Biogas Production from Cow Manure Using an Anaerobic Digestion Technique

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Abstract

The world is suffering from limited sources of energy thus finding a renewable and sustainable source is very crucial. Cow manure is an unexploited treasure and is expected to have a high potential for energy recovery. This study aimed to evaluate biogas production from cow manure (CM) under an anaerobic condition. The cow manure was collected from a local farm in Oman and diluted with a ratio of 1:3 (dry CM/Water). The diluted cow manure (DCM) was characterized and found to have pH 7.9, total solids (TS) 8930 mg/L, total dissolved solids (TDS)1390 mg/L, dissolved organic carbon (DOC) 8160 mg/L and electrical conductivity (EC) 2730 µS/cm. The used anaerobic reactor (20 litres, black) was fed with DCM (15 litres) and operated at atmospheric mesophilic conditions (40 to 45°C). The gas was measured by the water displacement method. The results revealed that the biogas was generated in low amounts after three days (119 mL) and achieved more than 20 litres after nine days. The percentage of volatile solids to total solids was found to be 71% and the production of the biogas was calculated as 131 L/kg VS. This study is believed to pave the way for reducing the pressure on landfills and converting an environmental burden into a product of added value serving the circular economy theme.

Keywords: Cow manure; Biogas; Renewable energy

1 Introduction

The improper management of animal manure in the open area causes various environmental concerns namely: soil nutrient saturation, water eutrophication and greenhouse gas emission (Díaz-Vázquez et al., 2020). Soil nutrient saturation results in the uncontrolled growth of microorganisms including pathogens infection. During heavy rain seasons, the runoffs will transport soil nutrients to the nearby water body. This eventually will cause water eutrophication due to the accumulation of nitrogen and phosphorus content. Consequently, that will lead eventually to rapid algal blooms disturbing the aquatic life's biodiversity. Greenhouse gases also are emitted by livestock waste such as ammonia, nitrous oxide and methane. The contribution of the livestock sector to global greenhouse emissions is counted as 7.1 Gigatonnes of CO_2 equivalent/ year representing 14.5% with 65% attributed to cattle (FAO, 2022).

However, utilizing animal manure by using an anaerobic technique is expected to mitigate greenhouse gas emissions and also provide a renewable energy source (Liebetrau et al., 2021).

Indeed, anaerobic digestion (AD) is a well-established technique (in Europe there are more than 17,000 biogas plants) which is used to digest organic waste collected from different sectors (food, agriculture, animal manure, sewage sludge) (Tampio et al., 2019). The composition of the biogas produced is 50 to 70% methane, 30 to 40 % carbon dioxide and the remaining are trace gases such as hydrogen, oxygen and nitrogen (Cheremisinoff NP, 1980).

AD process is a microbial-assisted sequential biodegradation process that involves different stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Jomnonkhaow et al., 2021). In the first step, the complex compounds: proteins and carbohydrates are hydrolyzed into monomers like compounds: amino acids, long-chain fatty acids and sugar. Then the generated compounds are fermented into fatty acids (lactic, propionic and butyric acids). Then the VFAs are consumed to generate acetic acid, carbon dioxide and hydrogen followed by methane production which is the final step (Haryanto et al., 2018).

AD generates intermediate products: volatile fatty acids (VFA) and biogas (e.g. hydrogen, CO2, methane). Both VFA and methane are valuable products that are classified as products of added value and may act as major elements in the circular economy. Indeed, VFA can be utilized for the production of bioplastic and biodiesel (Cavinato et al. (2017); Jomnonkhaow et al., (2021)). On the other hand, methane recovery from AD is more viable and feasible. In a comparative study, it was reported that food waste could produce twice the amount of methane compared to that produced by cow slurry (Tampio et al., 2019). That being said, the feasibility depends highly on the availability of raw wastes. Furthermore, biogas production from biomass is much easier than the extraction of the VFA for industrial applications. The methane potential from dairy cattle is 0.24 m^3 CH_4/ kg of VS (Liebetrau et al., 2021). In line with this study, it was reported that the highest methane yield was obtained from sheep dung while cow dung is the second and the least from chicken dung and tomato wastes (Adamu, 2014).

In German, the total production of fresh matter (cattle manure) is approximately 115 mt and 33% of that is used for biogas production. The production of electricity from the produced methane is calculated based on the below model (1) (Liebetrau et al., 2021):

$$9.32\text{t FM}*\text{yr}^{-1}\text{r per cow} * 10\%\text{TS} * 80\%\text{ VS} * \text{biogas yield of 380 l}*\text{kgVS}^{-1} * 5.3\text{ kWh}*\text{m}^{3} * 35\%\text{ electrical efficiency} *(365\text{days} * 24\text{hours})^{-1} = 0.06\text{ kW}_{e}\text{ per cow} \quad (1)$$

Therefore, for the production of 100 kWe (the typical size of the biogas plant), 1666 cows are required.

