

Manufacture a reactor for biogas production from food waste and cattle manure

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ABSTRACT

The current study aims to design and manufacture a simple biogas unit suitable for the small-scale holder in the remote areas of Egypt, to produce biogas from leftover food and kitchen waste; the hydraulic model of biogas system was selected as a simple model for biogas digester. The biogas unit was fabricated from simple material with a total capacity of 1m^3 . The results showed that the ambient temperature was ranged from $32\text{ }^{\circ}\text{C}$ to $39\text{ }^{\circ}\text{C}$, digester temperature was ranged from $30\text{ }^{\circ}\text{C}$ to $35\text{ }^{\circ}\text{C}$, pH was ranged from 7 to 7.3 and C:N ratio was ranged from 15~28:1, that indicates to these conditions were suitable for completing the fermentation process and biogas production. The total solid concentration (TSC) and fermentation time have an effect on biogas yield and CH_4 content, where the biogas yield was increased with the increasing of TSC. The highest biogas yield was obtained under TSC 14% in the week number 11th, and the biogas yield has limited increasing under the same TSC and different fermentation time. The fabricated unit was succeeded to produce economic biogas with CH_4 content 58% and 62% from leftover food and kitchen waste mixed with cow manures, respectively. The highest weekly biogas yield was 2.75 m^3 under TSC 14% with an average of 0.4 m^3 per days, it could be covering the biogas needs for 2 people, Thus, this unit could be recommended for farmers families in the remote areas as a simple biogas technology to produce biogas from their kitchen wastes.

Keywords: biogas technologies, leftover food and kitchen waste, animal manure, remote areas and small-scale holders.

INTRODUCTION

The energy crisis gets biogas one of the promising renewable energy resources in Egypt, especially in the remote areas, where the major challenge for the people in these areas how to find a cheaper and better resource of energy. Thus; the first thought about resource energy in these areas is to use biogas technology for energy production.

Biogas is a mixture of gases, comprising methane (CH_4), carbon dioxide (CO_2) as well as a small quantity of carbon monoxide (CO), oxygen (O_2), hydrogen sulfide (H_2S), nitrogen (N_2), Hydrogen (H_2) and hydrocarbons. Among them, CH_4 , CO, H_2 , and H_2S are combustible gases, O_2 is a combustion-supporting gas, and N_2 is an incombustible gas. Generally, the content of Methane (55–70%) and carbon dioxide (30–45%), other gases (contaminants) present are nitrogen (0–15%), oxygen (0–3%), and water (1–5%) (Olumide et al., 2017). Biogas is considered a clean fuel; upgraded biogas proves to be better than the untreated one. Upgrading includes various processes and one such important method is the reforming of biogas into Syngas (Vikram and

Bhale., 2014). Around the world, biogas technologies show an increased tendency in the last years. This is driven in Europe mainly by feed-in-tariffs, offered by different countries. This has led to an increase in biogas production plants in Europe at the end of 2014 by 18% increase compared to 2013. Germany leads the growth rate with 10786 plants, followed by Italy with 1491, UK 813, and France 733 (EBA, 2015), so biogas technologies are highly recommended for energy conversions from biomass. Food wastes are the least recovered materials in the municipal solid waste and is one of the most important materials to be reduced from landfills. Food that is disposed of in landfills decomposes to produce methane, a potent greenhouse gas that contributes to climate change. Both urban and rural remote area produces large amounts of food waste daily (Ananthakrishnan et al., 2013). Food waste is the organic material having the high calorific value and nutritive value to microbes that is why the efficiency of methane production can be increased by several orders of magnitude. It means higher efficiency and size of the reactor and the cost of biogas production is reduced. Also, in most cities and places, food waste is disposed of in the landfill or discarded, which causes public health hazards and diseases like malaria, cholera. Inadequate management of wastes like uncontrolled dumping bears several adverse consequences: It does not only lead to polluting surface and groundwater through leachate and further promotes the breeding of flies, mosquitoes, rats and other disease-bearing vectors. Also, it emits an unpleasant odor and methane which is a major greenhouse gas contributing to global warming (Thomas et al., 2009). The sustainability of conventional energy together with their pollutions to the earth made renewable energy as the prime need for the time being.

