Biogas Production: By Sewage and Human feces

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Abstract. The global quest for sustainable and renewable energy sources has become increasingly urgent in the face of contemporary energy and environmental challenges. In this context, biodigesters have emerged as a promising and ecologically viable solution for energy generation.

Biodigesters enable the production of biogas, a renewable fuel derived from the anaerobic decomposition of organic materials, including agricultural waste, food residues, and sewage sludge. This decomposition process is orchestrated by specific bacteria under carefully controlled conditions of temperature, pH, and humidity within the biodigester.

During this decomposition, the bacteria generate biogas, primarily composed of methane (CH4) and carbon dioxide (CO2). Biogas can be captured, stored, and employed as fuel in internal combustion engines or electricity generators. The capture and utilization of methane, a potent greenhouse gas, significantly contributes to mitigating greenhouse gas emissions.

Nonetheless, a notable challenge in utilizing organic waste and municipal sewage lies in the high concentration of human feces. To address this challenge, this study investigates the feasibility of utilizing human feces as a co-substrate for biogas production.

The study reveals promising results in biogas production from human feces, albeit with certain limitations. Biogas production initiated slowly, followed by gradual increases, but declined towards the experiment's end due to unregulated pH levels and an increase in ammonia nitrogen concentrations. Temperature fluctuations between 25°C and 35°C were also observed to influence biogas production.

These findings imply the potential for co-digestion of human feces with other substrates, such as cattle and poultry manure, to enhance biogas production and digestate utilization. The study emphasizes the need for further research to optimize co-digestion ratios, making the process not only economically viable but also environmentally sustainable.

In summary, this study underscores the significance of biodigesters as a renewable energy source, offering a promising solution for organic waste management and the reduction of environmental impact. However, it underscores the importance of careful consideration of substrate composition and operational conditions to maximize biogas production. Further investigations are recommended to fine-tune co-digestion parameters, with the aim of achieving enhanced efficiency in biogas production and digestate utilization.

Keywords. Biogas, Substrates, Anaerobic Digester. Biogas Production, Anaerobic Digestion, Sewage Sludge.

1. Introduction

The search for sustainable and renewable energy sources has become increasingly important given the energy and environmental challenges facing the world today. In this context, the use of biodigesters for energy generation has aroused great interest, offering a promising and ecologically viable alternative.

Biodigesters can be used to produce biogas, a renewable fuel obtained from the anaerobic decomposition of organic materials. These materials can be agricultural waste, food waste, sewage sludge, among others. Decomposition is carried out by specific bacteria under controlled conditions of temperature, pH, and humidity inside the biodigester.

During the decomposition process, the bacteria produce biogas, composed of methane (CH4) and carbon dioxide (CO2). Biogas can be captured,

stored, and used as fuel in internal combustion engines or electricity generators. Methane is a powerful greenhouse gas, so its capture and use as an energy source contributes to reducing greenhouse gas emissions.

According to the report published by the International Solid Waste Association (ISWA), 2.6 million tons of municipal solid waste (MSW, including food waste, green waste, wood, and others) is produced every day in the world and this amount is expected to reach 4.5 million tons/day by 2050 due to increasing urbanization and improving living conditions .(Elif Gulsen Akbay, 2024)

However, a huge problem with the use of organic waste and sewage from municipalities is that its composition contains a high concentration of human feces. We are not sure whether it can be viably utilized as a fuel for biogas production. For this reason, I carried out research to really find out whether the use of human feces becomes a truly viable fuel capable of producing an acceptable amount of biogas and biomass.

The use of biodigesters for energy generation offers several advantages. As well as providing a renewable energy source, it contributes to reducing the use of fossil fuels, reduces dependence on energy imports and promotes the use of organic waste, helping to manage it and minimizing environmental impact.

2. Methodology

To evaluate the potential for biogas generation from organic waste, the application of anaerobic digestion stands as a well-established and dependable technological solution. The present investigation centers on the anaerobic digestion procedure implemented within batch digesters, with the primary objective being the production of biogas through the co-digestion of human fecal matter (HF). It is imperative to conduct a thorough assessment of the feedstock's quality prior to initiating the anaerobic digestion process, as the suitability of digested waste for this purpose may vary contingent upon the degree of its stabilization.

