Journal of Sustainable Agricultural and Environmental Sciences
https://jsaes.journals.ekb.eg/
JSAES, 2022,1(1): 136 - 150

ISSN-Print: 2735-4377
ISSN-Online: 2785-9878

Effect of Stirring Time and Tow Digester Positions on Biogas Production from Cattle Dung

Abdelaal, M. M.[1*]; M. T. Ebaid[2]; M. S. A. Ghoname[1] and M. R. Darwesh[1]

[1] Department of Agricultural Engineering, Faculty of Agriculture, Tanta University, Egypt.
[2] Agricultural Engineering Research Institute, Dokki, Giza, Egypt.

*Corresponding Author: Abdelaal, M.M. (mesbah.morgan1114@gmail.com)

J.Sust.Agri.Env.Sci (JSAES)

Keywords:

Digester; Stirring period; Biological conversion efficiency; Flat plate solar collector; Cumulative biogas production.

ABSTRACT

Mechanical stirring has profound effects on the biological and physiological functions of the biological decomposition of organic and inorganic molecules during a stirring time interval in small scale digesters on the biogas production daily and cumulative. The study aims to maximize energy systems in Egypt, through the anaerobic digestion of cattle dung. Huge amounts of cattle dung are dumped on the land and local sewage without any management. It is necessary to treat and recycle this waste to be a useful component. The study was carried out on the roof of the Faculty of Agriculture, Tanta University during January and February of the year 2021 by using solar energy to heat the mixture under mesophilic conditions and at two stirring period of 5 and 15 min/1h. The results showed significant effects on biogas production. The horizontal digester recorded the highest cumulative biogas production of cattle dung with water; it was 28.095 and the vertical digester was 23.069 L, while the best stirring period of biogas production for both horizontal and vertical systems was 5min/60rpm; it was 14.45 and 12.85 liters, respectively. Biological conversion efficiency of 75.5% and the average methane percentage in the biogas was 55.2% and 48.8% for both horizontal and vertical digesters, respectively. The study showed the importance of the stirring period on the homogeneous distribution of the mixture and its temperature in addition to the activity of bacteria and the production of biogas.

NOMENCLATURE

T_k	Hot water temperature inside the tank, ◦C
T_{mix}	Internal digester temperature of the waste mixture,◦C
TiwD	Inlet water temperature of the digester, ᵒC
TowD	Outlet water temperature of the digester, ᵒC
$\mathbf{T_{s1}}$	Total solid of raw material (cattle dung), %
$\mathbf{T_{s2}}$	Total solid of fermentation material, %
X	Amount solid of raw material added, kg
Y	Dilution volume, liter
	Greek symbols
Φ	Latitude angle (degree)
β_o	Tilt angle, degree
δ	Declination angle, degree
$\boldsymbol{\omega}$	Hour angle, degree
Arc Cos	Inverse function
Cos	Cosine function
Sin	Sine function
	Subscripts

i, o	Inlet and outlet	HDU	Horizontal digestion unit
AC	Alternating current	TBP	Theoretical biogas accumulation, m^3
DC	Current direct	EBP	Experimental biogas accumulation, m^3
VDU	Vertical digestion unit		

1. INTRODUCTION

Globally, biogas produced from anaerobic digestion of organic waste such as dung of various types are the most significant sources of clean energy consumed mainly in many countries as it one of the foremost processes to combat of climate change for reducing the greenhouse gas emissions and to contribute a sustainable development of energy supply. Therefore, clean energy plays a vital role for our daily life. In addition, the problem of energy and its high prices is exacerbating abnormally in Egypt at the moment **(EIA, 2015)**. Agricultural wastes are estimated by about 35 million tons/year, of which, about 23 million tons/year of residues as well as animal wastes which reach to nearly 12 million tons per year **(Hassan *et al.*, 2014)**.

Egypt produces 31 million tones /year of cattle manure, in the middle delta region **(FAO, 2017)**. The aim of stirring is to properly distribute the organic waste within the biogas digester, to ensure good heat distribution and thus the activity of methanogen bacteria and to prevent stratification and foam formation **(Brehmer *et al.*, 2012)**.

Usually, mixing is done through numerous methods, such as mechanical mixer. The importance of mixing in achieving efficient substrate conversion has been reported by **(Stroot *et al.*, 2001)**. Continuous stirring inside the digester showed minimal improvement, while occasional stirring (total time of 4 h/day at 120 rpm) improved the total gas production and stability of the process **(Desai *et al.*, 1994)**.

The effect of continuous mixing (mixing for 5 min at 15 min interval at 100 rpm) on methane production was investigated in three lab-scale continuously stirred tank reactors and compared mixing speeds from 50 to 160 rpm. Also, higher methane content at 50 rpm was 26-41%, higher than at 80 rpm mixing speed **(Nandi *et al.*, 2017 and Ghanimeh *et al.*, 2018)**. The rate of production methane decreased when the mixing duration was reduced from 45 min/h to 15 min/h **(Lebranchu *et al.*, 2017)**. **(Shen *et al.*, 2013)** suggested stirring speed ranging from 20 to 160 rpm at intervals of 20 rpm to suitable stirring speed with a stirring period of 12 times a day with a stirring duration of 5 min each for higher biogas production from rice straw at a mesophilic temperature.