Municipal waste generation is increasing tremendously with the population and also the development of industrialization and urbanization. Municipal waste is being a nuisance to the earth by volatile organic compounds emission, leachate formation, attracting vectors (rodents, birds and insects) and also being jeopardy to the public health (Scaglia et al., 2009). Other waste management methods such as incineration and pyrolysis cause air pollution problems. Biogas is produced by bacteria through the biodegradation of organic material under anaerobic conditions. Natural generation of biogas is an important part of the biogeochemical carbon cycle. Singh and Sankarlal (2015), showed that biogas could be generated from kitchen waste and cow manure as by using anaerobic digesters (AD). A temperature range of 30-35 °C is maintained to facilitate the mesophilic conditions. The pH of the slurry is checked and maintained on weekly basis. The gas production is recorded with a retention time of 20 days. The methane content is measured by using the Syringe protocol. 0.05196 m³ of gas have been produced by the experiment. Usage of kitchen waste as the best alternative wastes for biogas production in a community level biogas plant has been recommended by (Ravi et al., 2013), where different ratios of kitchen waste with water and manure were compared in a metal made portable floating biogas plant. They have suggested in using aluminum made biogas digesters, as it increases the temperature inside the digester. High production of gas is found at ratio of 1:2 of waste and water. The biogas generated from food waste has been evaluated by (Ojikutu and Olumide, 2014) which consists of yam peels, plantain peels, orange rind and fish waste. They have conducted the experiments under mesophilic conditions of 30-37 °C and concluded that gas can be generated using the wastes, biogas fermentation microorganisms need lots of nutrition, and the major nutrition contents are C and N, which are mainly provided by fermentation material. C/N Ratio of raw materials exerts great influence on the growth of microorganism and the biogas yield. In the biogas fermentation process, the carbon-nitrogen ratio of raw materials for fermentation should be 10~30:1 when fermentation starts (Yin, 2016). There is another main product realized from the anaerobic fermentation process during

biogas production. It's the biogas-fertilizer or BIOSLURRY, also it called the brown gold, where farmers in the remote areas targeted by this research could use it for their agricultural activity. Bio-slurry is applied in several ways, for example, as crop or fruit fertilizer, fish pond feed or as basic material for compost making, as seen in the daily life of many smallholders who own a household biogas digester (Lennart and Bogdanski, 2013).

The purpose of this research is to conduct the production of biogas through anaerobic digestion & determine whether it is a green method or not. The current study aims to use kitchen wastes with cow manure to produce biogas for house use in the remote areas of Egypt, design and manufacture a simple digester suitable for small-scale holders in remote areas was done.

MATERIAL AND METHODS

The experimental part was carried out at biogas training center and agricultural waste Recycle - Moshtohor Research Station, during three months from June to September 2020 under the meteorological conditions in this area, the average temperature was recorded around 37°C. The following materials and methods have been used to conduct this research.

Biogas Unit

Leftover food kitchen waste and animal manure were fermented by biogas technologies to save the energy for local family living in remote areas. For this purpose, the hydraulic model of biogas system was selected as a simple model suitable for small-scale holders in remote areas. The working principles of the hydraulic model could be simply summed as follow, generated bio-gas presses upon fermentation solution (FS) at the time of gas generation, while the solution upon gas at the time of gas consumption. When a biogas digester produces biogas, the gas pressures the FS into hydraulic chamber, making liquid level higher in the overflow chamber. On the contrary, when biogas is consummate, FS get back into the digester from the fermentation chamber so the liquid level drops in overflow chamber. by this way, internal and external pressure is balanced. That's why we call it hydraulic biogas digester. Hydraulic digester has many advantages (Liu, 2016).

- Good performance, good adaptability for construction material;
- Simple structure, easy for construction;
- Low cost;
- Convenience for use and operation;
- Long service life: about 20-25 years.

