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A Proposed Method of Biogas Production from Agricultural and Animal Waste by Anaerobic digestion

Mohamed K. Hassan[†,‡*], Omar. A Khan[†], Mohammed S. Mahmud[‡†,‡‡], Ahmed F. Mohamed[†,‡‡†]

[†]Mechanical engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makah, KSA
[‡]Production Engineering& Design Department, Faculty of Engineering, Minia University, 61111-Egypt
[‡†]Department of engineering, The University of Technology and Applied Scienses , Suhar, Sultanate of Oman
[‡‡]Chemical Engineering Department, Faculty of Engineering, Minia University, Egypt
[‡‡†]Mechanical Engineering Department, Faculty of Engineering, Sohag University, Egypt

*Corresponding author E-mail: mkibrahiem@uqu.edu.sa;

ABSTRACT

The global energy crisis is a critical issue today, particularly given the threat of depletion of nonrenewable energy resources such as fossil fuels. As a result of this problem, it is critical to consider the use of renewable energy resources such as biomass energy**.** As a result, this work develops a mobile unit of biogas (1000 L) to be used for biogas production based on lab-scale (25 L) experimental results. At the start of this study in the winter, a small scale fermenter is used to ensure the production of biogas, which is observed after 20 days. Then, as feedstock, 25 kg of cow manure and other animal and agricultural wastes are used. Following that, a fixed digester with an agitator is designed to produce biogas; additionally, a floating dome digester and a fixed brush digester are used to produce biogas. For lab-scale and large-scale units, the biogas production rate is approximately 35 and 140 L/kg VSS, respectively. The presented method is simple, requires no mechanical or electrical components, is easily constructed, and produces gas at a low cost.

KEYWORDS

Biogas production, Anaerobic digestion, floating digester, fixed brush

INTRODUCTION

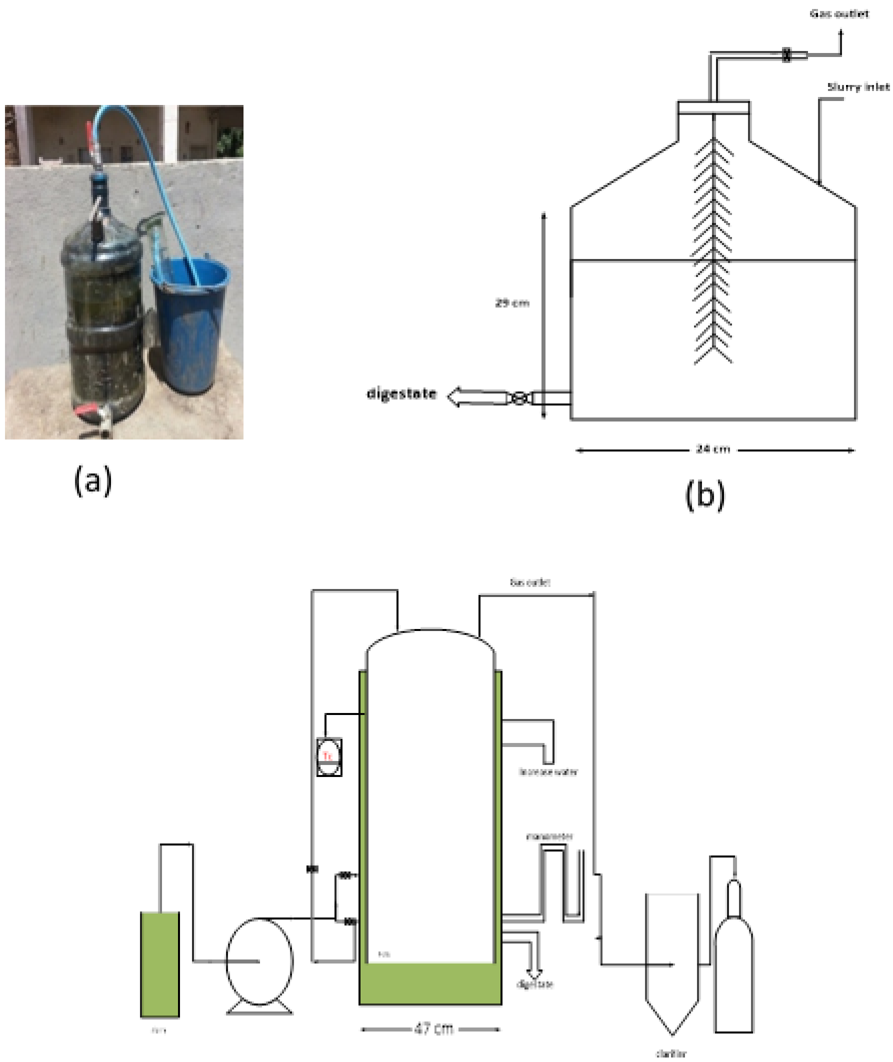
Governments, institutions, and organizations concerned with alternative energy sources have recently made unrelenting efforts in this regard. It is common knowledge that fossil fuel sources are under threat. Natural energy sources have frequently been identified as one of the primary alternatives for reducing fossil fuel consumption and realizing a sustainable energy system in the twenty-first century[1]. Animal and agricultural wastes are widely used as feedstock in the production of biogas. It was reported that low-cost porous materials could be used to boost biogas production[2]. Anaerobic digestion (AD) was presented as an effective approach to controlled waste disposal in the dairy industries because it allows them to properly manage waste while also extracting value from it. In particular, the process can contribute to its own energy consumption by utilizing the biogas produced by bio methanization of the waste they generate, while also addressing the serious environmental issues. The effect of hydraulic retention time was studied in a laboratory-scale anaerobic fixed-bed reactor filled with a hybrid material made of rubber tires and zeolite for 1.0 to 5.5 days [3]. The results showed that this type of reactor could work with dairy waste in 5 times less hydraulic retention time than a conventional digester.