The pH in an anaerobic digestion is maintained between pH 6.8 and 7.2 and the biogas consists of 55 to 80% methane and 20 to 45% carbon dioxide. Contingent on the source of organic matter and management of the anaerobic digestion process, small amounts of other gases such as ammonia, hydrogen sulfide, and water vapor **(Rajeshwari *et al.*, 2000 and Arogo *et al.*, 2009)**.

Occasional mixing seems preferable in terms of the quantity and quality of biogas produced, and this leads to maintenance costs associated and lower power consumption with large-scale biogas production **(Singh *et al.*, 2020)**.

Furthermore, there is little information available about the optimal selection of a mixers and mixing intervals and the time required for the best homogeneity and the effect of these stirring intervals and speeds on the cumulative gas production. The effect of stirring period has been studied by many researchers, but it is still a topic of debate **(Kariyama *et al.*, 2018)**.

The current study aims to understand and describe the effect of mechanical stirring at interval mixing periods and different speeds on the biogas productivity in an anaerobic digester; evade solid accumulation at the base of the digester, settlings and floating layers; Homogeneous distribution of nutrients and micro-organisms and Release the trapped biogas in the mixture.

2. MATERIALS AND METHODS

2.1. Experimental components

The anaerobic digestion system is consisted of animal waste, digester, gas holder, stirrer motor, electrical control panel, flat plate solar collector supplemented with digestion unit all in order to develop anaerobic digestion as an effective method for municipal solid waste management.

2.1.1 Animal waste

Raw cattle dung was taken from Fattening cattle farm in Tanta district, Gharbia Governorate and was collected in a plastic bag at capacity of 100L. All the wastes were taken fresh and used fresh once collected presented pH of 6.53. The waste was immediately transported to Tanta University's Agriculture Faculty's roof.

According to Castle Foundation for Scientific Research in Mansoura District, Dakahlia Governorate, Cattle dung has the following chemical composition: pH, 6.53; water content, 77.4%; total nitrogen, 0.723%; total solid matter, 20.3%; phosphate, 0.24% and C/N ratio, 28.077. The cattle dung with water is diluted therefore it is suitable for mixing for anaerobic digestion because of methane bacteria need water large quantities and their organic matter.

Two cylindrical digesters; vertical and horizontal were used in this research as shown in Fig. 1. Both digesters were manufactured in a local workshop from a stainless steel sheet, and each was 1.5mm in thickness, 80cm in length, and 40cm in diameter, with a total volume of 100L and one opening for feeding organic wastes and another expelling the digester materials, diameter 7.62cm. The system as a whole was insulated with a thickness of 5cm thick glass wool with specifications is summarized, maximum temperature is 150^{o}C, Bulk density is 48kg/m^3 and Thick is 0.05m. Each digester had a mixer shaft made from stainless steel, which was supported by two bearings and powered by a small electric motor (Gear-Box Motor, Mod. 37GB555-E05, 12/24V DC, 300 rpm, China) by AC adapter for each digester, the timer was adjusted automatically at 5 and 15min operation every one hour stop. The heating required for the bioreactor was generated using a solar collector combined with an electrical heater to heat the water inside the heat exchanger tubes.

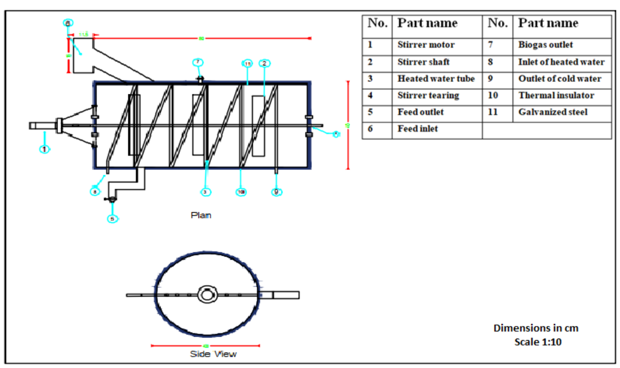


Fig. 1: Perspective view of digester supplemented with heated water tube and stirrer motor, DC

2.1.2 Flat plate solar collector

Flat plate solar collector with aluminum frame dimension is (2.48m long, 1.8m wide, and 0.1m deep) consists of cover plate of ordinary temper glass of 6mm in thick, a heat absorbent dark colored plate is placed inside to absorb the sun's rays and inner copper pipes has 14 copper pipes with a diameter of 12.7mm through which the water to be heated and the distance between each tube is 12cm and net surface area of 4.46m^2, Fig. 2. The product of heated water was stored in a thermally insulated tank (150L in capacity). Hot water is forced with a constant flow rate for heated water tube by a water pump, (Mod. JET 100A, 220-240Vac, 50Hz, 50 L/min, Italy).

