International Journal of Applied Energy Systems, Vol. 5, No. 1, Januray 2023

Anaerobic Co-Digestion of Cow Manure and Sugarcane Bagasse for producing methane Under Mesophilic Condition: Effect of Mixing Ratio

Mohamed M. Alsebiey [a] *, Mohamed H. Hatem [b], Yosri B. abdelhay [b], and Hassan H. Tarrabye [a].
a: Agricultural Engineering and Bio Systems Department, Faculty of Agriculture and Natural Resources, Aswan University, Aswan, Egypt. Email: mohamedmahmoud@agr.aswu.edu.eg
b: Agricultural Engineering Department, Faculty of Agriculture, Cairo University, Giza, Egypt.

Abstract — **Producing methane from wastes like sugarcane bagasse and cow manure has the dual advantages of reducing these wastes and trying to maximize energy recovery. By utilizing different mixture ratios, the research seeks to increase the methane output from the anaerobic co-digestion of cow dung (CM) with sugarcane bagasse (SB) in Aswan, Egypt. In a 700 mL glass reactor, biochemical methane potential (BMP) studies were carried out in mesophilic (35–37 °C) conditions. To find the optimum combination for the BMP tests, five mixes with CM to SB ratios of 100:0, 70:30, 50:50, 30:70, and 0:100 (based on volatile solids) were tested. In the second BMP experiments, a CM to Sb ratio of 30:70 (275 mL/g), which was greater than the individual digestion of the other used feedstock, produced the maximum methane output. The lowest methane output, however, was seen at a CM to SB ratio of 70:30. The ANOVA test was used for the results' statistical analysis.**

Keywords −**Methane Production, Anaerobic Co-Digestion, Cow Manure (CM), Sugarcane Bagasse (SB), Mesophilic Condition and Mixing Ratio**

I. INTRODUCTION

Energy availability is one of the most critical necessities that has a direct impact on living standards and is a prerequisite for long-term economic growth. In recent decades, many researches have been conducted throughout the world to create sustainable energy generation systems from renewable sources to replace fossil fuels. The fundamental goal of these research was to lessen reliance on fossil fuels while avoiding as many environmental issues as possible due to their usage. [1].

Anaerobic digestion is a promising method for producing renewable energy while reducing waste and creating a digestate rich in nutrients like nitrogen and phosphorus. Anaerobic digestion therefore benefits the environment by decreasing the size of waste materials, lowering the emissions of dangerous greenhouse gases, creating organic fertilizer, reducing the stink of waste materials, and producing renewable methane. [2].

Anaerobic digestion therefore seems to be a workable method for getting rid of large amounts of waste [3]. Anaerobic digestion generates methane gas, which may be utilized for cooking, heating, transportation fuel, or as green biogas to supplement the existing natural gas infrastructure [4]. The utilization of all anaerobic digestion biogas will reduce greenhouse gas emissions into the environment by replacing fossil fuels. [5].

Massive amounts of fossil fuel are used in the production of energy; using fossil fuel not only poses a challenge because of resource limitations, but it also increases global greenhouse gas emissions. As a result, many forms of renewable energy are becoming more and more well-liked. It has been suggested that food waste might be used as a feedstock for the production of bioenergy and biofuel. Technology for anaerobic digestion is helpful for enhancing food waste management and creating biofuels. [6].

Protein, fat, cellulose, and lignin are all found in cow manure, however due to the large amount of nonbiodegradable and degradation-resistant chemicals in cow manure, it cannot be completely converted into biofuels. [7]. On the other hand, agricultural residual trash is produced in enormous quantities worldwide. An estimated 35 million tonnes of agricultural waste are generated in Egypt annually [8]. Burning is the main method used to dispose of agricultural waste, and this can have serious negative effects on the environment. One of Egypt's most strategic agricultural commodities is sugar cane. It is grown mostly in upper Egypt and has the second-most significant position after wheat. [9]. From 1995- to 2014 the total area and average production of sugarcane were about 0.32 million feddan and 15.60 million tons [10].