Recently, two methods for improving the efficiency of methane production in anaerobic digestion (AD) have been tested: adding a large amount of surface area with a single electrically conductive carbon brush, or adding electrodes like in microbial electrolysis cells (MEC) to form hybrid AD-MEC[4]. These findings show that adding a carbon fiber brush with a large surface area is a more effective way to improve AD performance than using MEC electrodes with applied potentials. A year ago, the cassava starch extraction process was linked to the production of a large amount of effluent from the root washing and starch extraction processes (5 to 7 liters per kg - 1 root). The goal of this study was to evaluate the treatment of cassava starch wastewater in a horizontal reactor with an anaerobic fixed bed to remove organic matter and generate biogas in this context. [5]. Furthermore, molasses is used to generate methane in a two-stage fixed-bed anaerobic reactor [6]. Biogas was created using chicken waste and cow manure [7]. These findings demonstrated that the stages have an impact on gas production. The presence of stages within the reactor can increase gas production by up to 30%. In addition, the amount of protein consumed increases gas production. However, if the protein hydrolysis rate is high, it can disrupt the process because methanogenesis prefers neutral PH. Biogas production from palm oil plant effluents using various bioreactor configurations, on the other hand, was widespread [8].

Meanwhile, the microorganism's growth behavior before and after the addition of zeolite was identified using mathematical modeling and a statistical approach [9]. Biogas technologies are not widely used in Saudi Arabia, which has a large number of cows, poultry, goats, and sheep. The number of specialized cattle farms in the Kingdom reached 138 holdings, the number of cows exceeded 354 thousand heads, and the number of birds and poultry in the Kingdom exceeded 5 million. 600,000 birds, the number of camels in the Kingdom reached approximately 1.4 million heads, the number of goats reached approximately 6 million heads, and the total number of sheep in the Kingdom reached approximately 17.5 million heads. [10]. In Makkah, for example, agricultural and animal waste is deposited in a general waste landfill at a rate of 5200 tons per month, with an average daily rate of about 170 tons. It is buried alongside other waste with no benefit [11]. The information presented above clearly demonstrates the need for alternative energy sources derived from agricultural and animal waste. Furthermore, despite the availability of fossil energy resources in the Saudi Kingdom, the purpose of this research is to demonstrate the significance of using animal and agricultural wastes in the production of biogas as a simple and clean method. Furthermore, the current research aims to present a simple and easy method for producing biogas through anaerobic digestion. An economic study will also be conducted to demonstrate the economic feasibility of this biogas production method.