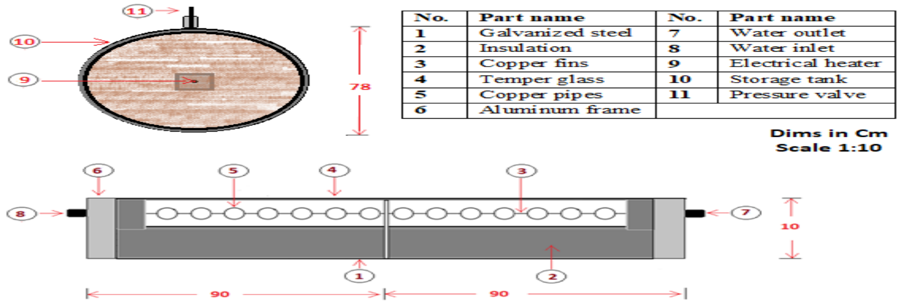


Fig. 2: Schematic drawing of flat-plate solar collector and storage tank

2.2. Experimental Procedure

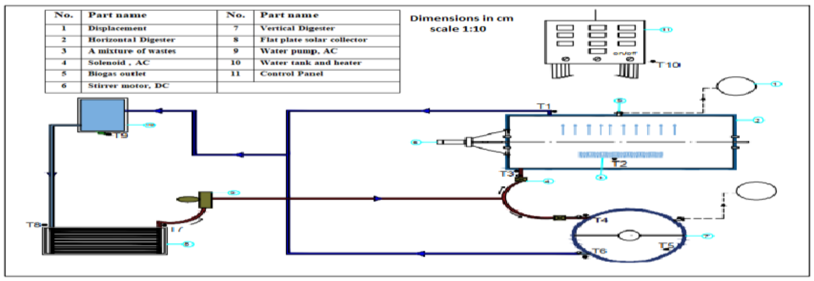
80 kg of waste (cattle dung) was transported fresh and used fresh as soon as it was collected from a fattening farm to the experiment site, Faculty of Agriculture, Tanta University, Gharbia Governorate. The cattle dung was diluted with water to final total solid (T.S) of 10% the required amount of water to adjust the total solid in biogas digester to be 10% was calculated using the following formula **(Lui *et al.*, 1981)**.

$$\mathbf{Y = x \left[\frac{T_{s1} - T_{s2}}{T_{s2}}\right]} \qquad [1]$$

The cattle dung after mixing with water is divided into two parts, the first part for the vertical biogas digestion unit and the second part for the horizontal unit for producing biogas. The experiment was carried out during the months of January and February of 2021under mesophilic conditions (37±0.2^{o}C) at a pH is6.53 Total solids of 10% and volatile solids of 75.93% where, were calculated with a calcinations oven (Precision drying oven type- made in Japan) at temperature of 105^{o}C and 550^{o}C for 24h, respectively at Rice Mechanization Center Lab, during the execution of the experiment according to **(APHA, 2005)**.

The waste mixture is placed inside the vertical and horizontal digester for 31 days with a constant mixing ratio and under the same operating conditions. The timer has been modified to provide two levels of 5 and 15 min stirring intervals. The temperature readings were recorded using sensors connected to the data logger and the volume of biogas produced by the displacement system during the anaerobic digestion process. The percentage of methane was determined using a gas analyzer (Geotech GA5000) and releasing through the valve 3mm diameter by opening the control valve.

To reach a homogeneous mixture and an appropriate temperature under mesophilic conditions, each digester has three sensors to measure the temperature of the water entering and leaving it, in addition to the heat of the mixture inside the digester, in addition to measuring the temperature of the water entering and leaving the flat type solar collector. Electric energy is used to heat the water to reach a temperature of 65 ^{o}C inside the water tank, because solar energy is not enough for biogas production during, carrying out of the experiment from January to February. Hot water enters the digester through two solenoid valves to control the inlet and exit of the water when the temperature of the mixture is 37±0.2^{o}C. The system as a whole is controlled through a control panel. if the internal temperature of the tank drops below 45°C, the electric heater heats the water until it reached up to 65°C, again and then the system works as a wholes shown in Fig. 3. A multi-range timer (SZR-M2) was used to control the time of stirring the cattle dung inside the digester (5 and 15min stirring every 1 hour stop) and A water pump to extract hot water from the tank and push it into the tubes inside the digester, in addition to a group of external electrical switches, electrical protection devices.



2.3. Measurements and Instruments

A solar power meter, model (TENMARS, TM-207, max. range of 1999W/m^2, accuracy ±10W/m^2, S/N: 131002468, Taiwan) was used to measure solar radiation incident over the solar collector surface at the experimental site during the months of January and February, Laptop balance meter, model (AC 220V, 15V A, 50/60 Hz - No. 0800594, accuracy of 1mg - made in Tokyo Japan) was used to estimate the weight of the sample before it enters and exits the oven for total solids and volatile solids determination and pH value of the effluent measured using AD11 Waterproof pH-Temp mete for the experimental work.