The AD process turns complex organic matter into biogas through a succession of biological processes supported by various of microorganisms. Biogas, which is primarily a 40–70% CH_4 and 60–30% CO2 combustible gas combination, may be used for cooking, power production, heating, and car fuel after upgrading to biomethane and removing corrosive chemicals like H2S [11].

The overall aim of this article is to see if boosting biogas and methane output from co-digestion of CM and

SB in Egypt is possible by utilizing 700 mL bottles as reactors instead of 500 mL reactors and seeing if the methane production changes. The goal of this research is to see how different mixing ratios of substrates and inoculum affect the co-digestion process, with a focus on maximizing methane productivity.

II. MATERIALS AND METHODS

1.Substrates preparation

Fig. 1. Grinded sugarcane bagasse (2-3) mm

In Aswan, Egypt, fresh cow manure (CM) was collected from a nearby livestock farm. In BMP test, it was utilized fresh. Kom Ombo Sugar Factory, Aswan, Egypt, provided sugarcane bagasse substrates, which dried at 70°C, fig. 1. Increased microbial activity is required to boost methane generation, which may be accomplished by increasing substrate surface area. Smaller substrate particles give a lot of surface area. Grinding substrate is the only approach to get a tiny particle size that reduces digester volume while having no detrimental impact on biogas output. [12,18]. SB was dried and grinded and a household grinder reduced its size to (2-3) mm [13]. The samples were then maintained at 4 degrees Celsius for three days to determine their features and feed the anaerobic digesters.

2.Analytical methods

volatile solids (VS), total solids (TS) and PH were tested as part of the anaerobic digestion process (VS), (fig. 2). These variables were determined using conventional APHA procedures for utilized substrates before and after anaerobic digestion [14]. The method used to quantify daily biogas output is water displacement. The features of cow dung and sugarcane bagasse used in biochemical methane potential studies are shown in Table 1.

2.1 Volatile Solids (VS) and Total Solids (TS) Tests:

The total VS test was used to determine the quantity of organic matter in the sample. The tests were conducted following the Standard Method [APHA].

Apparatus

- Drying oven, 103°C to 105°C
- Muffle furnace, controlled at 550°C

Procedure:

This test was carried out in replicates, and the mean was taken into consideration. In each test, the following procedure was implemented:

a. For a minimum of four hours, an evaporating dish was made by putting it in a 105 ± 3 °C drying oven. To be ready for use, the dish was chilled, dehydrated, weighed (W_1), and stored in a desiccator. The sample was placed in the prepared plate and dried for 24 hours at 105°C in the oven.

b. The dish was placed on a desiccator to cool after being removed from the drying oven. It was then reweighed three times to the nearest 0.0000 g, and the weight was recorded as W_2. In the muffle furnace, the sample within the dish was ignited for 4 hours at 500 °C.

c. The top lid of the desiccator was opened for roughly 2 minutes to let off the hot gas before the dish was completely cooled. The sample was weighed in a cold dish (W_3).