The biogas unit was designed and fabricated from simple material, by using plastic tank for the fermentation chamber, about 4 m of plastic tube, another plastic tank for the over flow chamber, and other material (glue, silicon, valves) to collect the unit together, the biogas unit (biogas plant) capacity was 1m³. This biogas unit is very easy to installation by the framer, and it should be installed in open area under the sun to facilitate heat energy absorption from the sun as shown in Fig. (1).



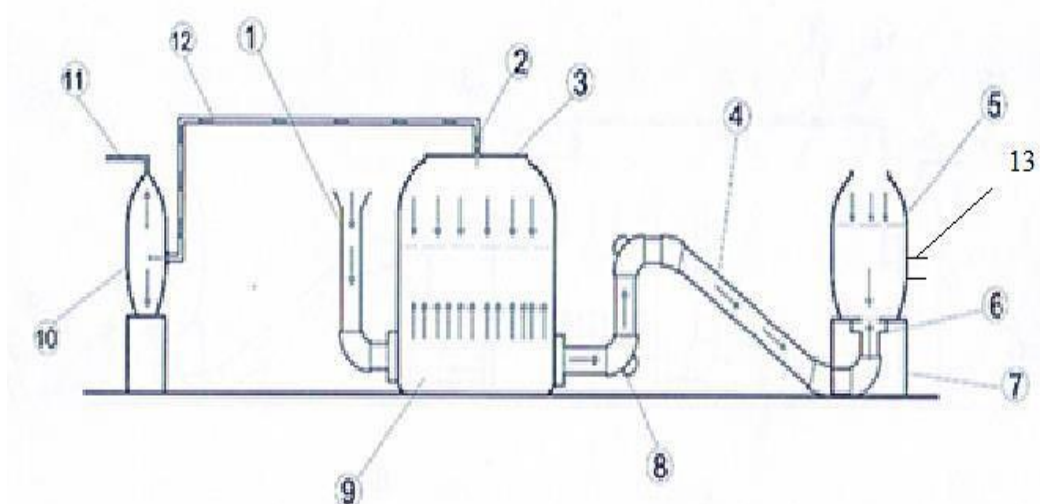
Fig (1): Photo of the biogas unit.

Raw Material

The main raw materials for this research were the animal manure collected from the caws in the place where the experiment was carried out, leftover food and kitchen waste from the farmers families and slurry coming from old digester in the area.

Experimental Procedure

The fermentation tank of the biogas unit was filling up to 200 litres by slurry, coming from old biogas unit located in the area where the experiments were carried out, and then 300 litres of freshwater was added. After that the feeding processes started by adding cow manure and food waste (100 kg of cow manure was collected from the nearby village and is mixed partly with warm water in a ratio of 2:1 and 60 kg of leftover food and kitchen wastes) concerning the quantity required for the digester. Leftover food and kitchen wastes were partly crushed and the particle sizes were determined to be ranging from 1-3 cm. The temperature data were collected daily from 9:00 to 5:00 PM and the PH measurement was recorded on weekly basis. The retention time of 15 days was taken to produce economical biogas yield. A set-up as shown in Fig. (2) was arranged to collect the biogas from the digester and take corresponding readings, after that the biogas generated was ready to use for house uses by the farmer family, and after that feeding process was carried out each 3days depending on the biogas yield required.



1	Raw materials inlet	2	Gas valve
3	Biogas internal chamber	4	Plastic tube
5	Overflow tank	6	Flexible plastic link
7	Bearer wall for the overflow tank	8	Discharge and drain hatch
9	The Digester (fermentation chamber)	10	Biogas tank
11	Gas outlet	12	Gas tube
13	Slurry outlet		

Fig. (2): Biogas unit outline

Total Solid Concentration (TSC):

The effect of total solid concentration on biogas yield and biogas quality was studied in this research, for this purpose 3 TSC were tested during the experimental duration (10, 12 and 14%), i) from the beginning of the experiment to 30 days the TSC were 10%, ii) after 30 days TSC was increased to 12% for other 30 days (until the day 60 from the beginning), iii) then TSC was increased to 14% for other 30 days (until the day 90 from the beginning). TSC was increased by increasing the concentration of feeding material.

Biogas Unit Evaluation:

To evaluate the biogas unit the fermentation conditions (Temperature, PH and C: N Ratio) were determined. Also, the produced biogas was evaluated quantitatively (weekly biogas supply) and qualitatively (CH₄ content).

