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Biogas Production from Manure of Camel and Sheep Using Tomato and Rumen as Co-Substrate

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ABSTRACT

Rumen accumulation in slaughterhouses produced by sheep is a significant issue that endangers human life and the ecosystem. Use of rumen appears to improve biogas production due to a high rate of hydrolytic bacteria. Hydrolytic bacteria are required for the breakdown of organic matter and biogas. This study proposes that combined camel and sheep manure with tomatoes and Rumen be co-digested under mesophilic conditions by anaerobically fermenting in a batch system to produce biogas. In the cross-sectional area of the study at the same operating conditions, biogas volume was measured for a period of 14 days, and on the last day, methane concentrations were measured. The study found that the rumen sample had the highest methane concentration, measuring 69.30%. Conversely, the control mixture without any additional co-substance had the lowest percentage of methane. Additionally, the tomato sample showed a slightly higher methane concentration of 0.1% compared to the control mixture. The study results show that efficient biogas production increased with rumen and tomatoes addition to manure compared to the control bio-digester sample. This demonstrates how waste can be transformed into wealth, which can be used to reduce costs for the community.

Keywords: anaerobic digestion, bio-digester, rumen, co-substance, biogas, retention time.

INTRODUCTION

The increasing use of non-renewable energy resources and the high demand for them is dangerous for the global climate, so the search for alternative sources of energy is on the rise to protect the world's environment. (Embuldeniya et al., 2017). One of the most significant sources of renewable energy is biogas which can help reduce reliance on fossil fuels (Rathod et al., 2015). Biogas, which is produced from organic waste, wastewater, manure, sludge, and other waste, can be utilized for creating electricity, heat, and fuel (Embuldeniya et al., 2017). There are many waste treatment methods, but anaerobic digestion emerges to be a promising option (Charles et al., 2009). Anaerobic treatment is a viable technology for digesting bio-wastes from both an energy and an environmental standpoint. Anaerobic digestion is a complex process involving various microorganisms to decompose various organic compounds. The outcome of this process is the generation of a mixture of gases comprising methane (CH_4), carbon dioxide (CO_2), and other gases. This method is commonly applied in treating different types of organic waste, enabling the production of valuable byproducts such as biogas, a gas with high energy content, and fertilizers (Nsair et al., 2020; Shokri, 2011). Bio-waste co-digestion and operational temperature are critical parameters influencing the production of methane gas (Alrowais et al., 2023). The type of feedstock used and operational technology such as temperature (T), pH, hydraulic retention time (HRT), and so on all influence the performance of the anaerobic bio-digestion process (Kelly Orhorhoro, 2017).

The various operational processes significantly impact the possibility of producing biogas (Nsair et al., 2020). When loading feedstock for batch feeds, it ferments immediately when kept closed for a suitable amount of time and then unloaded later (Samer, 2012). In general, there are four main stages for anaerobic digestion, which are hydrolysis, acidogenesis composition, the composition of acetogenesis and finally, methanogenesis. Each decomposition stage requires the involvement of different microorganisms. These microorganisms work in tandem and are partially dependent on one another to facilitate the different stages of the process (Ekstrand, 2019). Creating biogas from organic refuse is crucial and helpful to the waste management process, as food waste is a good source for producing biogas (Ismail et al., 2018). The use of organic farm waste such as manure and agricultural crop residues such as fruit and vegetable are increased to produce natural gas by anaerobic digestion (AD) (Gebrezgabher et al., 2010). Additionally, Sagagi et al. (2009) demonstrated that the majority of fruit and vegetable waste is biodegradable and can be transformed into energy, such as electricity and other forms for both domestic and industrial uses. The researcher Szilágyi et al. (2021) confirmed that the production of biogas from only tomatoes by the batch system does not reach desirable outcomes It is optimum to be used as a co-substance. Also, the best results are achieved through the continuous system.

Dinuccio et al. (2010) and Szilágyi et al. (2021) confirmed that the production of biogas by tomatoes is high during its early days in the biodigester. The work of Dinuccio et al. (2010) investigated the production of biogas from cattle dung and tomato waste as co-digestion. He measured the gas composition by an infrared sensor with the semi-continuous system. The average methane concentration was 67%. Similarly, Saghouri et al. (2018) also reported on the production of biogas from tomato waste inside a bio-digester, with a methane content of approximately 60.50%. Biogas production is more effective when manure is used, and animal rumen can be used because it contains a high percentage of anaerobic bacteria (Budiyono et al., 2014; Emetere et al., 2022). Budiyono et al. (2014) reported that the use of rumen fluid compared to the manure substrate caused the biogas production rate and efficiency to rise double to three times.

