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Enhancement of Biogas Production: Short-Term Evaluation of Biogas Unit in Egypt

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Abstract

In this study, a medium scale biogas digester has been operated to treat the cattle manure of 50 animals producing about 1000 kg of manure per day. The volume of digester is 200 m^3 and was designed to produce biogas for a 50 kWh/day electric generator and 28 day the hydraulic retention time (HRT) with daily feeding rate 6 m^3 of substrate. From the evaluation results, the daily feeding rate is 5 m^3 and HRT of 40 day. The biogas yield reached 11.51 m^3/day and the CH_4 and CO_2 concentration ranged from 37 % to 61 % and from 13.3 % to 37.8 %, respectively. On the other hand, a reduction in the organic contents of substrates is explored because of the anaerobic digestion process. These contents are volatile fatty acids (VFAS), carbon to nitrogen ratio (C/N), volatile solids (VS), and chemical oxygen demand (COD), where the maximum reduction percentages of VFAS, C/N ratio, VS, and COD are 78.2 %, 76.7 %, 76.5 %, and 87.0 %, respectively. Furthermore, the concentration of total nitrogen (TN), total phosphorus (TP), total potassium (TK), NO_3-N, and NH_4+N achieved an increase in the digestate compared with their corresponding values in substrates, especially TP and TK. From the evaluation results, we can put and illustrate some important issues that may increase the biogas digester efficiency; (1) the biogas purification unit should be fixed and operated to reduce the CO_2, H_2S and O_2 contents, (2) The substrate pH, and total solid should be more controllable, (3) The digestates should be treated before use for further benefits and more stable with environment, and (4) a periodically maintenance plan should be followed for improving biogas production and increase the life time of the digester components.

Keywords: Biogas, Anerobic digestion, Biogas composition, Cattle manure, Digestates

1. Introduction

By 2040, more than 500 million people will be added to Africa's cities, marking the largest urbanization in history. However, there are not nonrenewable energy sources to their needs, in addition to the global warming that increases with their increasing (Chen et al. , 2023). Therefore, the energy crisis is one of the most challenges that need to be explored in Africa (Ali et al. , 2020). Due to the abundance of biomass resources in Africa, production of biogas from biomass resources can be a predominant solution for the energy crisis and climate change (Ali, Ndongo, 2020, Chen, Xu, 2023). In African countries, 6671 domestic biogas units were installed in East Africa region followed by 5819 units in West Africa and 3259 units in North Africa. However, the lowest numbers of units were 1008 and 861 in South Africa and Middle Africa, respectively (Ghimire, 2013). In Egypt, the unit of El-Gabal El-Asfar is the largest unit which produces 0.5 MWh/day electricity. Another two medium size units are in Giza governorate, managed by the Agricultural Research Center, and in Moshtohor village, Qalubeya governorate and generate 200 kWh/day and 50 kWh/day, respectively. Furthermore, there are about 1300 small size working Chinese-type biogas units (2, 3, 4, and 6 m^3) (Samer et al. , 2020).

Anaerobic fermentation is a technology, which converts biowastes into two main products: biogas (a mixture of methane (50-75%), carbon dioxide (30-40%), and traces of other constituents (hydrogen, hydrogen sulfide, etc.) and digestates (Jin et al. , 2022a) and it is an attractive approach for agricultural waste resources utilization (Wang et al. , 2020). It is a complex biological process in which organic raw materials are converted into biogas, by means of a consortium of microorganisms that are sensitive to or completely inhibited by oxygen (Sánchez-Hernández et al. , 2013) and it is going through four main stages; hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Anaya Menacho et al. , 2022)

Many studies explored the anaerobic digestion process for many different types of biowastes which affect biogas production according to their type, nature, and concentration. These biowastes are chicken manure (Jurgutis et al. , 2020, mahmoud et al. , 2022), sewage sludge (Abdel daiem et al. , 2021, Jeong et al. , 2021), cow manure (Jafari-Sejahrood et al. , 2019, McVoitte and Clark, 2019), swine manure (de Castro e Silva et al. , 2022, Hollas et al. , 2021), macroalgal biomass (Farghali et al. , 2021), cattle manure (Dong et al. , 2019), submerged aquatic plant (*Hydrilla verticillata*) (Chen et al. , 2016), corn stover (Arias et al. , 2021), food waste (Anaya Menacho, Mazid, 2022, Muratcobanoglu et al. , 2020), vegetable peel (Lahbab et al. , 2021), pig manure (Li et al. , 2020), sheep manure (Li and Zhang, 2022), wild tree wastes (Mahmoodi-Eshkaftaki and Mahmoudi, 2021), rice straw (Mussoline et al. , 2012), Buffalo grass (Sawanon et al. , 2022), cotton straw (Wang et al. , 2021), poultry manure (Yılmaz and Şahan, 2020).

Other factors influence the biogas yield which are process factors such as digestion temperature, pH of substrate, organic loading rate, hydraulic retention time (HRT), volatile solids (VS), and carbon/nitrogen (C/N) ratio. Dong et al. (2015) studied 4 volatile fatty acids (VFAS) (acetic, propionic, isobutyric, and butyric acid) on the biogas production and reached that VFAS increased with hydraulic retention time acidification in the first five days and a small amount convert to H_2, H_2S, CH_4, and escape from the reactor, while the most VFAS remain in the slurry. They also found that it is beneficial for particulate organic matter hydrolysis, the pH value to be between 5 and 7. On the other hand, Higher organic loading rate (OLR) and total solid (TS) combined with lower hydraulic retention time (HRT) decreased removal of organic constituents (Arias, Veluchamy, 2021).

