

Water Treatment Plant Sludge as a Source of Clean Energy: Biogas

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Population growth also creates many essential needs, including the proper disposal of wastewater into sewage networks that will reach water treatment plants (WWTPs). In the treatment process, sludge is generated that has been used mainly as fertilizer in agriculture and in other cases is disposed of and confined, generating costs in its management for local governments. Another need of the population is the availability of energy, which is mainly obtained from fossil fuels such as petroleum and its derivatives, which is becoming increasingly scarce. In this context, the objective of the research was to evaluate the biogas production that can be obtained from the sludge of the Wastewater Treatment Plant (WWTP) of the Municipality of Comas - Lima, Peru. In the research, the physicochemical and microbiological properties of the sludge were characterized and by using biodigesters, biogas composed mainly of CH₄, CO₂ and O₂ was produced. Two samples of 1.7 (M1) and 1.2 kg (M2) of sludge were used in primary anaerobic processes, adding 500 g of vegetable biomass (potato peel, beet leaves) to the M2 sample in the biodigesters with a volume of 20 liters. The biogas generation process was carried out with three repetitions for a period of 60 days at 18 ° C approx., controlling the progress of biogas production every 10 days. As the most optimal result of the biodigesters, biogas was obtained for M2 with 58% methane, 34 % carbon dioxide, which corresponds to a calorific value of 5,800 kcal/m³. Biogas obtained from wastewater treatment plant sludge is a promising alternative as a source of bioenergy with environmental advantages.

1. Introduction

To produce natural energy, since the world is constantly growing in energy consumption, the alternative of obtaining clean energy from organic waste from wastewater treatment plants is being investigated and the information is available to everyone (Nathalie Bachmann, 2015). Renewable energies will be in the future the greatest existing energy on the planet to achieve, within it in wastewater treatment plants (WWTP) waste is generated in the form of sludge that are mostly poorly disposed without receiving adequate treatment, these sludge with nutrient load and characteristics conducive to obtaining energy can be exploited from biogas containing methane (CH₄) (Aguilar and Blanco, 2018), being this of high energy value (Martins das Neves et al., 2009), evaluating the physical-chemical parameters to control the volume of biogas production for greater energy efficiency (Huanca, 2017). Anaerobic digestion is a biotechnology that employs diverse microorganisms that convert organic matter into methane-rich biogas starting with hydrolysis, fermentation (acidogenesis and acetogenesis) and methanogenesis (Alvarado et al., 2014).

Research on the subject has already been carried out all generally seeking to achieve the best efficiency of energy potential, designing and building bioreactors for the transformation of organic matter into biogas, looking for the best conditions for biogas generation, such as anoxic forms to exploit it more efficiently with recovery of the final waste as fertilizer (Corcio, 2016). Likewise, techniques for obtaining clean or improved biogas are also sought (Gamba et al., 2014)(Gamba et al., 2014). Anaerobic digestion is used as a way to decrease greenhouse gas (GHG) emissions, by retaining methane emissions directly and using it to generate energy, it is estimated to reduce emissions by 50% (Blanco, 2015). It is indicated that biogas production can be cost-effective to obtain electricity using organic waste and sewage sludge (Zirngast et al., 2021).

In this context, the objective of the research was to use sludge generated in the WWTP of the district of Comas-Lima, performing the physicochemical and microbiological characterization of the sludge for biogas production, verifying that it is an eco-friendly energy source that can be used and at the same time allows reducing the emission of greenhouse gases that are emitted into the atmosphere.

2. Methodology

The following procedure was followed:

- For the generation of biogas, 6 PVC biodigesters of 20 liters capacity each were prepared (Figure 1), using 3 for the first treatment (M1) and 3 for the second (M2).



Figure 1: Plant residues added to the inoculum



Figure 2: Biodigester load



Figure 3: Control of the biodigester

- The biodigesters were closed for an anaerobic process, in this process the sludge will go through the stages of the anaerobic digestion process: fermentative, ecetogenic and methanogenic (Biogas production: methane and carbon dioxide and others). See figure 4.

Table 1: Quantity and type of inoculum used for feeding the biodigesters

Treatment	Biodigester	Residual sludge (kg)	Cofermenter (Vegetable waste: potato peelings and beets) (g)
M1	M1R1	1.7	-
	M1R2	1.7	-
	M1R3	1.7	-
M2	M2R1	1.2	500
	M2R2	1.2	500
	M2R3	1.2	500

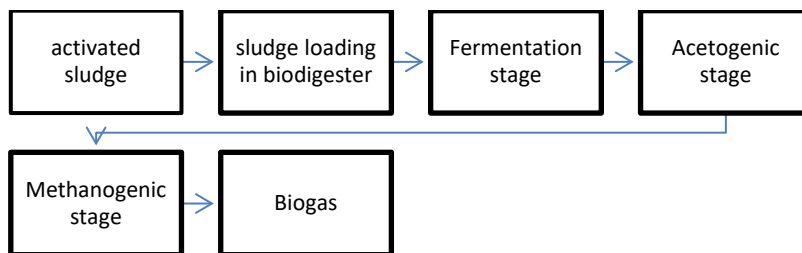


Figure 4: Anaerobic sludge digestion process

- Maintaining constant conditions of ambient temperature, pH and agitation cycles, the biodigesters were controlled and monitored for 60 days, evaluating the generation of CH₄, CO₂ and O₂ (Figure 3). A properly calibrated ALTAIR 4X portable gas detection equipment was used (Figure 5).
- Also at the end, a flame test of the biogas produced was performed (Figure 6).