MATERIALS AND METHODS

Cow manure, along with other farm wastes such as food waste and chicken sludge, is fed to the digester as substrate. The raw material used is made up of 80% cow manure and 20% food waste, with a water-to-solid ratio of 1:1. At the start of this winter study, a small scale fermenter is used. Figure 1(a, and b) depicts a lab scale fermenter. It is made up of a 25 (L) polycarbonate water bottle with a central 30 cm carbon brush. Carbon filaments with an average length of 10 cm are used in the brush. The feed substrate was poured in through a side opening to fill two-thirds of the tank volume. The gas was collected for examination. A 1000 (L) floating head digester was used for the pilot scale experiments. The setup is shown in Fig 1 (c). A large scale unit is designed and built based on the results of the lab scale one. It primarily consists of slurry, an agitating pump, a digester (1000L), a gas holder, a control unit, a clarifier, and a tank to collect the output composite. The process conditions are a PH of 7 and a pump that is used to agitate the fermented feed in order to reduce scum that forms on the top of the digester, preventing the gas bubbles to rise. The tank is outfitted with a mixer and strainer for inserting fresh feedstock and subsequent thermal convection streams as a result of gas bubble up flow. The floating dome unit has a temperature control, and it is observed that the temperature rises over time from 20 C to 35 C, and that after about 20 days, the gas floating head rises due to biogas formation, after which the unit is fed with a daily feed of 33.3 L/day. Following that, the flow rate of biogas is calculated from this unit by measuring the height of the gas holder while the pressure remains constant but the volume and temperature change according to the equation ($PV=nRT$).



(c)

Figure 1. Photo and schematic diagram for the used digester, (a, b) the lab scale digester V= 25 L, (c) the pilot scale unit used V= 1000 L.

Analytical methods

The feed slurry was analyzed to detect the chemical oxygen demand (COD), the nitrogen (ammonia) ($N–NH_4^+$), the phosphate ($PO_4^{3–}$), the total solids (TS), volatile suspended solids (VSS), metal content, and pH. The gas composition was analyzed by gas chromatography (CG) using (GC 2014 GC analyzer, Shimadzu, Japan). The metals were determined by atomic absorption spectrophotometer (ELICO SL 176). Also, the amount of hydrogen is detected for the lab scale unit by miniMAX XP provided by Honeywell *Lumidor* MicroMax^{Tm}, which detect hydrogen gas in the range of 1-999 ppm [ml/m^3]. Table 1 shows the average composition of the feed slurry used in both digesters. The total solid (TS) values for the three tests was not that high as suggested by Lo et al [12] who mentioned that the optimum TS of on farm digesters should be between 8-12%. The main metals appeared in the analysis are Fe, Zn, Cu, and other trace metals. The appearance of those metals depends on the feeding nature that is given to the cattle. The values of volatile suspended solids are generally considered the key design factor for the biogas process. Theoretically, higher values of VSS will produce higher yield of biogas [13].

Table 1. Average composition of the feed slurry used

Parameter	Exp 1	Exp 2	Exp 3	Average
pH	7.1	7.5	7.2	7.3
COD, mg/L	42561	38928	40198	40562.3
Total Nitrogen, mg/L	1095	985	1018	1032. 7
TS, g/l	49.1	42.8	38.4	43.4
VSS, g/l	24.17	20.3	20.7	21.7
Metals mg/L				
Fe	55.9	50.78	51.4	52.7
Zn	21.71	18.92	17.51	19.4
Cu	5.28	2.87	4.65	4.3
Pb	0.91	0.85	0.72	0.83
Cr	0.15	0.28	0.19	0.21

RESULTS AND DISCUSSION

Gas analysis and hydrogen production

Figure 2 depicts a qualitative analysis of the biogas produced. It is clear that methane gas accounts for approximately 55% of the gas and CO_2 gas accounts for 22%. These are typical values for biogas, which should contain between 55 and 65 percent methane and 35 and 45 percent CO_2 [14]. The presence of oxygen in the sample was caused by interference during the charging, transportation, and analysis of the samples. The presence of H_2S as a trace gas can have a negative impact on the processing or use of biogas. As a result, desulphurization is frequently used to remove sulfur compounds
found in biogas