Few studies have been performed to evaluate the biogas units, Dong, Cao (2019) carried out a long-term evaluation of large-scale plug flow reactor located in China. Techno-economic assessment was performed to illustrate the Household biogas units feasibility and technical efficiency in Egypt (Samer, Abdelaziz, 2020).

For our best knowledge, there is no studies related to evaluation the biogas performance and operation units in Egypt. Therefore, this study aims to evaluate the performance and operations of a medium scale biogas unit which were established to generate 50 kWh/day of electric power. To perform a short-term evolution, many factors are analyzed and determined such daily biogas production and composition, nutrients content in substrate and digestates, and some organic constituents (pH, electrical conductivity (EC), VFAS, VS, organic carbon (OC)). Finally, the conclusion can be drawn for operating the units from the achieving results.

2. Materials and Methods

2.1. Cattle manure and substrate characteristics

The physiochemical characteristics of the substrates and inoculum are listed in **Table 1**. Cattle manure was collected from the farm located in Moshtohor, Toukh, Qalubia, Egypt from 15th may, 2022 to 15th July 2022. Samples from cattle manure and substrate were taken in the beginning to characterize them as described in **Table 1**. Nine samples were collected from the biogas and biogas digestates during 57-day with 7-day interval for further analysis.

Table 1. Physio-chemical characteristics of cattle manure and substrate.

Item	Unit	Cattle manure	Entry substrate
Total Solid (TS)	%	14	5.2
pH		7.52	7.42
Electrical conductivity (EC)	ds/m	7.33	6.71
Total Nitrogen (TN)	%	1.11	1.45
NH_4+N	mg/l	331	526
NO_3-N	mg/l	25	42
Volatile solids (VS)	%	75.11	75.26
Organic carbon (OC)	%	43.56	43.65
Ash	%	24.89	24.74
Carbon: Nitrogen ratio (C/N)	-	39:1	30:1
Total phosphorus (P_2O_5) (TP)	%	0.56	0.61
Total Potassium (K_2O) (TK)	%	0.8	2.41
Volatile fatty acids (VFAS)	mg/l	1063	3771
Chemical oxygen demand (COD)	mg/l	40000	18880

2.2. Biogas unit description and operation

The biogas station was built by Egyptian Ministry of Agriculture and Land Reclamation, Research Agricultural Center (ARC), Production sector, Plant and Animal Production Improvement Unit, it located in Moshtohor, Qalubia governorate, Egypt. It was built in 2013 to treat 200 m^3 of cattle manure generating 50 kWh/day of electricity. This stationt consists of 7 units, the first unit is the mixing tank, it is connected with the animal houses by manure gutter. The manure collected and moved to the mixing tank through the gutter. In this mixing tank, the solid content of the manure is adjusted to be less than 6% by mixing with water. The pH of substrate is also adjusted to be 6.8-7.0 by adding $CaCo_3$. The substrate is mixed through mechanical agitator to be homogeneous and pumped to the second unit through the submerged wastewater pump. The second unit is the inlet tank, it is structured from reinforced concrete. The substrate is received from the mixing tank and pumped to the next unit which is the main digester. The third unit is the main digester, it is constructed from reinforced concrete for anaerobic digestion of cattle manure with volume 200 m^3. The digester has vertical cylindrical shape with inner diameter 8 m and height about 4 m above the ground, in the top of the digester, there is a gasholder to collect the produced biogas. The gasholder is fixed by a cylindrical neck with an inner diameter 1.66 m, outer diameter 1.96 m, and height 1.30 m. The fourth unit is the outlet tank, it is constructed from reinforced concrete with cylindrical shape to accept and store the anaerobic digestates from the digester. The anerobic digestion is operated continuously at HRT 28 d and without any control in fermentation temperature.

Due to the anaerobic digestion of cattle manure inside the digester, the biogas is produced and collected in the gas holder which passed to the gas purification unit. The fifth unit is the biogas purification unit, it consists of two filters, the first stage of purification unit is removing H_2S which is desulfurization. The second stage is removing the water vapor (H_2O). After that there is a need to storage the biogas until used, therefore, the sixth unit is established. It consists of plastic semi-sphere plastic bags. The seventh unit is electric generators, two generators with total power 50 kWh/day are used to generate electricity from biogas. These generators are connected to gas compressors to press the biogas. The full description of the biogas unit is illustrated in **Fig. 1**.

2.3. Actual biogas operation of the biogas unit

After the station was constructed and installed in 2013, it worked perfectly at standard operation. By the time, some units were stopped because of low maintenance and the availability of manure. Therefore, the actual operations now are different compared with the initial operations. Some units are not working such as gas purification unit, gas storage bags, compressor, and generators. The main working units are mixing tank, input tank, digester, and outlet tank. On the other hand, the number of animals is 50 therefore, the feeding rate is 5 m^3/day, which means the actual retention time is 40 days.