Figure 5: Measurement of methane



Figure 6: Biogas flame test

- The methane - CH₄ analyzer was used to measure the methane gas contained in the biogas. CH₄ gas sensors can be used in any scale of biogas process, from laboratory biogas plants and in industrial scale biodigesters.

3. Resulted and discussion

3.1 Physicochemical characteristics of the sludge

Table 2 shows the results of the physicochemical characterization of the sludge used. The sludge had a pH of 8.16, according to Galvis and Rivera, (2016) the ideal is that the pH ranges between 6.5 and 8 for optimal bacterial growth to occur, favoring the degradation of organic matter. The pH determines the inhibition or toxicity of methanogenic bacteria; if the pH is lower than 6 it does not favor the methanogenic stage, so the neutral point should be sought. The sludge presented 26% biochemical oxygen demand (BOD), a value that, being high, favored degradation by anaerobic bacteria.

A relatively low content of organic matter (26.7 %) was also observed, which is an adequate condition to favor the very fundamental digestion stage in the metabolism of the bacteria; it is recommended that this value be higher than 50 % (Padilla and Rivero, 2015). Volatile compounds had a relatively low percentage that if higher causes instability and decreases the biogas production yield (Yang et al., 2015).

The total solids found near 30 % could be an unfavorable factor for the efficiency and production of biogas because as it is higher the methanogenic bacteria reduce their mobility within the substrate; however, as batch biodigesters were used, the percentage is in the accepted range between 40 and 60 % (FAO - UN, 2011).

Table 2: Physicochemical characteristics of the sludge

Parameters	Unit	Results
Biochemical Oxygen Demand	mg/L	8,750.00
Chemical Oxygen Demand	%	26.71
Carbon Dioxide	mgCO ₂ /L	30.1
Humidity	NU	70.3
Organic Matter	%	26.71
Total Nitrogen	mg/SO ₂ /meq	569.4
Hydrogen Potential (pH)		8.16
Total Solids	%	29.699
Volatile Solids	%	14.255

3.2 Microbiological characteristics of the sewage sludge

The microbiological characterization of the sludge is shown in Table 3, evaluated using the most probable number (MPN) technique; with respect to total coliforms in 100 grams of sludge analyzed, 390,000 MPN/100g

of bacteria were found, according to (FAO - UN, 2011), the average concentration with possibilities of use for compost, biofertilizer and biogas should contain 0.1 and 0 N° colonies/ml. For the one under study, the high value was due to the little maintenance performed in the WWTP and pipes that reach it. As for fecal coliforms, they belong to a subgroup of total coliforms capable of fermenting lactose.

Table 3: Microbiological characteristics of sludge.

Parameters	Unit	Results
Fecal Coliforms	NMP/100g	200,000
Total Coliforms	NMP/100g	390,000
Salmonella spp (MPN)	NMP/gST	<3.0

3.3 Sludge digestion process monitoring and control

Table 4 shows the time and temperature information of the digestion process. An attempt was made to maintain an ambient temperature of approximately 18 °C, taking into account that this condition is considered a psychrophilic digestion where methane production is slower since it is in a temperature range between 10-20 °C, but it has advantages of process stability, and it is coincidentally in this range where less has been studied and where the research was proposed (FAO - UN, 2011).

Temperature and pH are unfavorable factors in the microbial population so they have to be controlled (Chen et al., 2014), temperature intervenes in the biochemical reactions that occur in the thermodynamic equilibrium, kinetics with microbial growth, substrate consumption and methane production since it mainly affects the thermodynamic equilibrium of the biochemical reactions, kinetics and stability of the processes (Wilson et al., 2008), microbial growth rate, substrate utilization (Fernandez-Rodriguez et al., 2013), CH₄ production (Rahman et al., 2019).