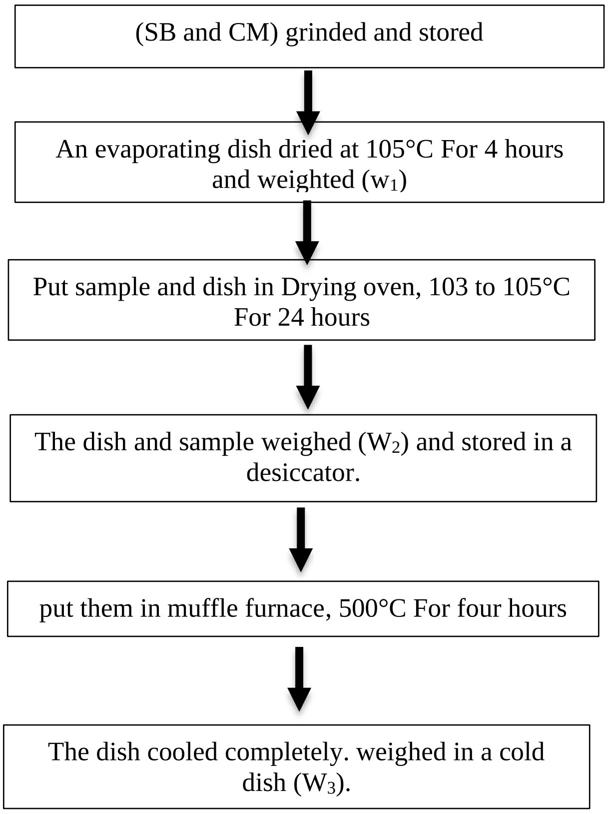

Fig. 2. simple graphical representation analysis processes

The following equations are used to determine the Total solids (TS) and Volatile Solids (VS):

$$TS = \frac{(W2-W1)}{V} \times 10^3 \ (mg/L) \qquad \text{(Eq. 1)}$$

$$VS = \frac{(W2-W3)}{V} \times 10^3 \ (mg/L) \qquad \text{(Eq. 2)}$$

$$VS[\%] = 100 - \frac{burned\ sample\ (g)}{dried\ sample\ (g)} \times 100 \qquad \text{(Eq. 3)}$$

Where;

W_1 is the weight of the clean dried dish (g),
W_2 is the weight of the dish and dried sample (g),
W_3 is the weight of the dish and burned sample (g),

And V is the volume of the sample in liter.

2.2 Hydrogen Power (pH) Test:

To ascertain if a solution was acidic or alkaline, a pH test was utilized. To determine whether the substrate's pH level falls within the range required for the production of biogas, the pH of the substrate must be tested.

Apparatus

- Bench meter with a pH sensor.

Procedure:

a. The pH sensor was calibrated and set to "pH" mode. After calibration, the gadget is immediately utilized by inserting the arm into the sample container.

b. Wait a few minutes for the value on the display screen to stabilize. The pH value is directly shown on the instrument's LCD.

pH electrodes were not allowed to dry. For rapid response, electrodes were stored in a solution as recommended in the manual.

Table (1): fresh cow manure and sugarcane bagasse characteristics utilized in the BMP tests with the standard deviations.

Characteristics	Cow Manure	S.D.	Sugarcane Bagasse	S.D.
TS (%)	20.13	1.74	94.14	3.25
VS (TS %)	72.96	2.05	96	2.83
TC (dry wt.%)	31	1.43	36	1.78
TN (dry wt.%)	1.02	0.07	1.7	0.04
TO (dry wt.%)	35.38	1.66	42.15	1.85
TH (dry wt.%)	3.56	0.14	4.27	0.3
C/N ratio	21:1	2	30:1	3
O.M (dry wt.%)	54	3.12	63	2.54

Notes: VS = volatile solids, TS = total solids, TC = total carbon, TN = total nitrogen, TO = total oxygen, TH = total hydrogen, O.M = organic matter, and C/N = carbon to nitrogen.

2.3 Experimental design and set-up:

In this study, the BMP test was done in triplicate under mesophilic conditions, comparable to the procedures published [12]. In the first experiments, fresh cow manure as inoculum was used to evaluate five CM:SB mixes (CM:SB ratios of 100:0, 70:30, 50:50, 30:70, and 0:100 on VS basis), referred to as A, B, C, C_{cm}, and C_{sb}, to discover the best combination for maximum methane production. BMP studies were conducted using 700-milliliter glass bottles as anaerobic batch reactors with 80% working capacity and 20% headspace volume (Fig. 3).