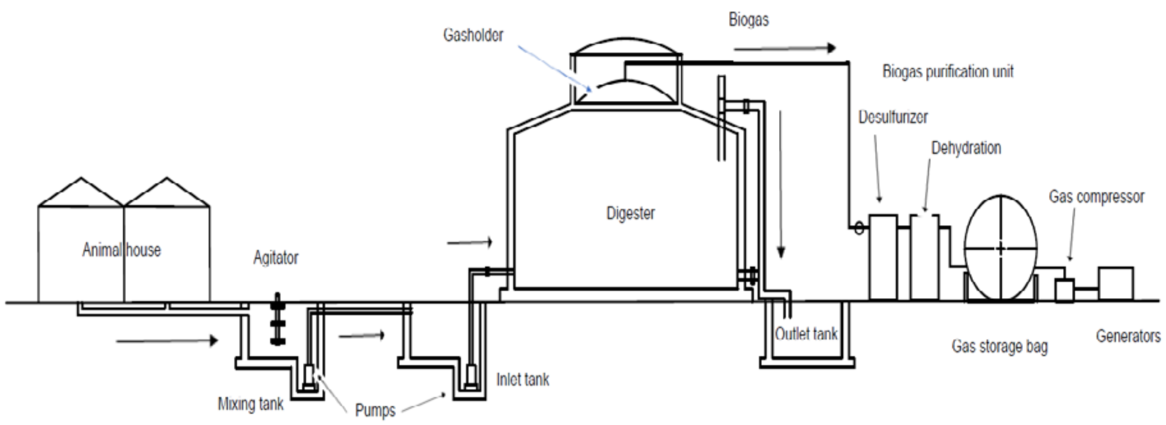

Fig. 1. Components of anaerobic digestion unit for treatment of cattle manure.

2.4. Physiochemical analysis

Volatile solids, VS, and VFAS of raw cattle manure, substrate, and biogas digestates were determined according to Standard Methods (Rice et al. , 2017). The pH and EC of influent feedstock mixtures and digestate was measured using a pH/EC meter **(Seven Excellence, Mettler Toledo, USA)** according to Standard Methods (Rice, Baird, 2017). Organic matter (OM) was determined by glowing dried samples at 550 ºC to a constant weight, as suggested by **(**Nelson, 1982**)**. Organic carbon content was calculated by multiplying the organic matter dry weight by 58% (Jackson, 1973). Ash content was calculated by % Ash = 100 – Organic matter.

The total nitrogen (TN) in dried samples was determined using Kjeldahl digestion method (Jackson, 1973). For ammoniacal and nitrate nitrogen, soluble nitrogen ($NH4^+$ and $NO3^-$) were measured according to Nelson (1982). Total phosphorus was estimated by Spectrophotometer (model 670 SUV/VIS, Jen way Company) in the acid solution of the digested samples utilizing ascorbic acid and mixed reagent as depicted by Jackson (1973). Total potassium was measured by flam photometer (model ILAE 20, Fisher Scientific Company) (Jackson, 1973). Chemical oxygen demand (COD) was measured by titration method according to Open Reflux Method (5220 B). Colloidal total organic carbon (TOC) was measured by subtracting the COD of liquid passed through a 1.2 µm membrane filter with the COD of the liquid passed through a 0.45 µm membrane filter.

2.5. Biogas yield and composition

The biogas yield was measured by digital meter, the reading saved every day at the same time and by subtracting the daily biogas yield was calculated. Biogas composition (CH_4, CO_2, and O_2) was measured by portable biogas analyzer (BIOGAS 500, Geotech, UK).

The CH_4 content of the dry biogas or corrected methane (CM) can be calculated using the following Eq. (Mahmoodi-Eshkaftaki and Mahmoudi, 2021):

$$CM = \frac{CH_4}{CH_4+CO_2+O_2} \times 100 \quad (1)$$

Where CM is the corrected methane (%), and CH_4, CO_2 and O_2 are the measured methane (%), carbon dioxide (%), and oxygen (%) in the biogas, respectively.

3. Results and Discussion

3.1. Properties of cattle manure and substrate

Table 1 illustrates the characteristics of cattle manure and entry substrates. The cattle manure used for biogas production was collected from cattle barns, it contains feces, urine, spilled feed, and litters. It scraped to the mixing tank to be homogeneous. The total solid was adjusted from 14% to 4-10% (in this work, it was 5.2%), and the pH was also adjusted to be about 7.0, here it was 7.42. Where, the pH of the manure was slightly alkaline with the values of 7.52. The cattle manure and substrate TN, NH_4+N, and NO_3-N values were 1.11 %, 1. 45 %, 331 mg/l, 526 mg/l, 25 mg/l and 42 mg/l, respectively. On the other hand, the values of TP, TK of cattle manure and substrate were 0.56 %, 0.61 %, 0.80 % and 2.41 %, respectively. Furthermore, the values of COD, VFAS, VS, and OC of manure and substrate were 4.0 × 10^4 mg/l, 1.89 × 10^4 mg/l, 1063 mg/l and 3771 mg/l, 75.11 %, 75.26%, 43.56 % and 43.65 %, respectively. The C/N values of manure and substrate were 39 and 30, respectively.

3.2. Biogas composition and corrected methane

Table 2 shows the gas composition, biogas yield, and the values of dried biogas for collected samples during the evaluation period. The biogas production fluctuated and ranged from 3.86 m^3/day to 11.51 m^3/day during the evaluation period. Biogas production depends on many factors such as pH, C/N ratio, VS, temperature and so on. In this study most of these factors are not controllable, only pH and total solid which are adjusted before entering the digester. Therefore, the fluctuation of biogas yield is too high.