The study aims to generate biologically degradable biogas using rumen as a co-substance instead of inoculum. The comparison will be made with manure and tomato waste to assess the concentration of methane yields in the batch system with different co-substance samples compared to the control sample. Additionally, the study aims to determine the minimum retention time required for biogas production.

MATERIALS AND METHODS

Samples collection

Fresh camel manure and sheep manure as substrates were collected from a farm in Bish City in Jizan Province, Saudi Arabia. Tomatoes as co-substrate were obtained from kitchen waste at home, and a rotary cutter was used to get particles smaller than 1 cm to increase surface materials and facilitate the interaction of microbial organisms. Rumen fluid was collected from sheep after these animals were sheared by the Islamic slaughter method. Then Manure and rumen fluid stored in dark polythene bags prior to use. The materials for the biodigesters were selected based on their ability to produce methane and their accessibility within KSA. Careful consideration was given to ensure that only the most suitable materials were chosen to optimize the efficiency and effectiveness of the biodigesters' performance. In this study, 1000 mL of plastic bottles were used for the construction of anaerobic biodigesters and gas produced was collected in Tedlar bags. Further, a set of glass graduated cylinders for measuring biogas volume was used.

Experimental

Two holes were carefully drilled into the lid of a plastic bottle to effectively monitor the temperature inside the biodigester and efficiently transport biogas into a Tedler bag. The first hole was explicitly designed to accommodate a thermometer, allowing for accurate temperature readings. The second hole, with a diameter of 5 mm, was created to hold a silicon tube responsible for collecting and delivering the biogas into the Tedlar bag. This tube was securely sealed with silicon thermal glue to prevent any potential gas leakage. The visual representation of the biodigester and its components are shown in Figure 1. During our research, six different bio-digester designs (A1 and A2, B1 and B2, C1 and C2) were carefully monitored. Each bio-digester was set up using a simple formation process to create biogas. We tested three of the bio-digesters specifically for methane

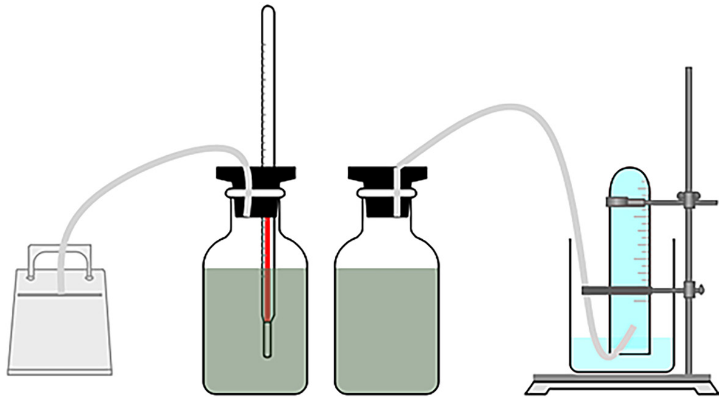

Figure 1. Schematic representation of the design of biodigester plant

concentrations. The gas analysis performed using the GC-US17273025 serial number was conducted with three detectors that utilized Helium (He) as the carrier gas. The Flame-Ionization Detector (FID) channel was utilized to examine hydrocarbon elements like CH_4, while the Thermal Conductivity Detector (TCD) channel was set up to analyze CO_2, O_2, N_2, H_2S, and H_2. The column used in this analysis was the Molecular Sieve 5A 60/80 mesh column. While the other three were used to determine the volume of biogas produced through water displacement. The experiment required various equipment, such as a thermometer to measure the temperature of substances, a digital analytics balance, and a pH meter to test the pH levels in each sample. To ensure the accuracy and validity of the results, measurements were recorded three times, and a mean average value was calculated. A visual representation of the biodigesters used in our study showed in Figure 2.