Statistical Analysis:

The data were analyzed by using SPSS package Ver. 20. The correlation and regression were used for analyzing.

RESULTS AND DISCUSSION

The Temperature Profile for the Study Area and the Digester:

The temperatures of the study area (ambient temperature T_{amb}) were measured each day it was ranged from 32 °C to 39 °C and the average temperature were calculated each week, the relation between T_{amb} and the collected samples from the digester during the experiment duration ($T_{digester}$) was estimated as shown in Fig. (3).

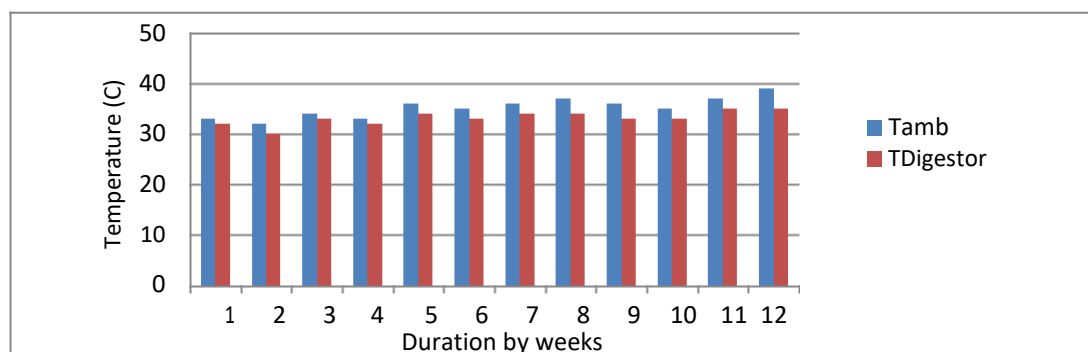


Fig. (3): The relation fermented period weekly between ambient temperate and digester temperature

From Fig. (3) the temperature of the samples collected from the digester (T_{digester}) are highly influenced by the ambient temperature (T_{amb}) and it was ranged from 30°C to 35°C , the relation between the two temperatures was positive relation. The temperature of the collected samples was suitable for that activity of microorganisms, especially the bacteria responsible for the processes of anaerobic fermentation that is lead to produce biogas in economic manner.

The pH Value for the Fermented Solution:

The pH value has an important role in the fermentations process, as it has a high effect on the microorganisms, especially the bacteria responsible for the processes of anaerobic fermentation, Therefore, the neutral medium pH must be preserved during the fermentation process to produce biogas. The pH value was measured over the course of the experiment during the 90's days and it was found that it ranged from 7.0 to 7.3 as shown in Fig. (4), this result indicates that the fermentation solution was suitable for completing the fermentation and biogas production processes.

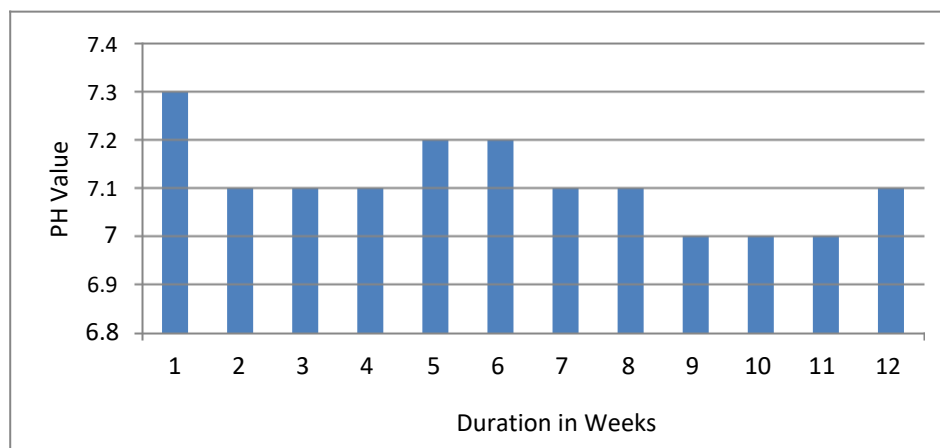


Fig. (4): PH value for the fermented solution.