The CH_4 concentration in the biogas ranged from 37.0 % to 61.0 %, it is influenced by fermentation temperature, where the anaerobic digestion process that occurs at higher temperatures exhibits the CH_4 bacterial community leading to higher methane content (Gaballah et al. , 2020, McVoitte and Clark, 2019, Sakar et al. , 2009). The higher methane content is achieved at the higher biogas yield and the lowest methane content is also achieved at lower biogas yield (4.71 m^3/day). For CO_2 concentration, it ranges from 13.3 % to 37.8 % and the higher percentage of CO_2 is observed at 54.5 % dry biogas contentment (corrected methane) and lowest O_2 concentration (1.5 %). The lowest CO_2 concentration is observed at highest dry biogas content (73.7 %) and 8.5 % O_2. The highest concentration of CO_2 reduces the biogas calorific value; therefore, it should be removed from the biogas using different techniques such as electrolysis (Anaya Menacho, Mazid, 2022). Furthermore, the high concentration of O_2 leads to lower biogas production, where the anaerobic digestion occurs in the absence of O_2, where the action of strict anaerobic methanogenic inhibits due to the higher concentration of oxygen which means the inhibition of bacteria (Anaya Menacho, Mazid, 2022). Techno-economical study of the household biogas digester technology and its environmental sustainability under Egyptian conditions have been carried out (Ioannou-Ttofa et al. , 2021).

Table 2. Biogas composition and corrected biogas content.

Time (day)	Biogas yield (m^3/day)	CH_4 (%)	CO_2 (%)	O_2 (%)	CM (%)
1	11.51	61.0	13.3	8.5	73.7
8	4.54	48.5	14.7	9.3	66.9
15	9.63	50.0	33.6	4.0	57.1
22	9.70	56.1	35.0	3.2	59.5
29	7.24	46.1	32.6	4.4	55.5
36	4.71	37.0	28.8	6.2	51.4
43	3.86	49.1	32.9	3.9	57.2
50	4.98	46.7	34.3	3.6	55.2
57	4.23	47.1	37.8	1.5	54.5

3.3. Biogas yield and reduction of organic contents

Fig. 3 shows the organic elements contents reduction because of an aerobic digestion process. The reduction percentage of VFAS reached 78.2 %, where the VFAS of entry substrates is 3771 mg/l and the lowest VFAS value of digestate is 823 mg/l and the highest VFAS value is 1371 mg/l with reduction percentage 63.6 % as seen in **Fig. 2a**. In terms of C/N ratio (**Fig. 2b**), the C/N ratio of substrate is 30:1. By the time of anaerobic digestion, The value of C/N ratio is reduced to 7:1 with higher reduction percentage (76.7 %) and the lowest C/N ratio value of digestate is 22:1 with reduction percentage of 26.7 %. This is due to the activity of methanogenic bacteria which use carbon to gross (Jafari-Sejahrood, Najafi, 2019, Noorollahi et al. , 2015). It should be mentioned that the optimal value of C/N ratio for an aerobic digestion process is 10:1- 30:1 (Jafari-Sejahrood, Najafi, 2019). In terms of volatile solids (**Fig. 2c**), the substrate VS is 75.26 % and it is reduced to the lowest value (17.7 %) with reduction percentage of 76.5 % at the higher values of biogas production (11.51 m^3/day). The highest VS value of digestate is 55.96 % with 25.6 % reduction at the lowest biogas production (3.86 m^3/day). These results illustrate the relations between VS and biogas production, where the high VS values lead to high biogas production (Jafari-Sejahrood, Najafi, 2019). The reduction of COD means the activity of methanogenesis bacteria, the COD value of substrate is 18880 mg/l and reached to 2447 mg/l with the higher reduction value (87.0 %) and the lowest reduction value is 50.8 % as seen in **Fig. 2d**.