Gas container unit is designed with dimensions, 50.8cm in length, 25.4cm in diameter and a capacity of 25.8 L, made of soft PVC plastic that has been filled with water. Each digester is connected to the gas container by plastic tubing and a control valve. The mechanism of calculate the volume of gas produced and storing as the volume of the displaced water with a previously calibrated scale.

Temperatures were measured in specific locations of the whole system (digesters, solar collectors and storage tanks) with a 5 minute interval where temperatures were measured by dixell sensors connected to a data logger and stored on a computer

2.4. The behavior of the solar system

The stationary solar collector tilt angle (βo) was selected based on the average of tilted angles for monthly January and February using Eqn. 2, that was selected at noon at the same site of the present study and the inclination angle of the solar collector was calculated and its characteristic for January, February are: 52.27◦ and 44.3◦, respectively and studying of parameters affecting the behavior of the solar collector according to **(Duffie and Beckman, 2005)**.

$$\boldsymbol{\beta_o = \text{arc cos}\,[\cos(\Phi).\cos(\delta).\cos(\omega) + \sin(\Phi).\sin(\delta)]\,,\text{degree}} \qquad [2]$$

2.5. Bioconversion efficiency of organic wastes to biogas

Biogas fermentation is a complex process for cattle dung, the theoretical biogas accumulation (BP) was compared to the experimental biogas accumulation (BP) for an understanding of bioconversion efficiency of organic wastes to biogas can be calculated using following equation, according to **(Elfeki *et al.*, 2017)**.

$$\mathbf{Biogas, BE\,\% = \frac{(EBP)}{(TBP)} \times 100} \qquad [3]$$

3. RESULTS AND DISCUSSION

The incident solar radiation on a horizontal surface of the flat plate solar collector and ambient air temperatures were recorded during monthly January and February. Figs. 4 and 5 Show that, the incident solar radiation was measured from sunrise to sunset which starts from starts from 8:00 to 17:00 h for all investigated variables and the average incident solar radiation rises up to a maximum value on solar collectors at 44.29° tilt angle was achieved during February month was 646.25W/m^2, at 13h afternoon. While, January month the maximum values of incident solar radiation on solar collectors at 52.27° tilt angle was 557.33W/m^2 at 12h noon where. These results agree with those published by **(Darwesh and Ghoname, 2021)**, the incident solar radiation value varies from time to time during the experimental period due to the different tilt angle of the solar collector during the experimentation of two stirring interval periods 5 and 15min, 1hr stop with one stirring speed of 60rpm. The average storage tank temperature during January and February reaching their highest values at 51.62, 59.36 ^{o}C, respectively as in Fig. 6.

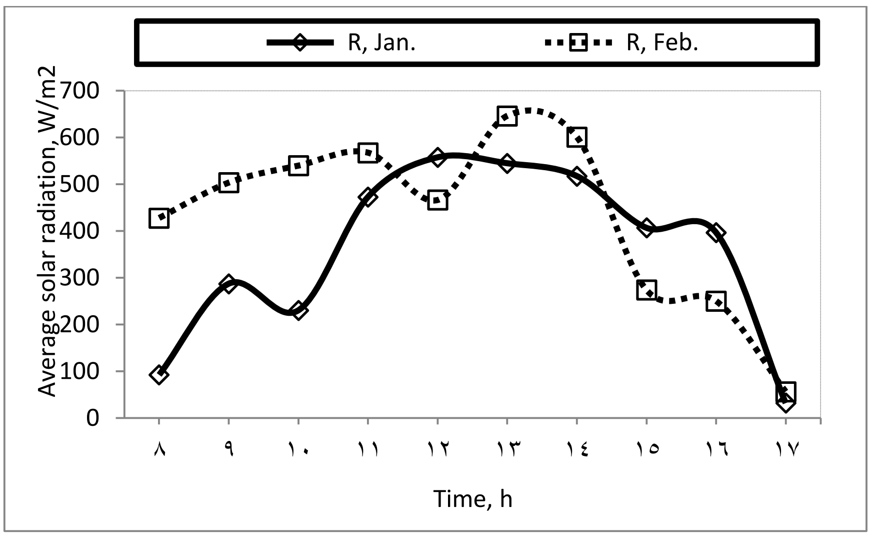


Fig. 4: Solar radiation incident on the solar collector during the experimental period