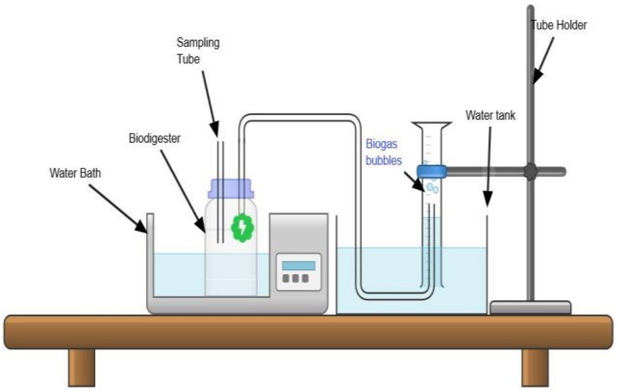

Fig. 3. Schematic diagram of a lab-scale experiment set-up.

In all of the reactors, used a water bath to maintain a temperature of (35-39) °C. Every day, all reactors were shaken for one minute [15]. Before the research began, the pH of the reactors was adjusted to a range of 7 to 7.2.

Using the water displacement technique, the created biogas was measured (Fig. 4). After the BMP test, the VS of digestate from each reactor was calculated. The methane generated by the inoculum was eliminated from the mixing ratios.

Fig. 4. A laboratory-scale BMP test set-up.

Biogas is a mixture of gases that contains methane (CH_4) (55–80%), carbon dioxide (CO_2) (20–45%), and a few additional gases in varying amounts [16]. In order to maximize the energy content of biogas while lowering compression costs, inflammable gases like CO2 must be removed through a purification procedure. CO2 absorption in alkaline solution is one of the purifying techniques. By passing the biogas through a 3 M sodium hydroxide solution, CO2 was eliminated (NaOH) [17].

2.4 Statistical analysis:

In this work, ANOVA software was used to assess the cumulative methane production as means. In each of the three-research series, the P value for the F-test is 0.05. 95 percent confidence intervals were calculated for the statistical analysis of the mean cumulative methane emission for the two BMP test trials.

III. RESULTS AND DISCUSSION

3.1 Inoculum and feedstock characteristics:

In anaerobic digestion (AD), analyzing the components of feedstock to determine its balance is essential, notably total solids (TS) and volatile solids (VS). First, as indicated in Table. 1., a high VS content (96 % TS) sugarcane bagasse (SB) substrate has a high level of biodegradability, which fits the criteria [18]. Second, cow dung contains a lot of VS (72,96 %).

3.2 Anaerobic co-digestion of CM with SB at various mixing ratios:

Fig(5) shows the highest peaks of daily biogas production for the co-digestion of SB and CM at mixing ratios of (0-100, 30-70, 50-50, 70-30, and 100-0). During the 26th day (12.78 mL/gvsadded), 17th day (15.63 mL/gvsadded), 18th day (11.90 mL/gvsadded), 19th day (13.53 mL/gvsadded), and 19th day (10.18 mL/gvsadded), SB-CM was noted. These maximum peaks are greater than the peak values associated with SB-CM digestion alone. At a mixing ratio of, the methane production peaked at its highest level (30 SB -70 CM).

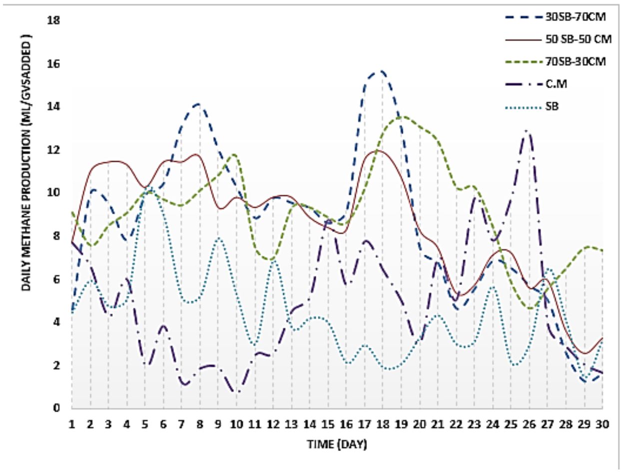

Fig. 5. Daily Biogas yields from co-digestion of SB-CM at various mixing ratios.