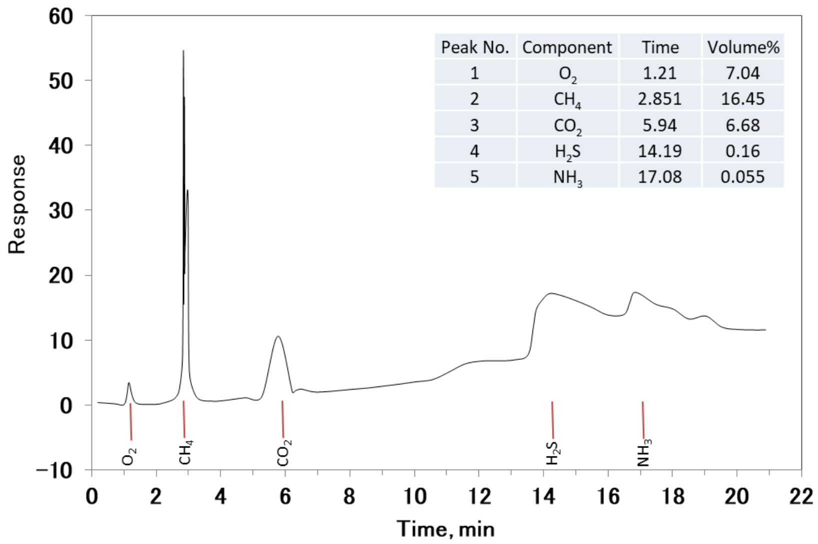


Figure 2. GC analysis of the produced biogas

One interesting route for hydrogen generation is the anaerobic digestion of biomass in the presence of certain bacterial strain. Hydrogen can be generated together with the biogas due to the presence of the facultative or obligate anaerobic bacteria, like *Escherichia coli, Enterobacter aerogenes, Citrobacter intermedius, Enterobacter cloacae, Ruminococcus albus, Clostridium beijerinckii,* and *Clostridium paraputrificum* [15]. In such processes, the biomasses like proteins and carbohydrates are hydrolysed following two pathways [16]: (1) production of acetate in the presence of acetyl coenzyme A with or without the consumption of nicotinamide adenine dinucleotide; NADH. (2) Conversion of glucose to byruvate augmented with conversion of NADH to NAD^+ via anaerobic glycolysis. This process is attractive for hydrogen generation despite its relatively low hydrogen yield. This is because of its high production rates, simple design and operation, and its double goal of wastewater treatment and hydrogen production. Figure 3 shows the rate of hydrogen production from the lab scale digester. It is evident that hydrogen production commences around day 10 and propagates until reach a maxima then decrease. This hydrogen production rate is relatively lower than that obtained by Jayalakshmi S et al, Gómez Xet al, and Nathao C et al [17-19]. This is typically due to the nature of the substrate that has been used in the fermentation process. For example, Jayalakshmi S et al have used kitchen wastes as substrate and mixed culture microorganism for their experiments. The hydrogen yield was 72 ml H_2/g VS compared to 45.8 ml H_2/g VS in this study.