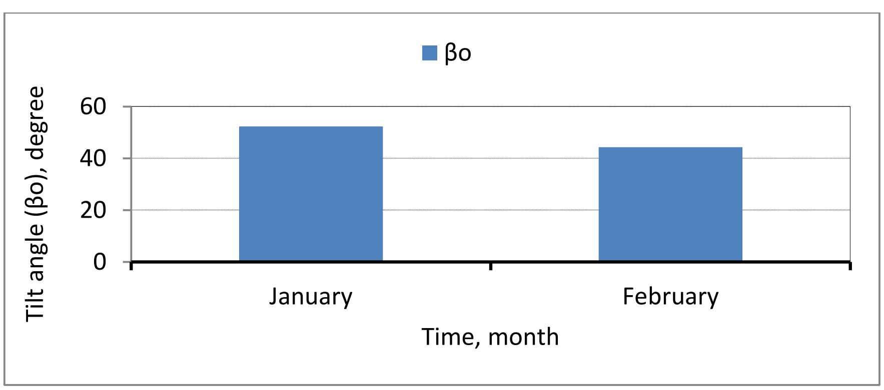


Fig. 5: Optimum tilts angle of solar collector during the experimental period

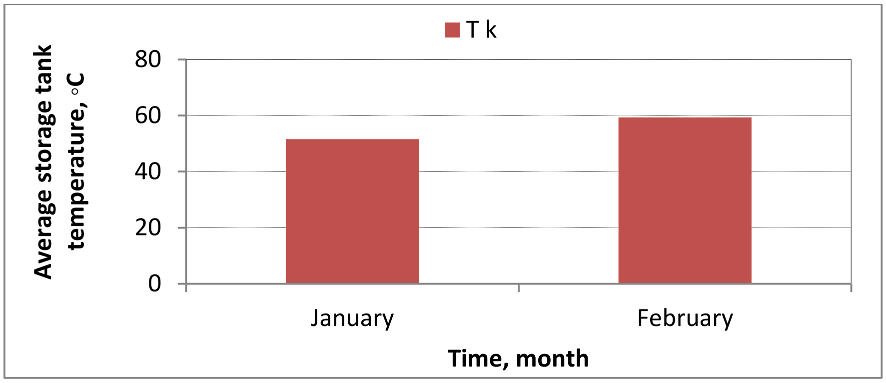


Fig. 6: Average storage tank temperature during the experimental period

3.1. Effect of stirring on digester temperature

In Fig. 7 show effect of two stirring periods on the temperature behavior of the waste mixture inside the digester and inlet and outlet water temperatures of the digester for both the vertical and horizontal systems. The vertical digester average mixture temperature for January and February months were 37.5 ◦C and 35.8 ◦C, respectively and the horizontal digesters average mixture temperature for January and February months were 35.4°C and 34.6°C, respectively, according to **(Rowayda, 2015; Grosser *et al.*, 2017; Hagos *et al.*, 2017; Darwesh and Ghoname, 2021)**, the optimal temperature was 35°C at mesophilic conditions. the digesters average mixture temperature for the vertical digester was higher than the horizontal one, and Increasing the stirring period from 5 to 15 min/h had a clear effect on the temperature behavior inside the digester, which made the mixture temperature in a state of stability in the vertical system, while there was no clear change in the horizontal system during the experimental period, which considered a better distribution of heat in the vertical system than in the horizontal system. Thus, there was controlling of each digester individually by a controlled solenoid and timer.

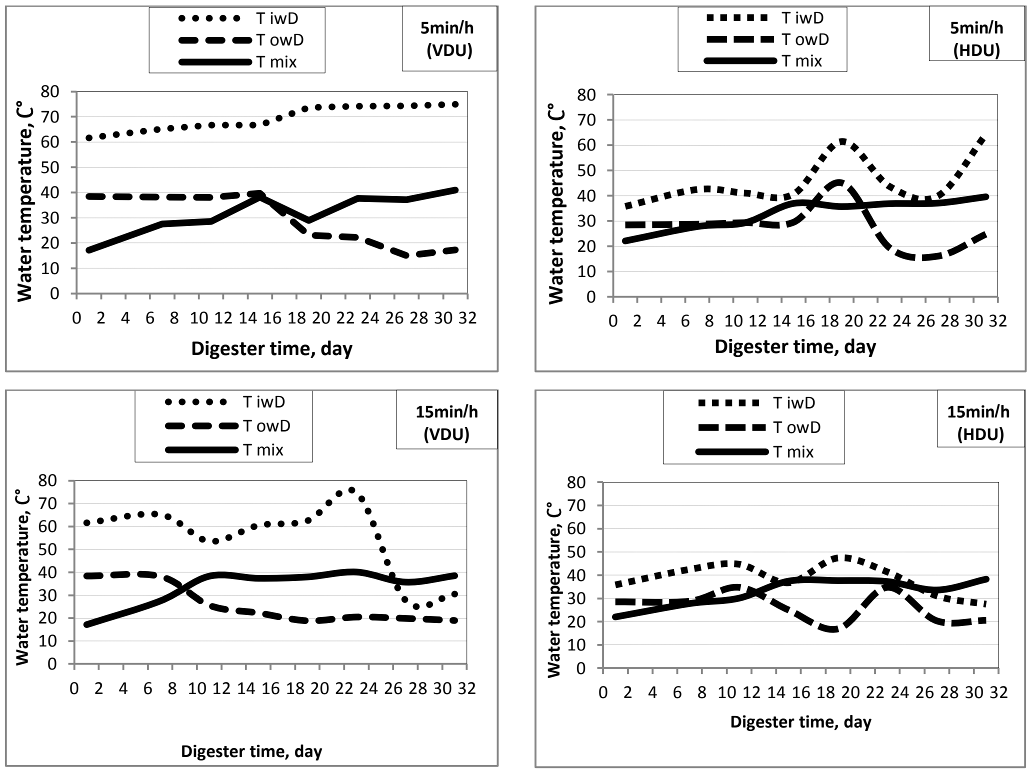


Fig. 7: The effect of two periods of stirring on the temperature behavior of the cattle dung inside the digester for both vertical and horizontal digestion units