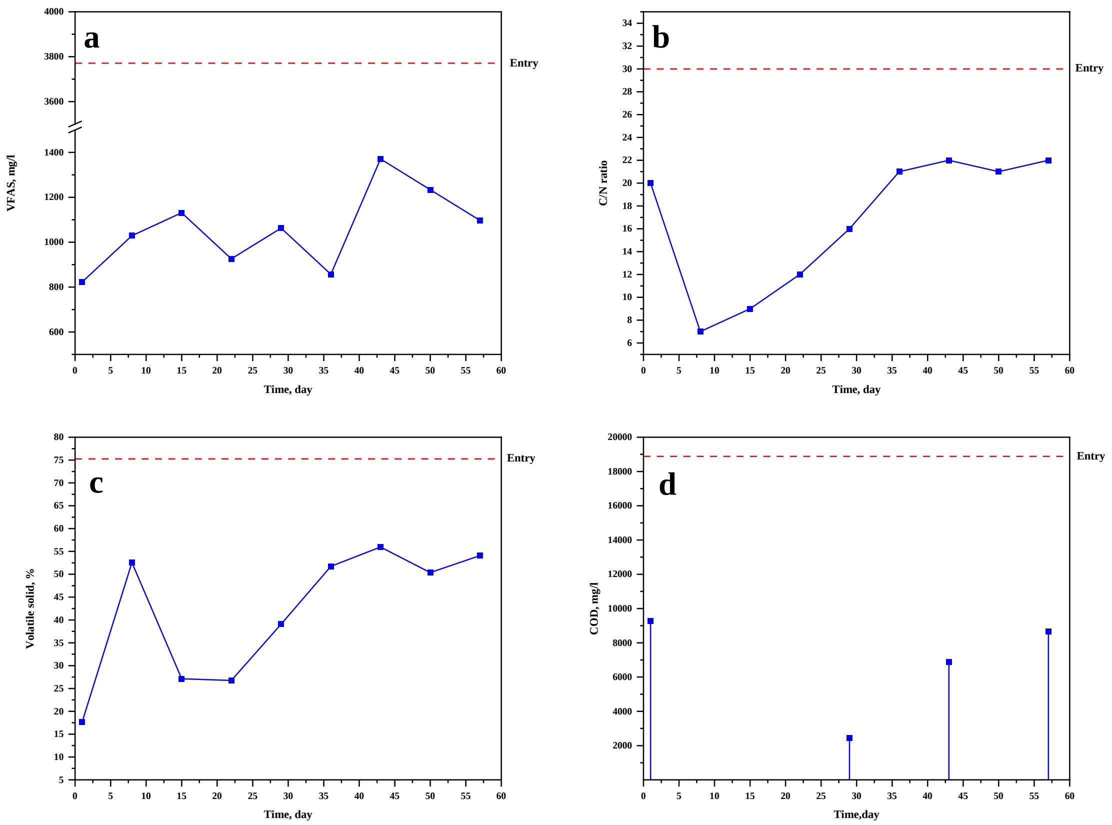

Fig. 2. Organic contents reduction during the biogas unit evaluation period; **(a)** VFAS, **(b)** C/N, **(c)** VS, and **(d)** COD.

3.4. Analysis of nutrients content in the digestates

The nutrient content of biogas digestates during the biogas unit evaluation period is illustrated in **Fig. 3**. In the anaerobic digestion process, there are two main products CH_4 and digestates, the latter can be used as bio fertilizers and can be applied directly in the soil or pretreated before using. It contains many nutrients such as nitrogen, phosphorus, potassium, and other micronutrients. Starting with TN, as seen in **Fig. 3a**, the concentration of TN is approximately the same with fewer changes after anaerobic digestion, where the TN value of substrate is 1.45 % and the TN value of digestates ranged from 1.25 % to 1.70 %. The increase in concentrations is achieved in TP of digestates (**Fig. 3b**), where the value of substrates TP is 0.61 % and it reached to 1.88 % in digestate and the lower TP value in digestates is 1.25 % which is much higher than the TP of substrates. In terms of the nutrients increasing, in addition to the TP, the TK concentration is also increased in the digestate. The TK value of substrate is 2.41 % and reached to the maximum value in digestate (17.68 %) as the minimum value is 2.50 % as seen in **Fig. 3c**.

In terms of nitrate and ammonia nitrogen (**Fig. 3d and e**), their lines are like the line of TN, where the concentration of NO_3-N and NH_4+N in substrate are 42 mg/l and 526 mg/l, respectively. For their concentration in digestate, it achieves a small fluctuation where it ranges between 15 mg/l to 85 mg/l and 322 mg/l to 1145 mg/l, respectively. These results indicated that the anaerobic digestates can be useful for plant nutrition, it can be used as biofertilizers or pretreated by different methods such ammonia stripping, solid liquid separation and so on (Jin et al. , 2022b, Wang et al. , 2022).