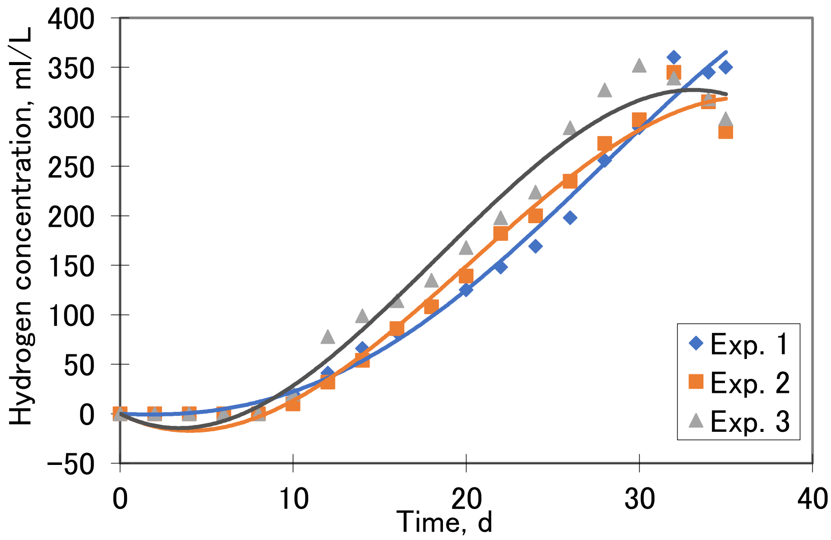


Figure 3. The rate of hydrogen production from the lab scale unit

Biogas production

The methane production profiles of the lab-scale and pilot scale fermenters are shown in Fig. 4. It is evident that around 20 days is necessary to start up the biogas production for both lab scale and pilot units. The three runs for each unit showed a propagation period then, the biogas production become stable after 10 days at 35 and 140 L/kg VSS for lab and pilot units, respectively. It is important to note that feeding the units is done at the beginning, then after day 20, the feeding starts continuously and in the same time digestate is removed with the same feed flow rate. It is noticeable that the pilot unit produces more biogas per VSS than the lab scale unit. This is attributed to the temperature control and the efficient mixing that is utilized in the pilot unit. However, the results are lower than that obtained by Gahyun Baek et al [20] who showed a biogas production of 280 L/kg VS from mixture of cow manure and agricultural wastes.

