Biogas as Clean Energy from Bovine, Porcine and Ovine Rumen Contents: Obtaining and Characterization

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Fossil energy sources and the pollution they cause is an environmental problem that urgently requires alternative solutions, one of which is biogas. Thus, the present research was carried out with the objective of evaluating the quality of biogas obtained from bovine, percine and ovine rumen content in a municipal slaughterhouse in the district of Huallanca - Ancash, Peru. A tubular biodigester with dimensions of 6 m long x 0.40 m in diameter was designed for the process. An iron chip filter treated with 5% HCL and 5% NaOH was also installed to reduce H_2S (the cause of unpleasant odors), and consequently improve the quality of the biogas. The ratio of organic load and water in the biodigester reactor was 1:2, resulting in a total load volume of 1.5625 m^3, and the hydraulic retention time was 85 days. It was observed that the temperature in the process ranged between 14.3 and 25.3 °C and the pH was maintained between 5.5 and 7.6. The biogas characterization showed 16.6 % CH_4, 37 % CO_2, 11.8 % O_2, 550 ppm H_2S and 19 ppm CO. From the results obtained, the viable alternative of using biomass composed of organic waste from slaughterhouses to generate biogas as a source of clean energy is clear.

1. Introduction

The need for energy in many rural areas, given the scarcity of non-renewable fossil fuels, has led to the use of vegetable and animal biomass as an alternative for obtaining biogas as a source of energy, with the advantage of being environmentally friendly. The meat industry generates a large amount of waste that often causes problems due to inadequate disposal (Guerrero and Ramírez, 2004), including rumen waste, which in some cases is discharged into rivers and pollutes them, but in others is used as compost (Uicab and Sandoval, 2018). Various raw materials have been used to obtain biogas, such as organic vegetable waste, sludge from treatment plants (Gamba et al., 2014), sludge and organic waste (Zirngast et al., 2021), animal manure, among others. In the literature, it has been verified that it is possible to obtain biogas from cow manure, banana and mango peels (Tewelde, 2018), fruit and vegetable waste (Deressa et al., 2015), corn straw and cow manure (Chukwuka et al., 2021) and pig manure (Sanchez, 2017; Venegas Venegas et al., 2019). Other authors such as Mejia and Peralta (2019) achieved the same objective using the mixture of semi-solid residues of manure (bovine and swine) and rumen. Also, Yusuf et al. (2021) obtained biogas from cattle manure digestion and co-digestion with *Typha Latifolia*.

The process of obtaining biogas from plant and animal biomass has allowed its transformation into an energy source with very good results that can be used in places where these residues are abundant (Palacios et al., 2020). The generation of this fuel is very important because of its nature as a non-polluting renewable energy that benefits the population due to its relatively low cost and easy production.

Therefore, the objective of the research was to obtain biogas from bovine, percine and ovine rumen content in a municipal slaughterhouse in the district of Huallanca - Ancash, Peru. The quality of the biogas obtained was also evaluated, determining the components such as CH_4, CO_2, O_2, H2S and CO.

2. Methodology

The research was developed through the following stages:

2.1 Stage 1: Obtaining ruminal content of cattle, pigs and sheep

First, samples of organic residues generated in the slaughterhouse of Huallanca - Ancash, Peru were collected. Then the viscera of cattle, pigs and sheep were washed, selecting all the material from the animal stomach that was not digested until the time of slaughter. The rumen content obtained is shown in Figure 1.

Figure 1: Rumen content of sheep, pigs and cattle

2.2 Stage 2: Construction of the biodigester

A tubular or Taiwanese biodigester (Figure 2-a) was designed with dimensions of 6 m long x 0.40 m diameter (García et al., 2017), taking into account the daily load and volume of biogas to be generated (Martí, 2008). The biodigester was designed for a capacity of 1.5625 m^3, and was installed at the "Ogopampa" municipal organic waste center in the district of Huallanca - Ancash, Peru. The biodigester was placed and conditioned in a greenhouse (Figure 2-b) due to the low temperatures of the site.

Figure 2: a) Tubular biodigester and b) Greenhouse

2.3 Stage 3: Characterization of rumen content

The homogenized rumen content was characterized by taking a sample to the Soil and Materials Laboratory of the Universidad César Vallejo. In the laboratory, pH and temperature (ºC) were measured, and the content of carbon (C), nitrogen (N), total solids (TS), volatile solids (VS), moisture (% H), electrical conductivity (EC) and organic matter (OM) were determined. For this purpose, a Hanna EDGE Multiparameter and Kjeldahl equipment were used.