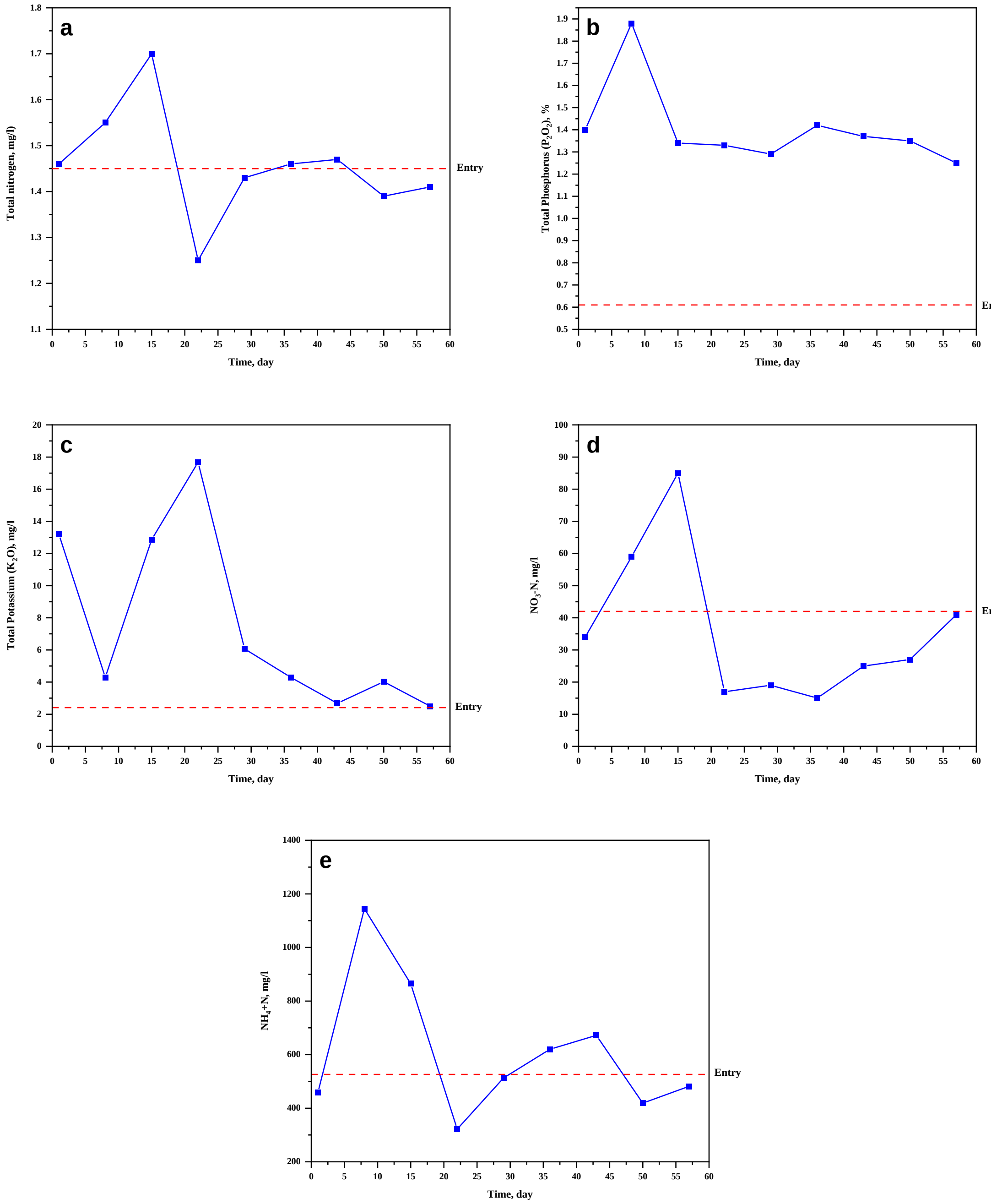

Fig. 3. Nutrients content of biogas digestates during the biogas unit evaluation period; **(a)** TN, **(b)** TP, **(c)** TK, **(d)** NO_3-N, and **(e)** NH_4+N.

4. Conclusions

This study aims to evaluate the biogas production from a biogas station to know its efficiency and know the problems in its operations. To evaluate the performance of biogas units, samples from substrate and digestate are taken for analysis and the biogas yield and composition are also analyzed during about 2 months. The results indicated that there are fluctuations in the biogas yield during the evaluation period which ranged from 3.86 m^3/ day to 11.51 m^3/day. The composition of biogas is also different by the time, where the CH_4 content is between 37 % to 61 % and the concentration of CO_2 is from 13.3 % to 37.8 %. These results indicate that there is a need for controlling the temperature of the unit and biogas refinery units should be working. The degradation of organic contents in substrates are determined, which considered as indicators for the anaerobic process, such as VFAS, C/N ratio, VS, and COD where all these components yielded a reduction. The maximum reduction percentages of VFAS, C/N ratio, VS, and COD are 78.2 %, 76.7 %, 76.5 %, and 87.0 %, respectively. Furthermore, many nutrients are analyzed in the digestate and compared with substrate, these nutrients are TN, TP, TK, NO_3-N, and NH_4+N. Most of these nutrients achieved an increase in the digestate compared with their corresponding values in substrates, especially the TP and TK. From these evaluation results we suggest the following points to maximize the operation of the biogas unit and increase its efficiency:

1. A source of heating should be installed to the unit to maintain the temperature at the desirable value (35 °C) for anaerobic digestion process.
2. Gas purification units should be fixed and operated to reduce the CO_2, H_2S and O_2 contents.
3. The substrate pH, and total solid should be more controllable.
4. The produced biogas should be used efficiently by the generator.
5. The Anaerobic digestate should be treated by different methods such as solid liquid separation and ammonia stripping to produce biofertilizers and add more values.
6. Periodically maintenance of all components in the unit should be done to ensure the high performance of the unit.
7. We recommend some practices such as technical training for labor and engineering, governmental biogas policy, public or government funding, and advertising for biogas and its benefits which can help for spreading and installing the biogas units around the country.

References

Abdel daiem MM, Hatata A, Galal OH, Said N, Ahmed D. Prediction of biogas production from anaerobic co-digestion of waste activated sludge and wheat straw using two-dimensional mathematical models and an artificial neural network. Renewable Energy. 2021;178:226-40.

Ali MM, Ndongo M, Bilal B, Yetilmezsoy K, Youm I, Bahramian M. Mapping of biogas production potential from livestock manures and slaughterhouse waste: A case study for African countries. Journal of Cleaner Production. 2020;256.

Anaya Menacho W, Mazid AM, Das N. Modelling and analysis for biogas production process simulation of food waste using Aspen Plus. Fuel. 2022;309.

Arias DE, Veluchamy C, Habash MB, Gilroyed BH. Biogas production, waste stabilization efficiency, and hygienization potential of a mesophilic anaerobic plug flow reactor processing swine manure and corn stover. J Environ Manage. 2021;284:112027.

Chen H, Xu Q, Cheng S, Wu T, Boitin T, Lohani SP, et al. Comprehensive Analysis and Greenhouse Gas Reduction Assessment of the First Large-Scale Biogas Generation Plant in West Africa. Atmosphere. 2023;14.