3.2. Effect of digester position biogas production

The substrate consists of cattle dung at 10% total solid, cumulative volume of biogas production was observed during 31 days as depicted in Fig. 8. Biogas production is slow at the beginning observation period due to the biogas production state is directly corresponds to growth rate of methanogen bacteria in the bio-reactor also indeed do not formed yet due to the lag of microbial growth since no microbial initiator has been used. In the range of 7 to 27 days observation, biogas production is significantly increased due to exponential growth of microorganisms. After 27 days of observation, biogas production is stable in both horizontal and vertical systems, biogas production tends to decrease after day 31 and this is expected due to the stationary phase of microbial growth. The highest biogas production from cattle dung with water, recorded for each of horizontal and vertical digester; it was 28.095 and 23.069 L, respectively. Many previous studies have reported similar biogas production from cattle dung with water **(Rowayda 2015; Darwesh, 2015)**, also shows that, generally, substrates consist of cattle dung, and horizontal digester exhibit higher biogas production than vertical digester.

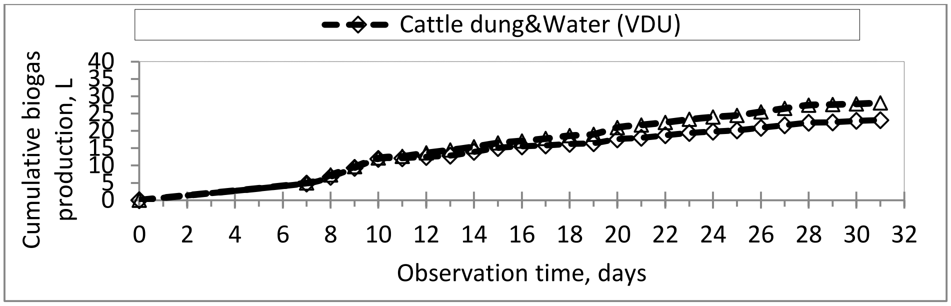


Fig. 8: The cumulative biogas production from cattle dung with water; both vertical and horizontal systems

Fig. 9 show that, at a mixing speed of 60rpm, the highest cumulative biogas production was for both horizontal and vertical systems at a stirring period of 5 min of cattle dung was 14.45 and 12.85 L, respectively. While the stirring period of 15 min, the cumulative production of gas was 10.39 and 8.52 liters, respectively at a mixing speed of 60rpm. The results showed that the best stirring period was 5 min/1h in both horizontal and vertical systems at stirring speeds of 60rpm, but when the stirring period was increased to 15 min/1h, this led to a decrease in the cumulative biogas production during the experiment compared to a period of 5 min/1h. Using cattle dung for biogas production, the pH varied from 6.2 to 7.41 and the average pH during the experiments around the value of 6.85. To maintain the conditions necessary for a homogeneous distribution of the micro-organisms responsible for organic matter decomposition, the mixture is stirred at periodically as in Fig. 10. The minima cumulative biogas production of cattle dung is 25.6L at pH 6.85. Industrial anaerobic digesters normally operate in the pH range of 6.0-7.0, and at pH levels less than around 6, occur reductions in biogas production output have been seen. And note that the nearer the pH is to the neutral mean of 7, it stimulates the growth of microbes and bacteria according to **(Azbar *et al.*, 2000 and Barua, 2018)**.

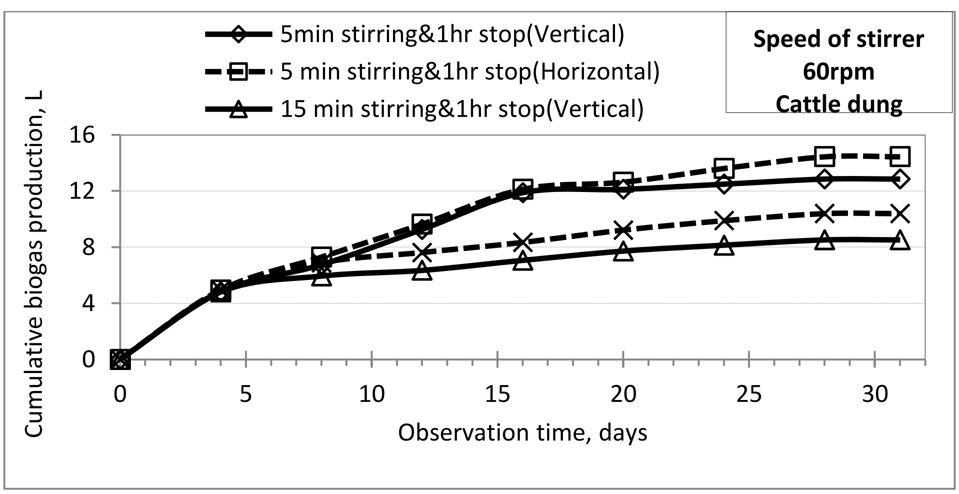


Fig. 9: The effect of two periods stirring on cumulative biogas production behavior of the waste mixture inside the digester at stirring speed 60rpm for both vertical and horizontal digestion units