2.1 Sampling and Slurry Preparation

Fresh human feces were procured from Manas, Lucknow, and then underwent mechanical fragmentation using a mortar and pestle to ensure uniform consistency, thereby facilitating efficient digestion. Three distinct digesters, designated as D1, D2, and D3, were established employing varying proportions of human feces. D1 was exclusively configured employing HF. Thereafter, this mixture was blended with water in a 1:1 w/v ratio, yielding an approximate volume of 4 liters of slurry. The experimental duration extended over 52 days (about 1 month 3 weeks) under continuous digestion conditions, with three replicates for each treatment.

2.2 Digester Configuration

The experimentation was executed using a laboratory-scale anaerobic digester to assess biogas production, relying solely on fresh HF as the primary feedstock. The equipment ensemble encompassed a 5 L reagent bottle outfitted with a glass stopper, fulfilling the role of the anaerobic digester. Additionally, a 3 L reagent bottle, similarly equipped with a glass stopper and featuring two side-bottom openings (designated as Bottle 1), served as the biogas collection vessel. Concurrently, a separate 3 L reagent bottle, also furnished with a glass stopper and featuring a single side-bottom opening (referred to as Bottle 2), functioned as the receptacle for water discharged from the collector (as depicted in Figure 1). The anaerobic digester was charged with the slurry, and internal agitation was achieved through the utilization of a magnetic stirrer. Daily biogas production for each anaerobic digester was recorded employing the water displacement method, subsequently facilitating the calculation of the corresponding cumulative biogas volume. The water displacement method quantifies the volumetric displacement attributed to an object. Bottle 1 was filled with water and interconnected with the anaerobic digester and Bottle 2. As biogas generation ensued within the anaerobic digesters, it was channeled into Bottle 1 via a gas hose. Consequently, the accumulated biogas in Bottle 1 led to the displacement of water into the second, initially empty bottle. Daily monitoring of the biogas production volume was conducted by measuring the water displacement within Bottle 1. The volume of biogas generated was equated to the volume of water displaced. The anaerobic digester was operated under ambient temperature conditions, ranging between 25 to 35°C. Temperature and pH values within the experimental slurry were recorded daily through the deployment of a thermometer and a digital pH meter, respectively.

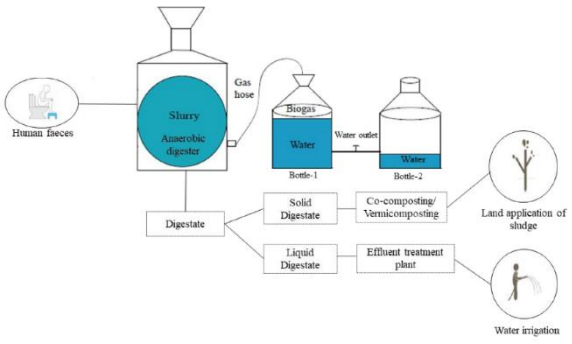


Fig (1) - Schematic diagram of biogas production

2.3 Sample treatment

The physical and chemical composition of the feedstock underwent comprehensive evaluation, both before and after digestion, adhering to standardized protocols (APHA, 2005). The feedstock was subjected to analysis encompassing pH, electrical conductivity (EC), moisture content, total

solid (TS), volatile solid (VS), C/N ratio, chemical oxygen demand (COD), ammonium (NH4–N), total nitrogen (TN), total phosphorous (TP), calorific value, E. coli, and Enterobacteriaceae. pH determination involved the agitation of 50 g of waste in 250 ml (about 8.45 oz) of water for 24 hours, followed by pH measurement. An electrical conductivity electrode was employed to gauge the EC of waste samples derived from saturation extract (IARI, 2011). Moisture content, total solid, and volatile solid were assessed using the weight loss on ignition method (ASTM, D1102). Carbon and nitrogen content were determined via a CHN/O analyzer, while COD was determined employing the open reflux digestion method. NH4–N, TN, and TP were determined through methods described in (Robert Okalebo et al., n.d.). Calorific value determination adhered to the protocols stipulated by the American Society for Testing and Materials (ASTM, D240). Enumeration of E. coli and Enterobacteriaceae was executed in accordance with standard procedures (APHA, 2012). Chemicals employed for these analyses were of high purity, sourced from MERCK, and stock solutions were prepared utilizing Mille Q distilled water. All reported results are presented as mean values, accompanied by their respective standard deviations.