2.4 Stage 4: Preparation and loading of raw material

First, the rumen contents (bovine, porcine and ovine) were mixed with water in a 1:2 ratio in a container (see Figure 3-a). Then the feedstock was loaded into the biodigester for biogas production (Figure 3-b).

Figure 3: a) Preparation of the raw material and b) Loading of raw material

2.5 Stage 5: Iron filter installation

A filter column (1m long x 0.5m in diameter) was installed with iron chips treated with HCL and 5% NaOH, in order to remove the hydrogen sulfide (H_2S) that caused the bad odor.

2.6 Stage 6: Process monitoring and control

In this stage, the ambient temperature (external temperature) and the temperature and pH of the biodigester load were measured. This control was carried out three times a week for 85 days.

3. Results and discussion

3.1 Characteristics of bovine, porcine and ovine rumen contents

Table 1 shows that the rumen residues obtained presented acid pH values, which can affect the biogas generation process. Organic matter is present in high levels that favor anaerobic digestion with the presence of microorganisms involved in biogas generation. This variable is important in biodigester operation and management due to the fact that in many cases it is evaluated as the chemical oxygen demand (COD) (Garcia et al., 2017).

The percentage of nitrogen and carbon are important to evaluate in the biogas production process since from the biochemical reactions with a nutrient-rich substrate they allow the activity of microorganisms. Macronutrients are in the rumen residues as a source of carbon for the microorganisms to have energy and nitrogen is necessary for the formation of new cells (García-Caro Andreu, 2013).

Table 1: Physicochemical parameters of rumen residues

Parameters	Type of rumen residue			
	Ovine	Porcine	Bovine	Mixture (ovine, porcine and bovine)
pH	4.75	6.62	5.62	5.26
Temperature (°C)	19.20	18.50	18.40	18.50
Electrical conductivity (µS/cm)	2523	2670	2594	2630
Moisture (%)	58.25	60.34	62.15	59.45
Organic matter (%)	86.96	62.15	89.21	87.35
Nitrogen (mg/L)	25.36	28.15	29.75	27.80
Total organic carbon (mg/L)	60.20	62.15	62.15	55.14
Total solids (mg/L)	15.62	15.78	15.69	15.50
Volatile solids (mg/L)	78.14	76.72	76.92	75.19

3.2 Factors in the generation of biogas from rumen waste

a) Carbon/nitrogen ratio

The carbon/nitrogen ratio is important because they are food sources for methanogenic bacteria. This ratio was calculated using Equation 1 (FAO - UN, 2011).

$$C/N \ (Mixture) = (C1 * Q1 + C2 * Q2 + \cdots Cn * Qn)/(N1 * Q1 + N2 * Q2 + Nn * Qn) \tag{1}$$

Where: C=% of carbon; N= % of nitrogen; Q=Fresh weight of residue (kg)

Table 2: Carbon/nitrogen ratio of rumen residues

Type	Weight (kg)	C (%)	N (%)	C/N ratio
Ovine	1	60.2	25.36	
Porcine	1	62.15	28.15	
Bovine	1	62.15	29.75	
	Resulted			2.2440

b) Rumen waste/water ratio

The biodigester was loaded three times per week using a 1:2 ratio for rumen waste/water. The loading was calculated taking into account the percentage of total solids in the ruminal waste, using Equation 2. The total waste loading in the process was 1,548 kg.

$$\% \ of \ TS \ (total \ solids \ diluted) = (1 \ kg \ rumen * \% \ TS \ rumen)/(1 kg \ rumen + water \ weight) \tag{2}$$

c) pH and temperature in the biogas generation process

The pH of the biodigester mixture (load) was monitored with a PH60S digital pH meter, with values in the range of 5.5 to 7.6. The internal temperature of the biodigester varied between 14.3 and 25.3 °C, while the ambient temperature (external temperature) in the greenhouse varied between 15 and 33.2 °C (see Table 3). The ambient temperature is an indicator for the retention time of the process; at high temperatures the retention time is shortened. The scientific literature recommends that at 10, 15, 20, 20, 25, 30 and 35 °C, the retention time should be 90, 60, 45, 37, 32 and 28 days, respectively (Prieto and Fajardo, 2017). However, in the research, the ambient temperature in the greenhouse was taken as a reference in view of the fact that the location has drastic values of variation. The retention time of the process was 85 days, with 30 temperature and pH controls, as shown in Table 3. It shows variable temperatures, generally low despite the installation of a greenhouse to raise the temperature, which did not favor anaerobic digestion (Rahman et al., 2019).