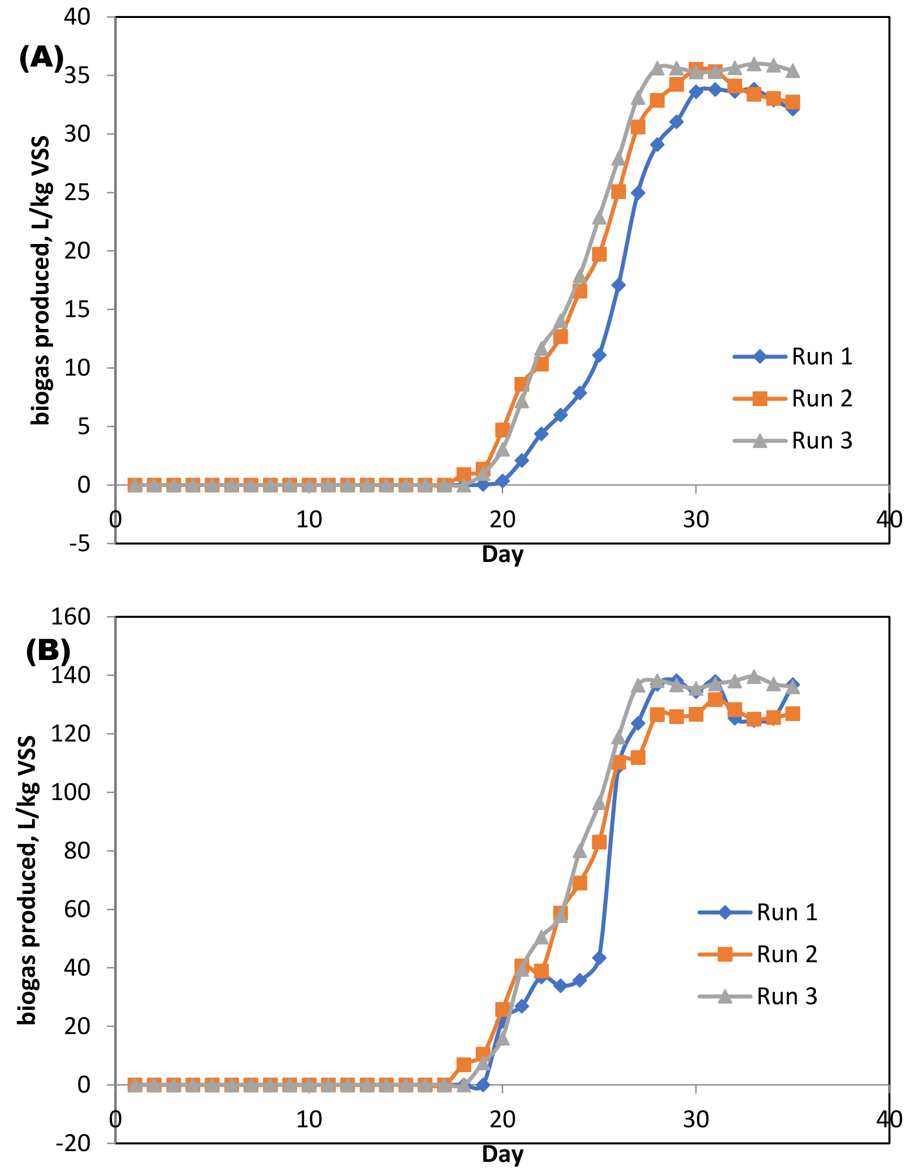


Figure 3. Profile of (A) commutative gas production rate vs. time for lab scale (25L) unit (B) cumulative gas production rate vs. time for pilot unit (1000L)

Preliminary economic study

Economic study for 1000 (L) digester for daily production of 280 L biogas
Total cost = fixed cost + operating cost

Fixed cost

Price of unit = $ 641
Desulphurization = $ 32
Fixed = 641+ 32 = $ 673
Assume service life = 20 years
Annually cost = 673/20 = $ 33.65

Operating cost

Maintenance = $154 yearly
Electricity = $116 yearly
Operating cost = 154 + 116= $ 170 yearly

- **Depreciation cost = 33.65+ 269,25= $ 302,80 yearly**
- **Amount of bio gas and digestate which produced from unit 1(m^3):**

Volume of digester = 1000L
Effective volume= (2/3) * 1000 L = 666 L
Hydraulic retention time = 20 day
The amount of substrate = the total volume of digester /retention time

- Assume density = 1 kg / L
- The amount of substrate = 666 L / 20 day = 33.3 L /day
- So amount of substrate = 33.3 kg /day

The organic material contain 67% moisture content and 33% dry material (by putting raw material in drying furnace at 105ºC)

The amount of dry organic material = 0.33*33.3= 10.9 kg dry material
1kg of dry organic material = 280(L) biogas =0.28 m^3
Theoretical Amount of biogas = 0.28 *10.9 =3.05 (m^3/day)
1(m^3) biogas = 0.4 kg butane
3.05 (m^3) biogas =? Kg butane
Amount of butane in 3.05 m^3 biogas = 1.221 Kg
Cylinder of butane = 8 kg butane
? = 1.221 kg butane
x = 0.153 cylinder
Number of cylinders monthly = 0.153* 30 = 4.59 cylinder
Price of cylinder = $ 6.5
SO the net profit is 6.5*4.6 = $ 29.9 monthly
ABOUT DIGESTATE
1 (m^3) digester = 90 kg monthly
Price of 1 ton digestate = $ 65
90 kg digestate = $5.76
Monthly profit = 29.9+5.76 = $35.66
Yearly profit = 35.66*12 – cost of unit yearly =427.92 – 302.8= $ 125.12

Return on investment = fixed cost / annual profit= 673/125.12=5.37 years

CONCLUSIONS

A simple and easy method for producing biogas from animal and agricultural wastes is presented, as well as a 1000 L portable unit. There are few mechanical or electrical components in this design. Also, it is simple to build, and produces gas at a low cost. Based on these findings, it is possible to conclude:

- Laboratory experiments show that it is possible to produce biogas from animal and agricultural wastes after a 20-day retention period. These findings were used in the simple and straightforward design of a 1m3 biogas production unit.
- There are about 20 days without producing biogas at the beginning, which is called the retention period. A fixed brush helps decrease retention time.
- Mixing is necessary for the production of biogas and the avoidance of layer formation.
- The digester's empty space should be sufficient for biogas production.
- Although the direct economic benefit from the production of biogas and its filling as gas cylinders, its more significant economic impact appears if the value of burying the waste used in its production is taken into account to the environmental impact of disposal of these wastes.

RECOMMENDATIONS

• Feed solid oxide fuel cells with unit production.
• Carry out experiments with Catalysts.

• To shorten the biogas production period, change the carbon brush, use different materials, and support them with nano particles.
• Conduct a comprehensive economic study demonstrating the benefits of the biogas production process for companies and municipalities to use.

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