3. Results and Discussion

3.1 Characteristics of the Utilized Substrates

In this section, we present an overview of the properties inherent to the substrates employed in this investigation, herein referred to as HF (as indicated in Table 1). It is incumbent to acknowledge the inherent variability in the composition of human fecal matter across individuals and geographic regions. The pH of human feces is reported at 5.2, and it is noteworthy that a judicious adjustment to approximately 7.0 preceded the onset of anaerobic digestion. This pH manipulation is deemed pivotal, as it assumes a pivotal role in shaping the efficiency of the entire anaerobic digestion process (Zhou et al., 2012, Romano & Zhang, 2011)

Comparatively, the pH levels associated with substrates such as poultry litter and cow dung are recorded at 7.6 and 6.9, respectively, conforming to the acceptable range requisite for successful anaerobic digestion. It is imperative to underscore that the conventional pH range deemed optimal for anaerobic digestion oscillates between 6.8 and 7.2. Nonetheless, tolerances ranging from 6.5 to 8.0 have been historically accommodated.

Within the spectrum of substrates investigated, human feces manifest the highest density, with the latter evincing the lowest total solid content. Furthermore, human feces substantiate the highest levels of volatile solids. The C/N ratio, herein computed at 12 for human feces, underscores a diminished potential for optimal biogas generation (Borja and Banks, 1995). However, the augmentation of this ratio can be methodically achieved through the strategic admixture of human feces with substrates such as cow dung, where the C/N ratio stands notably higher at 24 (Rouf et al., 2010).

Concurrently, it is expedient to report the variance in chemical oxygen demand (COD), with cow dung attaining the pinnacle at 280, while human feces were cataloged at 98.2. Notably, the conspicuous reservoir of ammonium nitrogen (NH4-N), scaling the zenith at 970 in human feces, necessitates circumspection. The anaerobic digestion of substrates characterized by an excess of ammonia content may precipitate the pernicious consequences of inhibition and toxicity within the ambit of the methanization process. It bears emphasis that the escalation of pH beyond the threshold of 9 catalyzes the conversion of ammonium into toxic ammonia (NH3). This transformation wields a potent inhibitory sway over methanogens, which stand as pivotal agents in catalyzing the methanogenesis phase intrinsic to anaerobic digestion (Krakat et al., 2017).

The total nitrogen (TN) quantum peaks in human feces at a value of 79, whereas the content dwindles notably in cow dung, registering at 6.7. In juxtaposition, total phosphorus (TP) exhibits augmented values within the domain of human feces, where a zenith of 14 is substantiated. In conclusion, the calorific value (Kcal/Kg) registers its nadir within the confines of human feces, attaining the quantum of 2300. It is noteworthy that the precipitation of moisture exerts perturbations on both the inherent combustibility and calorific value of biomass substrates. Concomitantly, an upsurge in moisture content engenders a corollary diminishment in calorific potential, ascribed to the latent heat of water vaporization.

In summation, bacterial enumerations for E. coli and Enterobacteriaceae (CFU/GTS) attain maximal figures within human feces, precipitating counts of 5.9 × 10^6 and 1.24 × 10^6, respectively.

Parameter	Human faeces (HF)
pH	5.2 ± 0.171
EC (mmhos/cm)	46 ± 6.02
Moisture content (%)	84 ± 3.70
TS (%)	18 ± 2.06
VS (%)	81 ± 3.50
C/N ratio	12 ± 2.38
COD (g/l)	98.2 ± 4.34
NH_4–N (mg/kg)	719 ± 8.66
TN (mg/g)	31 ± 1.70
TP (mg/g)	7.7 ± 0.45
Calorific value (kcal/kg)	2300 ± 80
E. Coli (CFU/g TS)	$5.9 \times 10^6 \pm 2.99$
Enterobacteriaceae (CFU/gTS)	$1.24 \times 10^6 \pm 1.21$

N = 3 for each parameter measured.