3.3 Cumulative Biogas yields (CBYs) from co-digestion of CM and SB:

As seen in (Fig.6)., CMYs from co-digestion of CM and SB at mixing ratios of (0-100, 30-70, 50-50, 70-30, and 100-0) SB-CM were 155.3, 255.22, 256.2, 275.219, and 132.94 mL/gVS$_{added}$, respectively, resulting in higher methane production of 1.70, 1.71, and 1.84 times than digesting CM alone, and higher methane yield of 2.07, Increased feedstock biodegradability and methane production need co-digestion of SB and CM depending on their mixing ratios [19].On the other side, the maximum CMYs were greater. Heo et al [21] estimated production of bio-methane from Food Waste and Waste Activated Sludge was 370 mL/ gvs$_{added}$ at an FW to WAS ratio of 50:50, and less than the greatest value of CMYs (446.23 mL/ gvs$_{added}$) obtained by Pellera and Gidarakos at a mixing ratio of 0.5 for winery waste (ww) and juice industry waste (JW) [20].

When compared to the other mixing ratios of (0-100, 30-70, 50-50, and 100-0) SB-CM, maximum CMYs were recorded at a mixing ratio of (70 SB-30 CM) (This result was statistically approved with a P-value (probability value) of the F-test of 0.05). with improvements of 22%, 12%, 15%, and 4%, respectively, when compared to the other mixing ratios. At a PS to FVW ratio of 50:50, [18] predicted the formation of bio-methane from primary sludge comprising fruit and vegetable wastes to be 141 mL/gVS., The maximum CMYs, on the other hand, were higher. and less than the value of CMYs (446.23 mL/ gvs$_{added}$) obtained by Pellera and Gidarakos [20] at a mixing ratio of 0.5 for winery waste (ww) and juice industry waste (JW) by Heo et al [21]. who estimated production of bio-methane from Food Waste and Waste Activated Sludge was 370 mL/ gvs$_{added}$ at an FW to WAS ratio of 50:50.

CM and SB are co-digested. The perfect mixing ratio (70 SB-30 CM) discovered in this work conforms to the anaerobic digestion optimum range for Xing et al [6], who claimed that the maximum CH_4 yields of 646.6 and 653.4 mL/g VS were obtained under the optimum FW/CM (2.5 VS/VS) and S/I (0.07 VS/VS) ratios, respectively. Previous research backs up the findings of this investigation [22].

The findings of a study on the co-digestion of cow dung and digested slurry showed that combining the slurry boosted gas generation from 108 l/kg dry matter to 158 l/kg dry matter, as well as the rate of gas production from 108 l/kg dry matter to 108 l/kg dry matter. Additionally, it led to a 36.1% diversion of all volatile solids. [23] In batch hemi-solid-state anaerobic digestion (HSS-AD) studies, co-digestion of rape straw (RS) and dairy manure (DM) at various S/I ratios (2:3, 1:1, 2:1, 3:1, and 4:1) was found. At Substrate/Inoculum ratios of 2:3 and 2:1, respectively, the maximum volumetric methane production of 0.4 L/(L.d) and the highest methane output of 209.1 mL/gVsadded were also accomplished.