Content preparation

All six bio-digesters A1 and A2 and B1 and B2 have the same content ratios, i.e. A1 and A2 with ratio 1:1, B1 and B2 with ratio 1:1, as for C1 and C2 with ratio 1:2. All samples use an equal mixture of camel manure and sheep manure. Samples A1 and A2 consist of a 100% mixture of manure mixed with 240 ml of seawater. Samples B1 and B2 consist of an 80% mixture of manure and 20% tomatoes mixed with 240 ml of seawater. Samples C1 and C2 consist of an 80% manure mixture and a 20% rumen mixed with 410 ml of seawater (Table 1). Samples of biodigesters A1 and A2 were created using a precise mixture of 240

Figure 2. The first cross-section of the experimental set-up

grams of manure and 240 ml of seawater, resulting in a total weight of 480 grams. The composition of biodigesters B1 and B2 included a mixture of 240 grams of manure, 60 grams of fresh tomatoes, and 240 ml of seawater, weighing 540 grams. Lastly, biodigesters C1 and C2 were prepared with a combination of 240 grams of manure, 60 grams of inoculum, and 410 ml of seawater, resulting in a total weight of 710 grams. The study used a batch digester, which is the most basic method of biodigestion. Finally, after feeding the mixed wastes into bio-digesters, the bio-digesters were put under sunshine for 14 days to monitor the biogas generation process. The bio-digesters were monitored daily to measure the biogas volume yielded by water displacement. The temperature was recorded twice, as shown in Table 2.

RESULTS AND DISCUSSION

The performance of the bio-digesters constructed was excellent. The bio-digesters were charged with different ratios of substance contained in the A1 and A2 samples, B1 and B2 samples, and C1 and C2 samples, 1:1, 1:1, and 1:2, respectively. The retention time selection was a meticulous process that considered several factors, such as the co-substrate type, internal content quantity, and compatibility with the digester volume. As a result, all bio-digesters displayed remarkable biogas yields. During the 14-day period at mesophilic conditions (37 ± 0.3 °C), a mixture of camel and sheep manure with seawater was used in three bio-digesters with different co-substances. Table 3 presents the daily biogas production amount during the start-up phase.

Table 3 illustrates the volume of biogas yields obtained from A2, B2 and C2 samples through the water displacement method. The background gas created in the blank samples was subtracted to calculate the daily methane output in each sample container. The first indications of gas production were observed in sample C2, which displayed a significant initial volume on the second day, surpassing all other samples. Sample B2, in contrast,

Table 1. Internal content of all biodigester

Samples	Substrate	Co-substrate	Water content (ml)	Ration (S:W)	Total content volume (g)
A1	Camel and sheep manure	-	240	(1:1)	480
B1		tomato	240	(1:1)	540
C1		Rumen	410	(1:2)	700

Table 2. The ambient and internal temperature for retention time

Samples	A1		A2		B1		B2		C1		C2		Ambient temp. of all samples °C	
Temp.	Internal °C		Internal °C		Internal °C		Internal °C		Internal °C		Internal °C			
Times	2 pm	2 am	2 pm	2 am	2 pm	2 am	2 pm	2 am	2 pm	2 am	2 pm	2 am	2 pm	2 am
Day1	31	29	31	29	31	29	31	29	31	30	31	30	31	26
Day2	32	28	32	28	32	28	32	28	33	30	33	30	32	27
Day3	33	30	33	30	33	30	33	30	33	30	33	30	32	27
Day4	31	30	31	30	32	27	32	27	33	28	33	28	31	26
Day5	31	26	31	26	32	26	32	26	32	27	32	27	31	25
Day6	30	27	30	27	30	27	30	27	31	28	31	28	31	25
Day7	32	29	32	29	33	29	33	29	33	29	33	29	31	26
Day8	31	29	31	29	31	29	31	29	32	28	32	28	32	25
Day9	32	27	32	27	32	27	32	27	32	27	32	27	32	24
Day10	32	27	32	27	32	27	32	27	32	27	32	27	31	25
Day11	32	28	32	28	32	28	32	28	32	28	32	28	31	27
Day12	33	27	33	27	33	27	33	27	33	29	33	29	31	26
Day13	34	31	34	31	34	31	34	31	33	29	33	28	31	27
Day14	32	31	32	31	32	31	32	31	30	26	30	26	31	26

Table 3. The biogas yields for a period of 14 days

Days	A2 (ml/day)	B2 (ml/day)	C2 (ml/day)
1	0.00	0.00	0.00
2	0.00	0.00	1.30
3	0.00	0.05	1.90
4	0.00	1.09	2.69
5	0.70	2.25	3.60
6	1.65	3.00	3.88
7	2.20	3.35	4.65
8	2.98	4.90	5.00
9	3.72	5.10	6.81
10	5.41	7.50	9.34
11	5.33	8.45	10.22
12	6.94	11.20	14.87
13	7.68	11.95	16.11
14	9.84	11.99	16.97

had a lower initial volume on the third day, while sample A2 took four days to start producing gas with a relatively higher volume of 0.70 ml. Gas production gradually increased in all samples until it stabilized in both B2 and C2 after twelve days. On the fourteenth day, the Tedlar bag was removed from the anaerobic biodigester for all samples to perform gas analysis by Gas chromatography (GC).