Table (1) - Characteristic of human feces used for the experiment

3.2 Biogas Production

The daily biogas production from HF, over a 52-day solid retention time (SRT) period is depicted in Figure 2. The study observed that biogas production initially commenced slowly and concluded with a gradual decline. Previous studies have noted that biogas production tends to be sluggish during the initial stages of experiments due to the lag phase of microbial growth when methanogens (microbial community) establish themselves within the digester medium. This lag phase is followed by exponential growth of the microbial community and eventually the stationary phase characterized by minimal growth but sustained living cells. In batch conditions, the rate of biogas production depends on the growth of methanogenic bacteria, which produce methane. Biogas production was observed in D1 began on the fifth day of loading the digesters. These production rates increased gradually due to the exponential growth of methanogens. In D1 and, there was no biogas production during the first 4 and 2 days, respectively, due to the lag phase of microbial growth. The maximum values of daily biogas production were recorded on the 14th, 13th, and 15th day for D1, digester, before a gradual decline in production rate was observed for the remainder of the study period. Towards the end of the experiment, biogas production showed a decrease, due to the employment of an unregulated pH range, which concurrently led to an increase in ammonia nitrogen concentration, assumed to inhibit the process. A high concentration of ammonia nitrogen is toxic to anaerobes, which would decrease the efficiency of digestion and disrupt the process. Temperature is also one of the most key factors influencing biogas production; biogas yields increase with rising temperature. It was observed that the digester temperature fluctuated between 25°C and 35°C.

Cumulative gas generation in different digesters for the 52-day SRT is plotted in Figure 3. The results reveal HF produced a total of 7.62×103, 9.85×103, and 12.96×103 ml (about 3.48 oz) of biogas were produced from D1.

3.3 PH Effect on Biogas Production

The observed pH levels in the digester D1 fall within the acceptable range for anaerobic digestion (Abubakar and Ismail, 2012). The pH ranges in D1 6.8–7.58, and pH changes in the digester feedstock daily are shown in Figure 4. The initial pH was 7, and a sequential increase in pH was observed after a sharp drop in the third week of digestion. A final pH of 6.78, for HF, was recorded at the end of the experiment. The highest biogas yields were observed at digester pH 7.52, for HF.

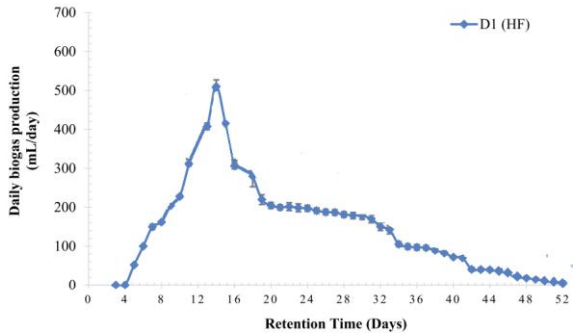
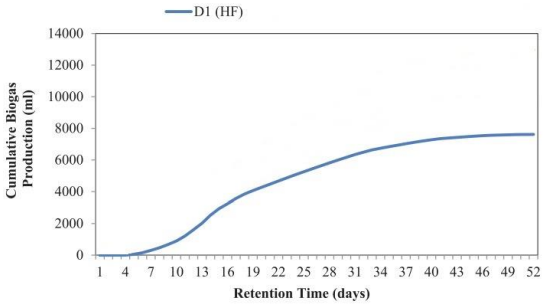


Fig (2) - Daily biogas production from HF (D1)



Fig(3) - Cumulative biogas production from HF (D1)

3.4 Effect of COD Reduction on Cumulative Gas Production

The Chemical Oxygen Demand (COD) is another important parameter affecting the biogas production process. The substrate's COD was reduced by the anaerobic digestion process, indicating a reduction in the organic compounds present in the water. This reduction of COD implies a decrease in the pollutant load from the substrate during the treatment process. The COD reduction and cumulative gas production for digesters D1, are shown in Figure 5. For digesters D1, the COD reduction was substantial. Recent experimental works have shown that substrates with higher COD values lead to better performance in terms of biogas production and COD reduction.

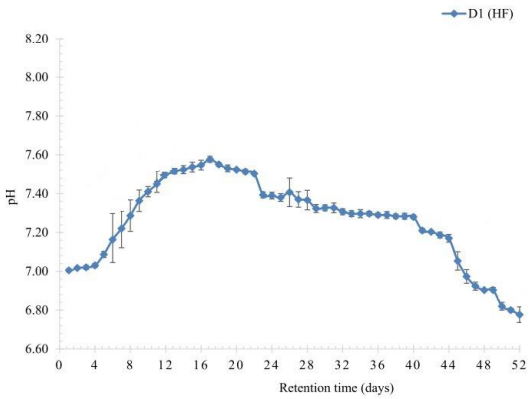


Fig. 4. pH of the digester feed stock at various time intervals.