Chen X, Chen Z, Wang X, Huo C, Hu Z, Xiao B, et al. Application of ADM1 for modeling of biogas production from anaerobic digestion of Hydrilla verticillata. Bioresour Technol. 2016;211:101-7.

de Castro e Silva HL, Huamán Córdova ME, Barros RM, Tiago Filho GL, Silva Lora EE, Moreira Santos AH, et al. Lab-scale and economic analysis of biogas production from swine manure. Renewable Energy. 2022;186:350-65.

Dong L, Cao G, Guo X, Liu T, Wu J, Ren N. Efficient biogas production from cattle manure in a plug flow reactor: A large scale long term study. Bioresour Technol. 2019;278:450-5.

Dong X, Shao L, Wang Y, Kou W, Cao Y, Zhang D. Biogas by two-stage microbial anaerobic and semi-continuous digestion of Chinese cabbage waste. Chinese Journal of Chemical Engineering. 2015;23:847-52.

Farghali M, Ap Y, Mohamed IMA, Iwasaki M, Tangtaweewipat S, Ihara I, et al. Thermophilic anaerobic digestion of Sargassum fulvellum macroalgae: Biomass valorization and biogas optimization under different pre-treatment conditions. Journal of Environmental Chemical Engineering. 2021;9.

Gaballah ES, Abdelkader TK, Luo S, Yuan Q, El-Fatah Abomohra A. Enhancement of biogas production by integrated solar heating system: A pilot study using tubular digester. Energy. 2020;193.

Ghimire PC. SNV supported domestic biogas programmes in Asia and Africa. Renewable Energy. 2013;49:90-4.

Hollas CE, Bolsan AC, Chini A, Venturin B, Bonassa G, Cândido D, et al. Effects of swine manure storage time on solid-liquid separation and biogas production: A life-cycle assessment approach. Renewable and Sustainable Energy Reviews. 2021;150.

Ioannou-Ttofa L, Foteinis S, Seifelnasr Moustafa A, Abdelsalam E, Samer M, Fatta-Kassinos D. Life cycle assessment of household biogas production in Egypt: Influence of digester volume, biogas leakages, and digestate valorization as biofertilizer. Journal of Cleaner Production. 2021;286.

Jackson M. Soil chemical analysis, pentice hall of India Pvt. Ltd, New Delhi, India. 1973;498:151-4.

Jafari-Sejahrood A, Najafi B, Faizollahzadeh Ardabili S, Shamshirband S, Mosavi A, Chau K-w. Limiting factors for biogas production from cow manure: energo-environmental approach. Engineering Applications of

Computational Fluid Mechanics. 2019;13:954-66.
Jeong K, Abbas A, Shin J, Son M, Kim YM, Cho KH. Prediction of biogas production in anaerobic co-digestion of organic wastes using deep learning models. Water Res. 2021;205:117697.
Jin K, Pezzuolo A, Gouda SG, Jia S, Eraky M, Ran Y, et al. Valorization of bio-fertilizer from anaerobic digestate through ammonia stripping process: A practical and sustainable approach towards circular economy. Environmental Technology & Innovation. 2022a;27.
Jin K, Pezzuolo A, Gouda SG, Jia S, Eraky M, Ran Y, et al. Valorization of bio-fertilizer from anaerobic digestate through ammonia stripping process: A practical and sustainable approach towards circular economy. Environmental Technology & Innovation. 2022b;27:102414.
Jurgutis L, Slepetiene A, Volungevicius J, Amaleviciute-Volunge K. Biogas production from chicken manure at different organic loading rates in a mesophilic full scale anaerobic digestion plant. Biomass and Bioenergy. 2020;141.
Lahbab A, Djaafri M, Kalloum S, Benatiallah A, Atelge MR, Atabani AE. Co-digestion of vegetable peel with cow dung without external inoculum for biogas production: Experimental and a new modelling test in a batch mode. Fuel. 2021;306.
Li H, Chen Z, Fu D, Wang Y, Zheng Y, Li Q. Improved ADM1 for modelling C, N, P fates in anaerobic digestion process of pig manure and optimization approaches to biogas production. Renewable Energy. 2020;146:2330-6.
Li Y, Zhang Z. Recognize the benefit of continuous anaerobic co-digestion of cow manure and sheep manure from the perspective of metabolic pathways as revealed by metatranscriptomics. Bioresource Technology Reports. 2022;17.
Mahmoodi-Eshkaftaki M, Mahmoudi M. An optimum process for anaerobic digestion of wild tree wastes under alkaline pretreatments in biogas plants. Environmental Technology & Innovation. 2021;24.
mahmoud I, Hassan M, Mostafa Aboelenin S, Mohamed Soliman M, Fouad Attia H, Metwally KA, et al. Biogas manufacture from co-digestion of untreated primary sludge with raw chicken manure under anaerobic mesophilic environmental conditions. Saudi Journal of Biological Sciences. 2022;29:2969-77.
McVoitte WPA, Clark OG. The effects of temperature and duration of thermal pretreatment on the solid-state anaerobic digestion of dairy cow manure. Heliyon. 2019;5:e02140.
Muratcobanoglu H, Gokcek OB, Mert RA, Zan R, Demirel S. Simultaneous synergistic effects of graphite addition and co-digestion of food waste and cow manure: Biogas production and microbial community. Bioresour Technol. 2020;309:123365.
Mussoline W, Esposito G, Lens P, Garuti G, Giordano A. Design considerations for a farm-scale biogas plant based on pilot-scale anaerobic digesters loaded with rice straw and piggery wastewater. Biomass and Bioenergy. 2012;46:469-78.
Nelson DW. Total carbon, organic carbon and organic matter. Methods of Soil Analyses. 1982;9:552-3.
Noorollahi Y, Kheirrouz M, Asl HF, Yousefi H, Hajinezhad A. Biogas production potential from livestock manure in Iran. Renewable and Sustainable Energy Reviews. 2015;50:748-54.
Rice E, Baird R, Eaton A. Standard Methods for the Examination of Water and Wastewater ed-23rd. Washington DC: American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF). 2017.
Sakar S, Yetilmezsoy K, Kocak E. Anaerobic digestion technology in poultry and livestock waste treatment — a literature review. Waste Management & Research. 2009;27:3-18.
Samer M, Abdelaziz S, Refai M, Abdelsalam E. Techno-economic assessment of dry fermentation in household biogas units through co-digestion of manure and agricultural crop residues in Egypt. Renewable Energy. 2020;149:226-34.
Sánchez-Hernández EP, Weiland P, Borja R. The effect of biogas sparging on cow manure characteristics and its subsequent anaerobic biodegradation. International Biodeterioration & Biodegradation. 2013;83:10-6.
Sawanon S, Leungprasert S, Sillapacharoenkul B, Khunanake R, Soiklom S, Sinbuathong N. Grass as a high potential by-product: Buffalo grass to biogas and the increase of system performance and stability. International Journal of Hydrogen Energy. 2022.
Wang J, Feng K, Lou Y, Lu B, Liu B, Xie G, et al. The synergistic effect of potassium ferrate and peroxymonosulfate application on biogas production and shaping microbial community during anaerobic co-digestion of a cow manure-cotton straw mixture. Bioresour Technol. 2021;333:125166.
Wang P, Zhang X, Gouda SG, Yuan Q. Humidification-dehumidification process used for the concentration and nutrient recovery of biogas slurry. Journal of Cleaner Production. 2020;247.
Wang Q, Huang Q, Wang J, Li H, Qin J, Li X, et al. Ecological circular agriculture: A case study