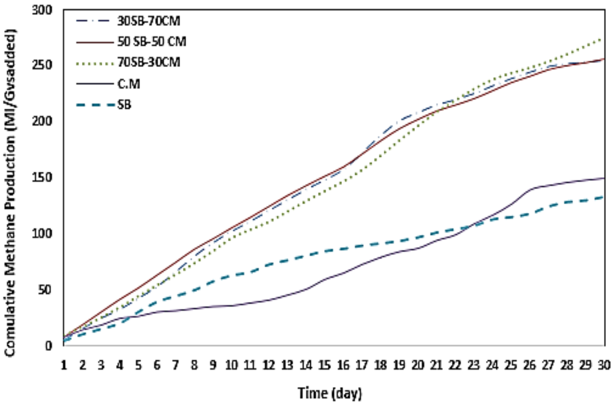

Fig. 6. CMYs from AD of SB and CM at various mixing ratios.

IV. CONCLUSION

This study used biochemical methane potential (BMP) experiments in mesophilic settings to examine the potential for producing biogas from the anaerobic digestion of SB and CM. Methane outputs from the anaerobic digestion of SB and CM are increased both daily and over time. CMYs from anaerobic digestion of CM and SB were 149.93, 255.22, 256.2, 275.219, and 132.94 mL/gvsadded, respectively, at mixing ratios of (100:0), 70:30, 50:50, 30:70, and 0:100. The high degree of biodegradability of 30:70 (CM:SB) may be the cause of the largest biogas generation generated from anaerobic digestion.

V. RECOMMENDATION

The effect of mixing ratio on anaerobic co-digestion process of Sugarcane Bagasse (SB) and Cow Manure (CM) in batch reactors is considered a future scope that further research in this area can be extended to study the effect of stirring speeds and stirring/break periods in anaerobic co-digestion. And using 700 ml bottles as reactors give a good results similar to 500 ml.

VI. ACKNOWLEDGMENTS

The department of agricultural engineering and biosystems, faculty of agriculture and natural resources, and the ministry of higher education in Egypt, who financed this work, are gratefully acknowledged by the authors.

VII. REFERENCES

[1] H. Ünyay, F. Yılmaz, I. A. Basar, N. A. Perendeci, I. Çoban, and E. Sahinkaya "Effects of organic loading rate on methane production from switchgrass in batch and semi-continuous stirred tank reactor system," Biomass and Bioenergy. Volume 156, 106306, January 2022.

[2] M. U. Khan, and B. K. Ahring "Anaerobic digestion of biorefinery lignin: Effect of different wet explosion pretreatment conditions," Bioresource Technology 298, 122537, ISSN 0960-8524, 2020.

[3] A. H. Igoni, M. J. Ayotamuno, C. L. Eze, S. O. T. Ogaji, and S. D. Probert "Designs of anaerobic digesters for producing biogas from municipal solid-waste," Applied energy, 85(6), 430-438, 2008.

[4] M. Poeschl, S. Ward, and P. Owende "Prospects for expanded utilization of biogas in Germany," Renewable and sustainable energy reviews, 14 (7), 1782-1797, 2010.

[5] J. T. Lee, M. U. Khan, H.Tian, A. W. Ee, E. Y. Lim, Y. Dai, Y. W. Tong, and B. K. Ahring "Improving methane yield of oil palm empty fruit bunches by wet oxidation pretreatment: mesophilic and thermophilic anaerobic digestion conditions and the associated global warming potential effects," Energy conversion and management, 225, 113438, 2020.

[6] B. S. Xing, Y. Han, S. Cao, X. C. Wang "Effects of long-term acclimatization on the optimum substrate mixture ratio and substrate to inoculum ratio in anaerobic co-digestion of food waste and cow manure," Bioresource Technology, 317, 2020, 123994, ISSN 0960-8524, 2020.

[7] S. Bi, X. Hong, H. Yang, X. Yu, S. Fang, Y. Bai, J. Liu, Y. Gao, L. Yan, W. Wang, and Y. Wang "Effect of hydraulic retention time on anaerobic co-digestion of cattle manure and food waste," Renewable Energy, 150, 213-220, 2020.

[8] A. Yasser, S. Hatm, M. Fayza "An Economic Study of Recycling Agricultural Wastes in Egypt," Arab Universities Journal of Agricultural Sciences, 22(2), 213–222, 2014.