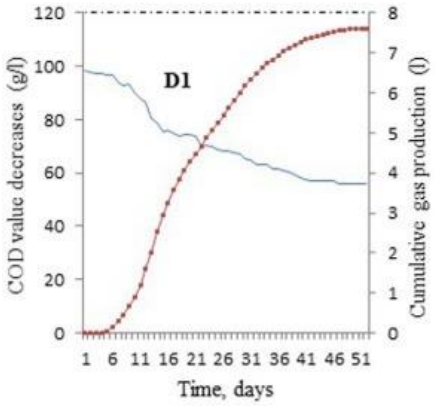


Fig. 5. COD reduction and cumulative gas production with time in digesters D1

3.5 Characteristics of Digestate

Anaerobic digestion produces two primary products: digestate and biogas (Fig. 1). Digestate is the material remaining after the anaerobic digestion of a biodegradable feedstock. After solid–liquid separation of the digestate, the nutrients are distributed between the solid and liquid portion. A sizable portion of nutrients becomes dissolved within the liquid fraction of digestates generated from the anaerobic digestion of organic waste (Botheju et al., 2010). Digestates exhibit characteristics such as elevated ammonium content, reduced organic material, higher pH values, and a lower carbon-to-nitrogen (C/N) ratio when compared to undigested materials. Further treatment of both the solid and liquid digestate is essential to meet the requirements for water and land reuse or safe discharge into the environment. Cost-effective technologies such as waste stabilization ponds or wetlands can be employed for liquid treatment, while co-composting and vermicomposting methods can be applied for solid treatment (Singh et al., 2017).

Regarding the solid portion of the digestate (Table 2). The pH values for both the solid and liquid digestate of HF were within acceptable ranges, with values of 6.7 and 6.78.

The COD reduction values were recorded in human feces digestate, with values of 50.9 ± 3.92 and 52 ± 4.31 for the solid and liquid portions, respectively (Table 2).

When assessing pathogenic microorganisms, the count of E. coli and Enterobacteriaceae was highest in the liquid portion of human feces digestate, with counts of 4.8 × 106 and 1.03 × 106. The anaerobic digestion process showed a limited reduction in pathogenic microorganisms, with both Enterobacteriaceae and E. coli counts showing a slight decrease of about one logarithmic unit. Previous investigations have also reported similar reductions in Enterobacteriaceae, and E. coli counts of 1–2 logarithmic units (Forster-Carneiro et al., 2010; Saunders et al., 2012).

Parameters	Unit	Digestates
		HF
Solid portion		
pH		6.7 ± 0.21
TS	(%)	9.86 ± 0.91
COD	(g/l)	50.9 ± 3.92
E. Coli	(CFU/g TS)	$3.5 \times 10^5 \pm 2.11$
Enterobacteriaceae	(CFU/g TS)	$1 \times 10^5 \pm 0.44$
Liquid portion		
pH		6.78 ± 0.17
COD	(g /l)	52 ± 4.31
E. Coli	(CFU/g TS)	$4.8 \times 10^6 \pm 3.60$
Enterobacteriaceae	(CFU/g TS)	$1.03 \times 10^6 \pm 0.32$

N = 3 for each parameter measured.

Table (2) - Characteristics of the digestates after digestion

4. Conclusion

From the results obtained, we can see that the production of biogas generated from human feces is (7.62 × 103 ml). The anaerobic digestion of HF had only minor effects on pathogen inactivation within the solid and liquid digestate, resulting in a reduction in the population of E. coli and Enterobacteriaceae by one logarithmic unit. Consequently, supplementary post-treatment methods such as co-composting and vermicomposting would be essential to eliminate pathogens and facilitate the utilization of digestate for agricultural purposes.

Considering these findings, it is strongly recommended that further research endeavors be undertaken to explore additional formulations involving the inclusion of human feces as a co-substrate alongside cow and chicken manure. It is believed that once an optimal blend of these substrates has been ascertained, more favorable outcomes can be anticipated, potentially yielding enhanced efficiency in terms of biogas production and the utilization of the resulting digestate. This investigation aims to identify and optimize the most effective co-digestion ratios, thus potentially rendering the process not only more economically viable but also more environmentally sustainable.

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