The Gulf Cooperation Council (GCC) countries produce one-third of the crude oil in the world and have one-fifth of the gas reserve (Al-Badi et al., 2019). The total energy consumption in GCC countries was 536 TWh (Terra Watt-hour) and that is expected to increase to 2000 TWh by 2040. In 2018, the contribution of renewable energy (solar, wind, bioenergy) to electricity generation is the highest in UAE reaching 600 MW and around 140 MW in Saudi Arabia while it is nearly 40 MW for Kuwait and Qatar whereas it is less than 10 MW for Oman and Bahrain (Basha, et al., 2021). The GCC countries plan to increase the contribution of renewable energy to the total electricity produced. In particular, Oman and Bahrain 10% and 5% respectively by 2025, Saudi Arabia and Kuwait aim for 30% and 15% respectively by 2030, and UAE aims for 44% by 2050 (Atalay et al., 2016). In the GCC countries, the contribution of bioenergy to the total renewable energy is expected to be 2% by 2030 while the solar energy sector contributes 75%. Indeed, the biomass generated from municipal solid waste and animal waste reach 19.5 Mtpa and 25.52 Mtpa respectively. Therefore, the bioenergy potentials in biomass could secure 23% of the total electricity demand in the GCC countries (Welfe & Al Awadhi, 2021).

Currently, most of the biomass is sent to landfills and minimal is utilized. However, there are a few pioneer projects in the region utilizing biomass for bioenergy production such as Sharjah using sewage sludge and Ras Al Kaimah using camel manure (Basha et al., 2021).

The aim of this study was to assess the potential of biogas production using cow manure treated anaerobically. The reaction was conducted under ambient temperature (35 to 40 ºC) for 10 days and the gas volume was measured using the water displacement method. This project is expected to pave the way for more research in this area.

2 Methodologies

2.1 Sample Collection

The cow manure (CM) (4 kg, fresh) was collected from a local farm in Oman and placed in a plastic container. The CM was diluted with deionized water (DI): 1:3 (CM: DI) to assure good microbial activities. The characterization of the sample was conducted before starting the treatment.

2.2 The Operation Condition of the Reactor

The reactor was made of high-density polyethylene (HDPE) material and provided with the required fittings (Figure 1). The reactor was placed in an open area (campus of the University of Technology and Applied Sciences-Muscat). The size of the reactor is 30 litres, painted with a black colour to prevent the photosynthesis process. The reactor was provided with two outlets: the first for gas sampling (at the top) and the second for biowaste sample collection (5 cm from the bottom). Two third of the reactor volume was filled with the diluted CM (total 20 litres). The ambient temperature was in the range of 35 to 40 ºC which was within the range of mesophilic conditions 20 to 45 ºC and that proved to be ideal for anaerobic digestion.

Fig. 1: Reactor arrangement (HDPE container, 30 litres size)
with stainless steel valve (bottom) sampling outlet, gas outlet (top)

2.3 Characterization of Sample

The diluted cow manure was characterized before and after the anaerobic digestion. pH, total dissolved solids TDS, and electrical conductivity were measured using a digital meter. The total solids content was measured as per the standards method (2540). For the dissolved organic carbon, prior to the measurement, the sample was filtered through a cellulose membrane filter with pore sizes of 0.45 microns. Then the measurement was conducted using Sievers InnovOx ES Laboratory TOC Analyzers (conditions: 1% 6M phosphoric acid and 15% oxidizer (30% Sodium persulphate solution).

2.4 Gas Measurement

The reactor was operated for more than 10 days, and gas samples were collected using a well-established method called the water displacement method (Figure 2). The gas outlet from the reactor was connected via a hose (3/4 inch) to an inverted graduated cylinder (1000 mL) filled with water. Upon opening the gas valve, the water will be displaced by the biogas and the difference in the water height will be recorded.

Fig. 2: Water displacement method setup for measuring gas volume

3 Results and Discussion

Samples of the cow manure (CM) were analysed before and during the anaerobic digestion (AD) process (Table 1). The results revealed that the pH of CM before the AD process was 7.9 and reached 6.1 on the 9^{th} day. The drop in pH value might be explained by referring to the mechanism of the AD in which it is expected to generate higher quantities of acetic acids. This indeed came in line with another study which also reported a similar observation (Tampio et al., 2019). The EC values also increased aligned with the progress of the AD process which may be attributed to the accumulation of the ions in the digested biosolids.

The initial VS/TS ratio was 64% and it reached 74% after 9 days which is comparable to what was reported by (Baek et al., 2020; Haryanto et al., 2017). The VS/TS is a very good indicator of biomass biodegradability. That increment in VS content might be attributed to the acidogenesis stage of the AD process where most long-chain acids are converted to volatile fatty acids. Moreover, VS content in CM might change from one country to another depending on the feeding system, bedding material in the pens floor and method of manure collection.

Table 1: The characteristics of the diluted cow manure (CM) at different time intervals

Day	pH	EC (µS/cm)	VS/TS %
0	7.9	2730	64
3	7.5	2555	74
4	7.4	2460	72
5	6.6	2350	72
7	6.0	4810	70
9	6.1	4815	74

DOC levels fluctuated during the period of observation (Figure 3). In the beginning, the apparent sudden increment in the DOC within the first three days might be attributed to the hydrolysis process where most of the organic complex compounds are converted into more soluble compounds. Then, in the following seven days the DOC level remained constant and then drop to 7.5 g/L on the ninth day. That behaviour was expected due to the production of the biogas at the final stage where acetic acids (DOC) were converted into biogas (Tampio et al., 2019).