Figure 3 shows the graph of the relation between the volume of biogas and the HRT of biodigesters. It was observed that the lowest gas production from these bio-digesters might be due to the absence of co-substance, which helps to quickly break down into microorganisms that reduced the methane concentration of the biogas. This agrees with numerous studies that have revealed that using inoculation materials as a co-substance has a positive impact on biogas production. This is because the inoculum not only reduces HRT but also accelerates the reaction and regulates the pH levels at the start of the reaction, as indicated by Saghouri et al. (2018).

In addition, wasted tomatoes are among the vegetables that can be utilized as a source for biogas production, according to Simeonov and Koumanova (2009). A comparison of the methane contact concentrations of tomato samples

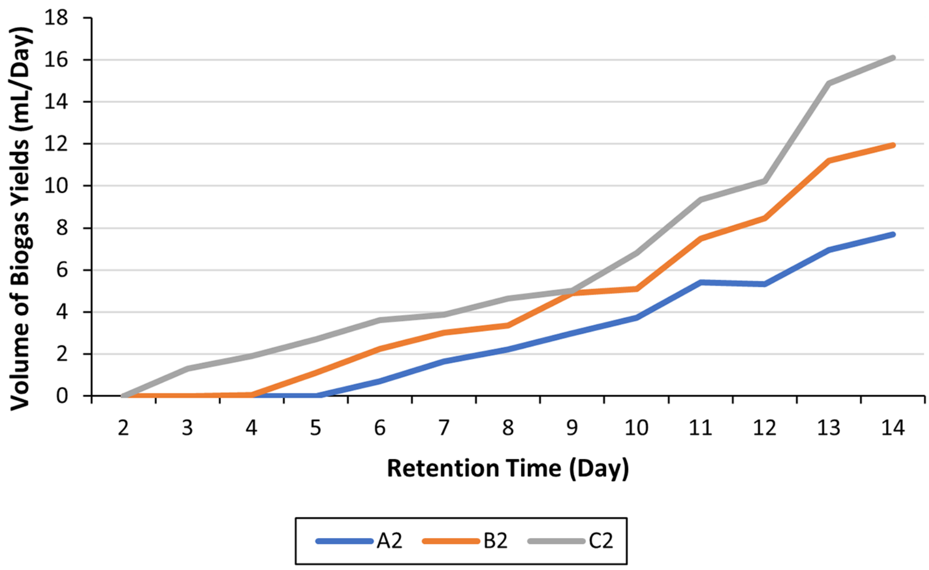

Figure 3. Accumulation of biogas in each HRT of biodigesters

used under mesophilic conditions with other substances in the current study and others is shown in Table 4. Table 5 shows that each sample had its pH tested both at the beginning of the fermentation process and after 14 days. Furthermore, the pH values observed in the 5.5 to 7.56 range were different according to the types of feedstocks. The ideal pH for methanogenic bacteria ranges from 6.8 to 7.2, whereas it ranges from 6.8 to 6.5 for hydrogenation and acetogenic (Zhou et al., 2016). All hydrolytic, acidogenic, and methanogenic bacteria achieved in this pH range is due to their rapid doubling period and high growth (Wang et al., 2014). A1 biodigester before the digester had 5.5, which was below the optimum value of pH, and after finishing HRT, it was 7.1, which is in the range of methanogenic bacteria, but consequent unfavorable pH levels also caused a reduction in methane concentration. While the pH values were more stable in B1 and C1 biodigesters. B1 biodigester starts with a pH of 7.20 and increases to 7.65. In fact, biodigester B1 contains tomato as a

Table 4. Comparison of measurement results of methane contact concentrations with tomato waste

No.	Contact digesters	Feeding system	Day	Temperature (°C)	Methane content (%)	References
1	Tomato with camel and sheep manure	Batch	14	27–34	59.08%	In the current study
2	Tomato with cow dung	Batch	30	37	46–48	Szilágyi et al. (2021)
3	Tomato crop residue	Batch	50	36	57.9	Liu et al. (2018)
4	Tomato with inoculation material	Batch	40	35	60.3	Saghouri et al. (2018)
5	Tomato skins and seeds with inoculum	Batch	40	40	78	Dinuccio et al. (2010)

Table 5. The effect of mixed substance and co-substance on pH before anaerobic digestion and after 14 days

