H. Polanía-Vorenberg, J. J. Toro-Calderón, C. López-Balmaceda, A. Rodríguez-Ruales, L. J. Jaramillo-Campuzano and A. M. León-Taborda, "El Sector Agropecuario y la Seguridad Alimentaria en San Andrés Isla. Historia de una Experiencia del Programa Nacional de Transferencia de Tecnología Agropecuaria en el Cambio de Siglo", Universidad Nacional de Colombia Sede San Andrés, Bogotá: Cargraphics S.A. pp. 3-16, 2004.

[4] C. López-Balmaceda, "Evaluación Ambiental de los Sistemas de Producción Porcina en San Andrés Isla", Cuadernos del Caribe, vol. 7, no. 1, 2006, pp. 133-135.

[5] M. Vélez, "Análisis Preparatorio para Suministro de Energía Sostenible en las Islas Colombianas San Andrés y Old Providence", 2005. [Online]. Available at: https://es.scribd.com/doc/174523434/Energia-San-Andres-Informe-GTZ-Generacion-San-Andres-Primera-Parte-Traduccion-EEDAS

[6] C. Wereko-Brobby, "Biomass Conversion and Technology", Fuel and Energy Abstracts, vol. 37, no. 3, 1996, pp. 197. https://doi.org/10.1016/0140-6701(96)88741-8

[7] G. Mariscal-Landin, "Tecnologías disponibles para reducir el potencial contaminante de las excretas de granjas porcicolas", 2007. [Online]. Available at: http://www.fao.org/3/x6372s08.htm

[8] G. Moncayo-Romero, "Biodigestores Tropicalizados", 2014. [Online]. Available at: https://www.aqualimpia.com/app/download/14551168722/BD-Tropicalizado.pdf?t=1503867654

[9] G. Moncayo-Romero, "Dimensionamiento, Diseño y Construcción de Biodigestores y Plantas de Biogás", 2010. [Online]. Available at: https://www.academia.edu/6179555/DIMENSIONAMIENTO_DISE%C3%91O_Y_CONSTRUCCI%C3%93N_DE_BIODIGESTORES_Y_PLANTAS_DE_BIOG%C3%81S_MANUAL_PR%C3%81CTICO_DE_DISE%C3%91O