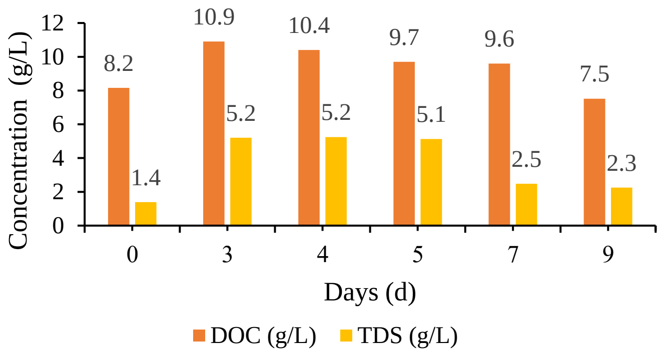

Fig. 3: The concentration of DOC and TDS during anaerobic digestion of the diluted cow manure

Interestingly, the production of biogas was observed since the third day (Figure 4). The methane content is expected to be between 65% to 70% of the total biogas produced (Adamu et al., 2014; Vazquez et al., 2020; Haryanto et al., 2017). The accumulated produced biogas after 9 days was 47 biogas L/kg VS which is equivalent to 30.6 CH_4 L/ kg of VS (considering CH_4 is 65%). That indeed is very comparable to the value of 40 CH_4 L/ kg of VS reported by Baek et al. (2020) after 10 days. Nevertheless, Tampio et al. (2019) reported higher production of methane at 200 L/kg VS. The discrepancy in the previously mentioned study might be attributed to the dilution factor used, and the characteristics of CM.

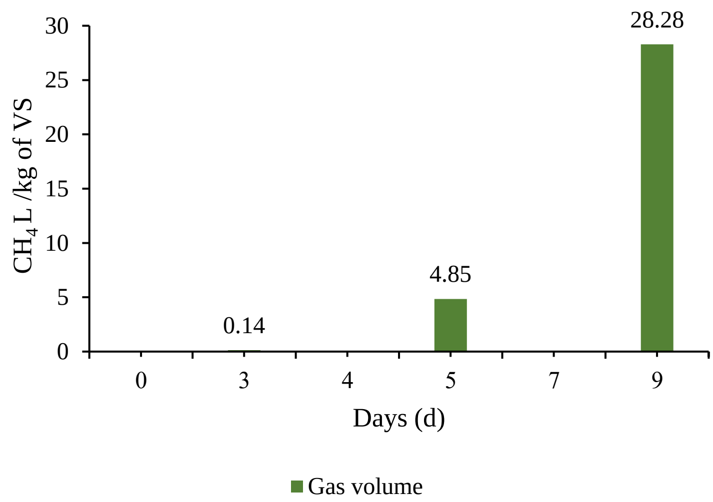

Fig. 4: Gas volume production during anaerobic digestion of the diluted cow manure

4 Oman Implications

In Oman, the total number of cows is around 421,000 cows (National Centre for Statistics and Information, 2021). The total annual national natural gas consumption was 46642.5 million m^3 in 2019. Using the AD technique will be able to provide as per this study 0.003 m^3 of CH_4/kg VS/day. The total production of the CM/year/cow is 9320 kg. Consider the total solid content 20% and VS

64%. Therefore, the total VS content equals 1192.96 kg VS/cow/year. Therefore, the total production of methane in Oman can be predicted by the model below:

$$\mathbf{CH_4\ m^3\ /\ year} = 1192.96 \text{ kg Vs/cow} * 0.003 \text{ m}^3 \text{ of } CH_4\text{/kg VS/day} * 365 \text{ day/year} * 421{,}000 \text{ cow} =$$

$$\mathbf{550\ million\ m^3\ CH_4/\ year}$$

The calculated amount of methane represents around 1.2% of the total natural gas consumed in Oman. This can be extended if other sources of biomass are considered such as municipal wastes and sewage sludge and other animal waste (horse, camel, chicken). In fact, a detailed study is required to address the unexplored potentials of this sector and what is the best way to manage this huge sector.

5 Conclusion

This study successfully achieved the main objective by evaluating the potential of biogas production from cow manure using an anaerobic digestion technique. This study found that, under the experimental conditions (mesophilic, 10 days of reaction), the total amount of the biogas produced was 20 litres which is corresponding to 3 L of CH_4/kg of VS/day. The mentioned value came aligned with what was reported in the literature. This study predicted that the total amount of cow manure in Oman could produce 1.2% of the total natural gas consumption in the country. Nonetheless, a comprehensive study is required to address the potential of bioenergy utilizing different sources of biomass including animal wastes, municipal wastes, and sewage sludge. This study is expected to pave the way for more studies to evaluate this sector from different perspectives.

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