evaluating biogas slurry applied to rice in two soils. Chemosphere. 2022;301:134628.
Yılmaz Ş, Şahan T. Utilization of pumice for improving biogas production from poultry manure by anaerobic digestion: A modeling and process optimization study using response surface methodology. Biomass and Bioenergy. 2020;138.

تعزيز إنتاج الغاز الحيوي: تقييم قصير المدى لوحدة الغاز الحيوي في مصر

تم في هذه الدراسة تشغيل مخمر غاز حيوي متوسط الحجم لمعالجة روث الماشية لعدد 50 حيوان تنتج حوالي 1000 كجم من الروث يوميا. يبلغ حجم المخمر 200 م3 وقد تم تصميمه لإنتاج الغاز الحيوي لمولد كهربائي بقدرة 50 كيلووات ساعة/يوم ووقت الاحتفاظ الهيدروليكي (HRT) لمدة 28 يومًا مع معدل تغذية يومي يبلغ 6 م3 من الركيزة. من نتائج التقييم فإن معدل التغذية اليومي هو 5 م3 و العلاج التعويضي بالهرمونات لمدة 40 يوم. وبلغ إنتاج الغاز الحيوي 11.51 م3/يوم، وتراوح تركيز الميثان وثاني أكسيد الكربون من 37% إلى 61% ومن 13.3% إلى 37.8% على التوالي. من ناحية أخرى، تم استكشاف انخفاض في المحتويات العضوية للركائز بسبب عملية الهضم اللاهوائي. هذه المحتويات هي الأحماض الدهنية المتطايرة (VFAS)، ونسبة الكربون إلى النيتروجين (C/N)، والمواد الصلبة المتطايرة (VS)، والطلب على الأكسجين الكيميائي (COD)، حيث تكون نسب التخفيض القصوى هي VFAS، ونسبة C/N، وVS، و COD هي 78.2%، 76.7%، 76.5%، و 87.0%، على التوالي. علاوة على ذلك، حقق تركيز النيتروجين الكلي (TN)، والفوسفور الكلي (TP)، وإجمالي البوتاسيوم (TK)، وNO3-N، وNH4+N زيادة في الهضم مقارنة بقيمها المقابلة في الركائز، وخاصة TP وTK. ومن نتائج التقييم يمكننا وضع وتوضيح بعض الأمور المهمة التي قد تزيد من كفاءة هاضم الغاز الحيوي؛ (1) ينبغي إصلاح وحدة تنقية الغاز الحيوي وتشغيلها لتقليل محتويات ثاني أكسيد الكربون وكبريتيد الهيدروجين والأكسجين، (2) يجب أن يكون الرقم الهيدروجيني للركيزة والمواد الصلبة الكلية أكثر قابلية للتحكم، (3) يجب معالجة المواد المهضومة قبل استخدامها لمزيد من الفوائد وأكثر استقراراً مع البيئة، و(4) ينبغي اتباع خطة صيانة دورية لتحسين إنتاج الغاز الحيوي وزيادة العمر الافتراضي لمكونات الهاضم.