Biodigester	Before	After
A1	5.5	7.1
B1	7.20	7.65
C1	7.8	7.3

Table 6. Percentage of components biogas for the biodigester

Type of gas	A1(Mole%)	B1(Mole%)	C1(Mole%)
CH_4	58.98	59.08	69.30
CO_2	31.06	28.73	23.33
Other gases	9.96	12.1	7.37

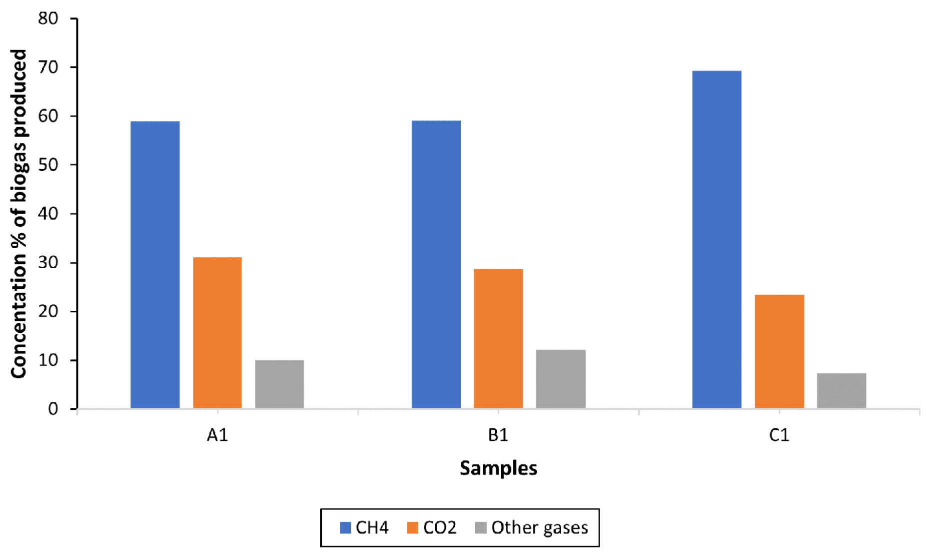

Figure 4. Biogas concentration of anaerobic bio-digester samples

co-substant, possibly mostly raising the methanogenic bacteria. But C1 biodigester starts with a pH of 7.8 and is reduced to 7.3. These results showed that pH 7.3 gave the highest methane concentration. On the other hand, the biogas samples that were generated underwent gas chromatography (GC) analysis to ascertain the levels of CH_4 and CO_2, and the outcomes are presented in Table 6. This result demonstrates that the methane concentration in A1 bio-digester was the lowest from B1 and C1. While B1 slightly increased from A1 containing 58.98% and 31.06% of methane and dioxide carbon respectively. Moreover, C1 sharply increased to 69.30% and 23.33% of methane and carbon dioxide content respectively. Consequently, it was observed rumen fluid used as a co-substrate was adequate in raising the methane content in the bio-digestion process. Among the very recent works of Meyer et al. (2022) they used rumen fluid as inoculum to decrease HRT and increase the volume of biodigester needed for generating biogas. A comparison of the concentration of all samples that were analyzed through the bio-digester is shown in Figure 4.

The results of our study indicate that the methane levels and other gas components present in the samples were found to be suitable for our research purposes. In addition, these levels were found to be consistent with the values previously documented in the Liu et al. (2018), which adds further credibility to our findings.

CONCLUSIONS

Based on the experiment's findings, it was discovered that the A1 biodigester, which solely utilized manure without any other materials, generated the least amount of methane at 58.98%. Conversely, the C1 biodigester, which used both manure and inoculum, had the highest methane production at 69.30%. Additionally, the discrepancy between the biogas produced in samples A1 and B1 in terms of methane content quality was relatively minor, with the B1 biodigester coming in at 59.08%. It was also evident that the inoculum significantly influenced the production of biogas, as illustrated through methane content analysis.

Sheep and camel dung are abundant in the Kingdom of Saudi Arabia. Generating bio-degradable and sustainable energy will make the country more healthy, economically sound future, and avoidable environmental pollution caused by general waste disposal methods of burning and burying. After benefiting from it in the energy production field, the output content known as sludge can also be used in the field of agriculture as fertilizer for the soil.

This study's findings indicate that adding rumen sheep as a co-substrate in biogas production can lead to higher efficiency than using only manure for biogas production. This suggests that incorporating rumen sheep may be a viable strategy for enhancing the sustainability of biogas production in the future.

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