C:N Ratio of Raw Materials:

In order to meet the nutrition demand of biogas fermentation for microorganism, diverse raw materials should be used for rural household biogas digesters. C:N ratio was measured and it was ranged from 15~28:1, that is agreed with (Yin, 2016). Where, the carbon-nitrogen ratio of raw materials for fermentation should be 10~30:1 when fermentation starts.

Total Biogas Production during the Experiment Duration (m³):

The total biogas produced during the experiment duration was measured; by the end of the day 90 the total biogas produced was 22.5 m^3 as shown in Fig. (5). this result was indicated that the total biogas produced during the experimental duration was economical.

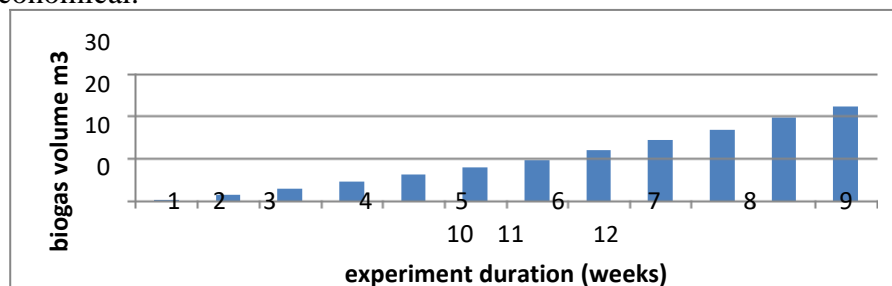


Fig. (5): Total biogas produced (m^3).

Weekly Biogas Supply (WBS), and the Effect of Total Solid Concentration (TSC) and Time on Biogas Supply:

To evaluate the biogas unit the biogas supply was measured each week, and the effect of total solid concentration on biogas yield and biogas quality was estimated. Results showed that the biogas yield was increased limited increasing under the same TSC treatment, but the increasing rate was high under different TSC treatment as shown in Fig. (6).

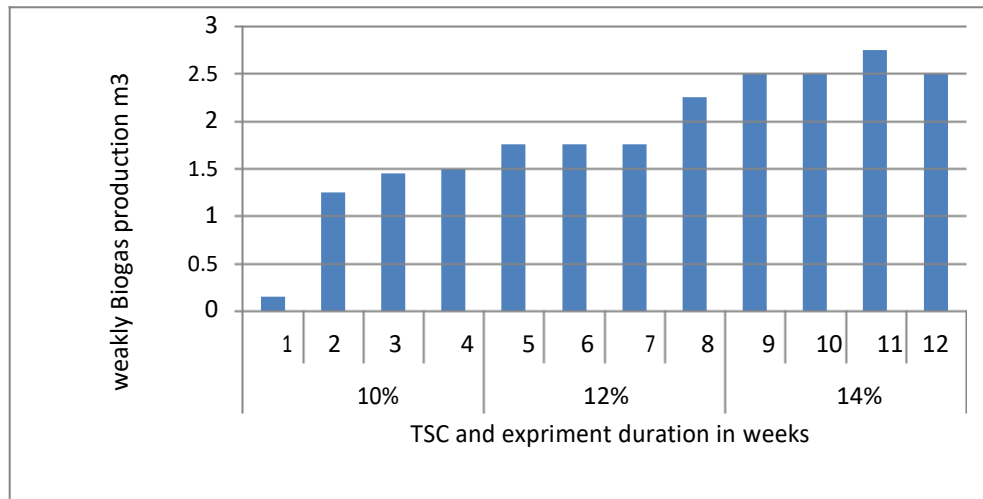


Fig. (6): The weekly biogas Supply.