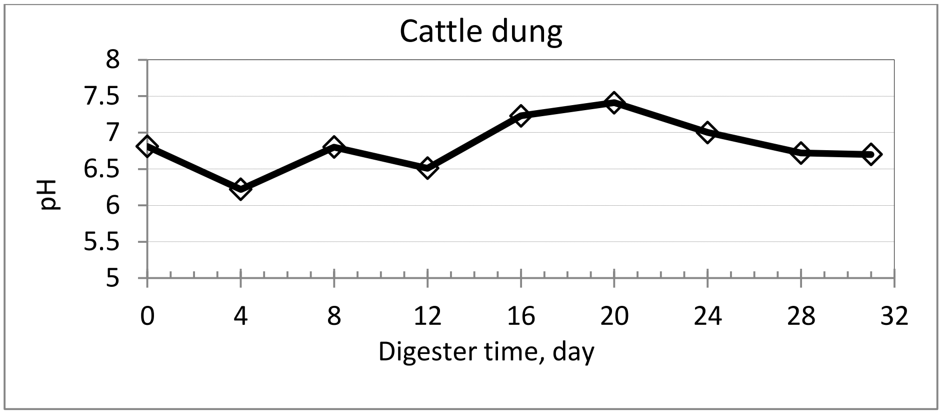


Fig. 10: The behavior of pH during the experiment period and effecting on cumulative biogas production with time

Fig. 11 shows that, Also, biogas production rate in the 31 days observation. In general, the maximum biogas production rate when mixing cattle dung with water was 8.165 and 6.285 L/(L slurry. d) at day 10 with an average daily production rate during the cycle was 1.163 and 0.923 L/(L slurry. d) for each of the horizontal and vertical systems, respectively. These numbers were consistent with those published by **(Alagoz *et al.*, 2018)**. The implication is that, biogas production rate of horizontal digesteris higher than vertical digester. Lastly, the most important outcome from this research can be drawn the conclusion that the use of the horizontal digester is much better than the vertical digester in terms of biogas production rate and cumulative biogas production.

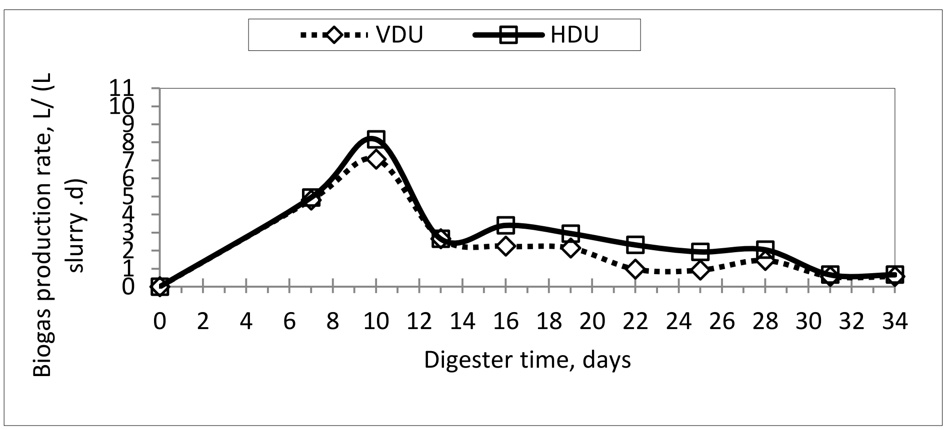


Fig. 11: Daily biogas yield of cattle dung with water mixture during the fermentation period

The bioconversion efficiency, % was obtained via experimental (BP) divided by the theoretical (BP), as shown in Fig. 12. The average biological conversion efficiency of cattle dung mixture with water was 75.5% in this study. On the other hand, the highest efficiency of biological conversion at a stirring period of 5min/1h at a mixing speed of 60rpm was 78.3% and the minimum efficiency of biological conversion at a stirring period of 15 min/1h was 35%, approximately.