Table 3: Temperature and pH of the biodigester process

Nº	Internal temperature ºC	External temperature ºC	pH	Nº	Internal temperature ºC	External temperature ºC	pH
1	16.3	16.5	6.90	16	18.3	21.9	6.90
2	17.0	17.4	5.50	17	19.2	20.8	6.60
3	14.3	15.0	5.69	18	18.5	25.2	7.00
4	17.2	17.4	6.13	19	19.5	20.6	6.50
5	18.0	20.0	6.15	20	21.2	28.5	6.00
6	24.3	24.5	6.18	21	22.6	21.5	6.90
7	23.6	30.0	6.50	22	23.3	30.0	6.00
8	25.3	28.5	6.43	23	17.40	18.30	7.60
9	22.5	24.0	5.90	24	16.90	17.20	5.96
10	16.2	30.5	6.10	25	17.30	19.20	7.30
11	16.3	33.2	5.98	26	19.40	17.00	7.20
12	15.9	35.0	7.00	27	15.90	18.00	6.58
13	16.2	30.8	7.40	28	18.40	22.90	6.50
14	15.2	30.0	5.72	29	17.50	21.40	6.35
15	17.4	25.0	7.00	30	19.50	18.30	6.80

Table 4 shows the characteristics of the by-product (digestate) generated in the biodigester. It can be seen that the pH was 6.35, a value that is close to neutral, but not in the range of 7 to 8, a value recommended to prevent problems of action and with favorable conditions for the action of microorganisms (Chen et al., 2008);

It is also mentioned that acetogenic and methanogenic bacteria are susceptible to pH and that the optimal range is between 6.5 and 8 (Toledo-Cervantes et al., 2017). When pH is below 6.2, acidity inhibits the activity of methanogenic bacteria, at values between 4.5 and 5.0, inhibition of fermentative bacteria occurs, and it is also

not advisable to work at pH above 8.0 - 8.5 (Canales et al., 2010). This was the difficulty faced by the research, with the pH being mostly below 7 (see Table 3), which affected the biogas generation yield.

Table 4: Characteristics of the generated digestate

Parameters	Value	unit	Retention time (days)
pH	6.35	-	
Electrical conductivity	9.45	µS/cm	85
Totals solids	11.90	mg/L	

3.3 Biogas composition

Table 5 shows the results of the analysis of the biogas samples at 57, 62 and 85 days of retention. The total volume of biogas was 0.39 m3, and the results in sample 1 correspond to unfiltered biogas, while sample 2 and sample 3 were passed through a treated iron chip filter.

The iron chip filter helped to reduce the presence of unpleasant odors caused by hydrogen sulfide (H_2S), through adsorption on its inner surface forming iron sulfide and water (Torres-Calderón et al., 2020). This allowed obtaining better quality biogas, as was done in the research of Ortega Viera et al. (2015) that reduced by physical methods of adsorption H_2S from 1,781 to 350 ppm. In another case, 15.6 % decrease of this pollutant was achieved (Huertas, 2019). On the other hand, Bernal and Palacios (2020) indicate that steel wool can be used in the removal of hydrogen sulfide.

Table 5: Composition of the generated biogas

	Methane (%)	Carbon dioxide (%)	Oxygen (%)	Hydrogen sulphide (ppm)	Carbon monoxide (ppm)	Retention time (days)
Sample 1	5.5	67	10.8	1,800	190	57
Sample 2	2.3	19	16.8	69.0	30	62
Sample 3	16.6	37	11.8	550.0	19	85

Considering the monitoring of sample 3 conducted at 85 days, the highest percentages of methane and carbon dioxide equivalent to 16.6 and 37%, respectively, were found. This percentage of methane generation is relatively low compared to other investigations that reached values of 70% methane and 15% carbon dioxide (Linares et al., 2017). This effect was due to the ambient temperature factor, which varied and changed abruptly from day to night, indicating that the conditioning of the biodigester should be improved to a more conducive environment that maintains a high temperature suitable for biogas generation. Literature indicates that between 30 to 35 °C is the best interval that favors optimal growth and high operation of mesophilic microorganisms in biogas production (Poh et al., 2015). The probable presence of inhibitory substances such as lignin compounds that are harmful to methanogenesis, hindering the action of microorganisms and consequently the generation of biogas, is not ruled out (Chen et al., 2008).

4. Conclusions

It was found that biogas can be generated from bovine, porcine and ovine rumen residues using a tubular biodigester. The total volume of biogas obtained was 0.39 m3, with percentages of 16.6% methane and 37% carbon dioxide. It was verified that the operating conditions such as temperature and pH influenced the biogas production yield, not discarding that probably other inhibitors such as the presence of lignin in the rumen residue impaired the anaerobic digestion of the microorganisms. With all the above mentioned, it is concluded that rumen residues can be used to obtain biogas to be converted into sustainable energy for the benefit of rural populations.

Acknowledgments

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