The highest weekly biogas yield under TSC 10% was in the week number 4 producing 1.5 m³ per week. In the week number 5 the biogas yield was increased, and the increasing rate was higher than the previous weeks due to the TSC was increased to 12%, the total biogas yield under TSC 12% was stable during the weeks number 5, 6 and 7 where the highest biogas yield in under TSC 12% was obtained in the week number 8 producing 2.25 m³. In the week number 9 the TSC was increased to 14%, thus the biogas yield in this week was increased from 2.25 m³ to 2.5m³ that showed that the effect of TSC and fermentation time on biogas yield. The highest biogas yield ever in this experiment was determined in the week number 11 it was 2.75 m³ per week.

The daily biogas consumption standard according to the present living standard in rural areas is estimated at 0.2 m³ per capita and family has 3 to 6 people (Liu, 2016). The highest daily biogas supply from the current unit was about 0.4 m³, it could cover the biogas needs for 2 people.

The Relation Between WBS, C: N Ratio, and TSC.

To investigate the relations between these three factors and clarify the effect of these factor on each other under the conditions of this research, the correlation was calculated, and the results shows that the correlation for WBS and TSC, WBS and C:N ratio, and C:N ratio and TSC was 0.86, 0.912 and 0.93 respectively, this means there were highly positive correlation between the three elements that is lead to the increasing in one of these elements lead to increasing the other two elements and vice versa.

A step wise regression was made by using SPSS Statistics program to confirm the most factors effect on the correct cut percentage (CC) and remove the other factors. The results give the following equations as shown in Tables (1 and 2):

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	-2.379	.608		-3.914	.003			
	X2	.188	.027	.912	7.021	.000	.912	.912	.912

a. Dependent Variable: Y

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.912 ^a	.831	.814	.31274

a. Predictors: (Constant), X2

b. Dependent Variable: Y

$$CC = -2.379 + 0.188 X2 \dots\dots\dots (1)$$

$$R=0.91, R^2 =0.83, \text{adjusted } R^2=0.81, \text{ and S.E}=0.31.$$

Where;

X2= C:N Ratio,

R= Correlation,

R^2 = Coefficient of determination,

S.E= Standard error.

That is mean the most factor affect in weekly biogas supply was the C:N ratio, however this ratio plying the important role for microorganism's nutrition needs, where the major nutrition contents are C and N, which are mainly provided by fermentation material. C:N Ratio of raw materials exerts great influence on the growth of microorganism and the biogas yield.

Methane Content in Biogas Produced Samples:

Three biogas samples were tested from different TSC treatment (by mean one sample from each TSC treatment) and CH₄ was measured. Results in Fig (7) showed that the methane content was 58%, 62% and 62% under the TSC 10%, 12% and 14% respectively, which is showed that the TSC has limited effect on CH₄ content.

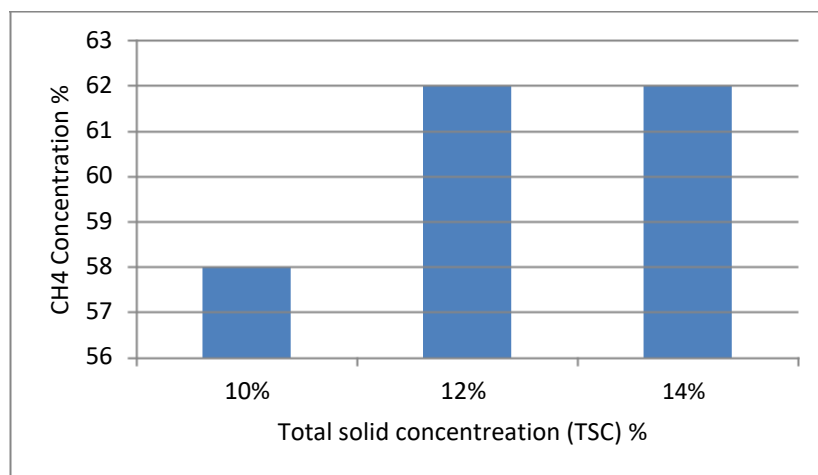


Fig. (7): Methane Content in Biogas Samples

CONCLUSION

The current study was succeeded to design and manufacture a simple biogas unit suitable for small farmers' families in the remote areas. The biogas unit was filling of by 200L of slurry; 300L of fresh water, after that the feeding processes was started by adding 100 kg of cow manure mixed partly with warm water in a ratio of 2:1, and 60 kg of leftover food and kitchen waste, three total solid concentration (TSC) 10, 12 and 14% were used and tested in this experiment.