Table 4: Temperature during the research process

Treatment	Number of days						Average T°
	10	20	30	40	50	60	
M1 y M2	19 °C	18°C	18°C	17°C	17°C	17°C	17.6°C

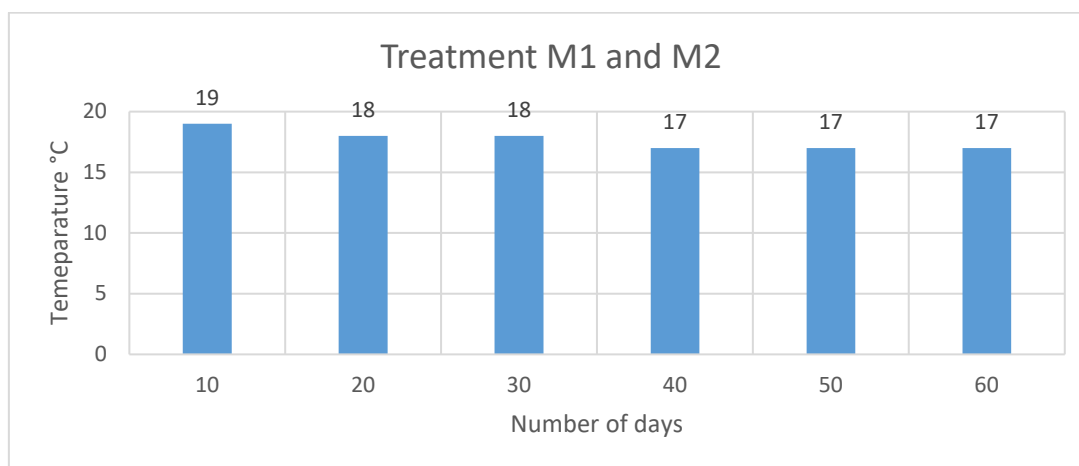


Figure 7: Temperature during the research process

3.4 Biogas production

Table 5 shows the biogas production every 10 days in the biodigesters. Higher production was obtained in biodigester M2R1 (58 %). It can be seen that in general in the M2 treatment biodigesters a greater amount of biogas was generated, this due to the presence of organic vegetable matter added in the load that fulfilled the function of accelerating the fermentation of all organic matter for the release of volatile solids susceptible to

become biogas (FAO - UN, 2011); this also to increase the organic load of the sludge as indicated by Montenegro (2016), who used potato peel and Guerrero (2014) who used beterraga, for co-digestion (Julio et al., 2016). The CH₄ sensor detects CH₄-concentration data (Vol., %), which can then be processed by different control systems. The improvement in methane production could also happen with the pretreatment of the sludge and the addition of biochar as indicated by Zirmgast et al., (2021).

Table 5: Methane production per biodigester for 60 days

Treatment	Biodigester	Methane Production (%)					
		10 days	20 days	30 days	40 days	50 days	60 days
M1	M1R1	0	0	5.2	11.2	15.2	18
	M1R2	0	0	4	15.3	22.3	20.6
	M1R3	0	0	4.5	13.8	20.6	23.8
	Average	0	0	5	13	19	21
M2	M 2R1	0	0	15.3	35.6	48.9	58
	M2R2	0	0	13.8	31.4	42.6	56.5
	M2R3	0	0	15.1	32	43.2	57.1
	Average	0	0	15	33	45	57

3.5 Carbon dioxide generation

Table 6 shows the generation of carbon dioxide (CO₂) in the biogas produced in the biodigesters, with the greatest amount found in M2R3 (33 %). This component must be controlled due to the pollution it represents in the atmosphere.

Table 6: Methane production per biodigester for 60 days

Treatment	Biodigester	CO ₂ Production (%)					
		10 days	20 days	30 days	40 days	50 days	60 days
M1	M1R1	0	0	16	19	20	19.8
	M1R2	0	0	14.3	21.5	19	18.1
	M1R3	0	0	12	22	21.2	20
	M 2R1	0	0	18	24	29	34
M2	M2R2	0	0	17.8	25	28.5	34
	M2R3	0	0	19.6	20.5	28.9	33

3.6 Power calorific of biogas

Following the information indicated in the FAO Biogas Manual (2011), where it is mentioned that 60 % of methane in an anaerobic digestion biogas has a calorific value of approximately 4,800 to 6,000 kcal/m³, then for 100 % methane there would be 10,000 kcal/m³. Considering that 58% of methane was obtained in the research, it is equivalent to a calorific value of 5,800 kcal/m³.

4. Conclusion

In the process of generating biogas from the sludge of a wastewater treatment plant, biogas containing 58 % methane and 34 % carbon dioxide was obtained after 60 days of sludge treatment with the addition of vegetable organic matter in the biodigester load. It was also tested without vegetable load with less optimal results. The calorific value of the biogas according to the percentage of gas generated in the most efficient treatment (M2R1) is equivalent to 5,800 kcal/m³. The results indicate that biogas generation is possible even under limiting circumstances at low temperatures (anaerobic psychrophilic digestion). This method is very viable for obtaining renewable bioenergy due to its low cost and easy implementation in marginal areas of large cities, where energy is scarce and there is waste (sludge) from water treatment plants, while improving the quality of life of the population.

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