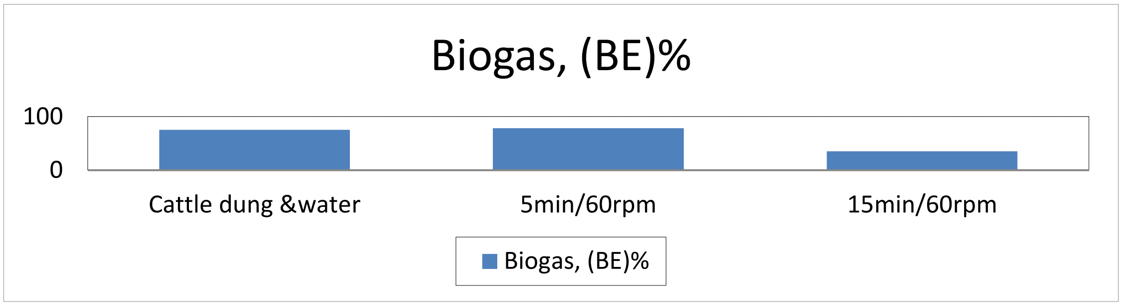


Fig. 12: The influence of two stirring periods with stirring speed of 60rpm on bioconversion efficiency of organic wastes to biogas for the mixture of cattle dung during experimental

4. CONCLUSION

In the stirring periods plays a vital role in the homogeneous distribution of the mixture and its temperature in addition to the activity of bacteria and the production of biogas. The obtained results of the experimental work could be summarized and determined as follows:

a) The average incident solar radiation rices up to a maximum value on solar collector at 48.28° tilt angle was achieved during the experiment period was 602 W/m^2.
b) Increasing the stirring period from 5 min to 15 min/h had a clear effect on the temperature behavior inside the digester, which made the mixture temperature in a state of stability in the vertical system, while there was no clear change in the horizontal system.
c) A better distribution of heat in the vertical system than in the horizontal system.
d) The minima cumulative biogas production of cattle dung with water mixture is 25.6 L at pH 6.85.
e) The results show that the best stirring period was 5 min/1h in both horizontal and vertical system at stirring speed of 60rpm, but when the stirring period was increased to 15 min/1h, this led to a decrease in the cumulative biogas production during the experiment compared to a period of 5 min/1h.
f) The highest efficiency of biological conversion at a stirring period of 5min/1h at a mixing speed of 60rpm was 78.3% and the minimum efficiency of biological conversion at a stirring period of 15 min/1h was 35%, approximately.

Furthermore, additional studies that include stirring periods, biological aspects of gas production and environmental conservation are also necessary to develop integrated and sustainable strategies for waste management.

Credit authorship contribution statement and declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research received no external funding.

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Journal of Sustainable Agricultural and Environmental Sciences ISSN-Print: 2735-4377
https://jsaes.journals.ekb.eg/ ISSN-Online: 2785-9878
JSAES, 2022,1(1): 136 - 150

تأثير زمن التقليب ووضعين للمخمرعلي إنتاج الغاز الحيوي من روث الماشية

مصباح مرجان عبدالعال[١]، محمد طه عبيد[٢]، محمد سعيد احمد غنيم[٣]، محمد رمضان درويش[٤]

[١] قسم الهندسة الزراعية - كلية الزراعة - جامعة طنطا – مصر.
[٢] معهد بحوث الهندسة الزراعية - مركز البحوث الزراعية – دقي – جيزة – مصر.

مجلة العلوم الزراعية والبيئية المستدامة

الملخص

التقليب الميكانيكي له تأثيرات على الوظائف البيولوجية والفسيولوجية للتحلل البيولوجي للجزيئات العضوية وغير العضوية خلال فترة التقليب في الهواضم صغيرة الحجم لإنتاج الغاز الحيوي اليومي والتراكمي. وتهدف دراستنا إلى تعظيم أنظمة الطاقة في مصر، من روث الماشية عن طريق الهضم اللأهوائي لمخلفات الطاقة، حيث يتم إلقاء كميات هائلة من روث الماشية على الأرض ومياه الصرف الصحي دون أي إدارة. ومن الضروري معالجة هذه المخلفات وإعادة تدويرها لتكون عنصرًا مفيدًا. أجريت الدراسة على سطح كلية الزراعة، جامعة طنطا خلال شهري يناير وفبراير من العام ٢٠٢١م. بإستخدام الطاقة الشمسية لتسخين الخليط في الظروف الميزوفيليك عند فترتين تقليب؛ ٥، ١٥ دقيقة\١ساعة ايقاف. وأظهرت النتائج تأثيرات كبيرة على إنتاج الغاز الحيوي، وسجل الهاضم الأفقي أعلى إنتاج تراكمي للغاز الحيوي من روث الماشية مع الماء؛ كان ٢٨،٠٩٥ لتر وكان الهاضم الرأسي ٢٣،٠٦٩ لتر في حين أن أفضل فترة تقليب لإنتاج الغاز الحيوي لكل من الأنظمة الأفقية والرأسية كانت ٥ دقائق \٦٠ لفة في الدقيقة ؛ كان ١٤،٤٥ لتر و ١٢،٨٥ لترا، على التوالي. كفاءة التحويل البيولوجي للمخلفات العضوية؛ كانت ٧٥،٥٪ ومتوسط نسبة الميثان في الغاز الحيوي ٥٥،٢ ٪ و ٤٨،٨ ٪ كل من الهاضم الأفقي والرأسي، على التوالي. وأظهرت الدراسة أهمية فترة التقليب على التوزيع المتجانس للخليط ودرجة حرارته بالإضافة إلى نشاط البكتيريا وإنتاج الغاز الحيوي.