Results showed that ambient temperature was ranged from 32 C to 39 C, digester temperature was ranged from 30 C to 35 C, pH was ranged from 7 to 7.3 and C:N ratio was ranged from 15~28:1, That's indicates to the fermentation conditions was suitable for completing the fermentation process and biogas production. The biogas unit was succeeded to produce economic biogas with CH₄ content 58% and 62% from food waste mixed with caw manures and the highest weekly biogas yield was 2.75 m³ under TSC 14% that could cover the biogas needs for 2 people.

Therefore, this unit could be recommended for farmers families in the remote areas as a simple biogas technology to produce biogas from there wastes.

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الملخص العربي

تصنيع مخمر إنتاج البيوجاز من مخلفات الغذاء وروث الماشية

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أجريت الدراسة الحالية في مركز تدريب البيوجاز وتدوير المخلفات الزراعية بمشتهر خلال شهر يونيو 2020 ولمدة ثلاثة أشهر في ظل ظروف الأرصاد الجوية في هذه المنطقة. حيث تم تسجيل متوسط درجة الحرارة حوالي 37 °م، وتهدف الدراسة إلى تصميم وتصنيع وحدة إنتاج الغاز الحيوي مناسبة ألسر صغار المزارعين في المناطق النائية، وتم اختيار نموذج المخمر الهيدروليكي. تم تصنيع وحدة الغاز الحيوي بنجاح بواسطة فريق البحث وتم تصنيعها من مواد بسيطة، باستخدام خزان بالستيكي لغرفة المخمر، وحوالي 4 أمتار من الأنبوب بالستيكي، وخزان بالستيكي آخر للتدفق الزائد، ومواد أخرى لتجميع الوحدة معًا، بلغت سعة وحدة الغاز الحيوي 1 م³. تم ملء وحدة الغاز الحيوي بحوالي 200 لتر من بادئ التخمر؛ 300 لتر من الماء. بعد ذلك تمت عمليات التغذية بإضافة 100 كجم من روث الماشية الممزوج جزئياً بالماء الدافئ بنسبة 1:2، وحوالي 60 كجم من مخلفات الطعام، تم استخدام ثالث تركيزات من المواد الصلبة الكلية (TSC) (10، 12، 14 % في هذه التجربة. أظهرت النتائج أن درجة الحرارة المحيطة تراوحت من 32 °م إلى 39 °م، وتراوحت درجة حرارة المخمر من 30 °م إلى 35 °م، وتراوحت قيمة PH من 7 إلى 7.3، وتراوحت نسبة C: N من 15 إلى 28:1، وهذا يشير إلى أن ظروف التخمر كانت مناسبة لإتمام عمليات التخمر وإنتاج الغاز الحيوي. أظهرت النتائج أيضاً أن تركيز المواد الصلبة الكلية (TSC) وزمن التخمر لهما تأثير واضح على إنتاج الغاز الحيوي ومحتوى CH₄، حيث تم زيادة إنتاج الغاز الحيوي مع زيادة المواد الصلبة الكلية. أوضحت النتائج أن أعلى إنتاج للغاز الحيوي كان عند استخدام تركيز للمواد الصلبة الكلية بنسبة 14 % في الأسبوع الحادى عشر. نجحت الوحدة المصممة في إنتاج غاز حيوي اقتصادي بمحتوى CH₄ بنسبة 58% و 62% من مخلفات الطعام الممزوجة بروث الماشية، وكان أعلى ناتج أسبوعي من الغاز الحيوي 2.75 م³ عند تركيز للمواد الصلبة الكلية 14 %، ويمكن أن يغطي احتياجات الغاز الحيوي لشخصين، وبالتالي، يمكن التوصية بهذه الوحدة ألسر المزارعين في المناطق النائية كتقنية غاز حيوي بسيطة لإنتاج الغاز الحيوي من المخلفات هناك. ويمكن تكبير هذه الوحدة لتغطية احتياجات الغاز الحيوي حسب عدد أفراد الأسرة.