[9] B. M. Abdel-Maksoud "Sugarcane Production in Egypt: Synthesis of Salient Research findings," in International Conference on: "New Role for the World Sugar Economy in a Changed Political and Economic Environment," Aswan, Egypt, 10-13 November 2012.

[10] E. Ahmed "Economic Study for the Supply Response of Sugar Crops in Egypt," Arab Universities Journal of Agricultural Sciences, 26(3), 835–861, 2018.

[11] B. Singh, K. L. Kovács, Z. Bagi, J. Nyári, G. L. Szepesi, M. Petrik, Z. Siménfalvi, and Z. Szamosi. "Enhancing Efficiency of Anaerobic Digestion by Optimization of Mixing Regimes Using Helical Ribbon Impeller" Fermentation 7, no. 4: 251, 2021.

[12] M. Elsayed, R. Hassany, and M. Soliman "Anaerobic co-digestion of sludge, sugarcane leaves, and Corchorus stalks in Egypt," Biomass Conversion and Biorefinery, 1-15, 2021.

[13] L. Luo, Y. Qu, W. Gong, L. Qin, W. Li, and Y. Sun "Effect of Particle Size on the Aerobic and Anaerobic Digestion Characteristics of Whole Rice Straw," Energies, 14, 3960, 2021.

[14] APHA, 'Standard methods for the examination of water and wastewater, 'American Public Health Association/American Water Works Association /Water Environment Federation, vol. 552, 2005.

[15] W. Zhang, Q. Wei, S. Wu, D. Qi, W. Li, Z. Zuo, and R. Dong "Batch anaerobic co-digestion of pig manure with dewatered sewage sludge under mesophilic conditions," Applied Energy, 128, 175–183, 2014.

[16] A. Demirbas, and T. Ozturk "Anaerobic digestion of agricultural solid residues," International Journal of Green Energy, 1(4), 483-494, 2005.

[17] Z. Siddiqui, N. J. Horan, and K. Anaman "Optimization of C:N Ratio for Co-Digested Processed Industrial Food Waste and Sewage Sludge Using the BMP Test," International Journal of Chemical Reactor Engineering, vol. 9, no. 1, 2011.

[18] M. Elsayed, D. Asmaa and S. Mohamed "Methane Production from Anaerobic Co-Digestion of Sludge with Fruit and Vegetable Wastes: Effect of Mixing Ratio and Inoculum Type," Biomass Conversion and Biorefinery. 11(3), 989-998, 2020.

[19] M. El-Bakhshwan, A. El-Ghafar, M. Zayed, and A. El-Shazly "Effect of mechanical stirring on biogas production efficiency in large scale digesters," Journal of Soil Sciences and Agricultural Engineering, 6(1), 47-63, 2015.

[20] F. M. Pellera, and E. Gidarakos "Effect of substrate to inoculum ratio and inoculum type on the biochemical methane potential of solid agro-industrial waste," Journal of Environmental Chemical Engineering, 4(3), 3217-3229, 2016.

[21] N. H. Heo, C. S. Park, S. J. Lee, H. Kang, and H. D. Don Park "Single-Stage Anaerobic Co-digestion for Mixture Wastes of Simulated Korean Food Waste and Waste Activated Sludge," Applied Biochemistry and Biotechnology, Vol. 105-108, 567-579, 2003.

[22] A. K. Kalia, S. P. Singh "Effect of Mixing Digested Slurry on the Rate of Biogas Production from Dairy Manure in Batch Fermenter," Energy Sources, 23:8, 711-715, 2001.

[23] X. Ma, T. Jiang, J. Chang, Q. Tang, T. Luo, and Z. Cui "Effect of substrate to inoculum ratio on biogas production and microbial community during hemi-solid-state batch anaerobic co-digestion of rape straw and dairy manure," Applied biochemistry and biotechnology, 189(3), 884-902, 2019.