EFFECT OF TOTAL SOLIDS CONTENT ON BIOGAS PRODUCTION IN A FAMILY SCALE BIOGAS DIGESTER

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ABSTRACT

Anaerobic digestion is a biological degradation process used to convert organic wastes from Animals and plants into biogas. Produce biogas from these wastes gives a new and clean energy and good organic fertilizer as a method to protect environment from pollution by wastes. In this paper, a continuous flow family scale biogas digester was designed and constructed in Abiss, Alexandria governorate at the year of 2011. The study was conducted to develop biogas digester for farmer family scale. It was designed with installed capacity of cattle dung from 5 to 6 heads or about 100.0 kg/dung/day. The digester was operated in mesophilic conditions of 22 to 27 °C temperature range at three levels of average total solid content (TS) 6 %, 10 % and 17 % under one month hydraulic retention time (HRT) for each treatment. The experiments were conducted to investigate the production of biogas (BP) rate from Cattle wastes by using anaerobic digestion process. The results indicated that, the biogas production rate was about 3 m^3/day at average total solids of 10 % with methane content (MC) of 77 % and it was about 1.85, and 2.33 m^3/day at average total solids of 6 % and 17 % with methane content of 58 and 71 % respectively. The digester showed stable performance with highest biogas production (3 m^3/day) and yield (0.43 Liter gas/Liter of volume/day) with volatile solids (VS) reduction of around 90% during loading rate (LR) of 21 kg VS/day.

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INTRODUCTION

In Egypt, biogas applications as an alternative energy source is still limited due several restrictions for construction such as too highly investment and manually handling; although the first digester was existed in 1939 in Elgabal El- Asfar farm to treat sewage sludge, hence it is not a new innovation, but limited number of biogas digesters has been established while most of them didn't run since long time.

Due to the increasing prices of fossil fuels and taxes on energy sources in most countries, finding alternative, clean and economical sources of energy has nowadays become a major concern for households' and nations' economies. In addition, economic prosperity and quality of life is a great determinant and indicator of economical development of energy demand and is a critical reason for extensive climate change, resource exploitation, and also restricts the living standards of humans **Li, G. et al. (2007)** and **(2009).** By the time fuel and fertilizer reaches rural areas, the end price is relatively expensive due to high transport costs, leaving people to find alternative resources other than oil, **(Parikh, J.K. and Parikh, K.S., 1977).** Although animal wastes contain energy, the primary motivation for biomass processing of animal wastes is mitigation of a disposal issue rather than generation of energy. This is especially true for animal manures **(Anonymous, 2003)**. In Egypt, with about 7.0 millions head of cattle and buffalos has more than adequate volumes of manure necessary for a biomass projects. These cattle collectively produce roughly 52,000,000 tons of raw manure (wet basis) per year; and this does not include significant populations of sheep, poultry, goats, sheep and other livestock **(Egypt Yearly statistic book, 2000).** The important advantages of using biogas digester system are reduce greenhouse gas effect, decrease unpleasant odor, prevent disease transmission, and produce heat, power (mechanic/electricity) and by-products such as solid and liquid fertilizers. Utilization of wastes as energy source will economically be competitive in line with increasing petroleum and inorganic fertilizer prices. Besides, this method is considered as environmentally-friendly and sustainable agricultural practices (**Marchaim 1992).**

Biogas, which is one of the byproducts of anaerobic digestion, comprises about 60% methane and 40% carbon dioxide. It has been used as a source of fuel in countries like India, China, Sweden, Bangladesh etc. for lighting and cooking purposes (**MOMOH et al., 2008**). In addition co-digestion of organic waste with sludge or cow dung has been mentioned in the works of **Anhuradha et al. (2007)** and **Godliving (2007)** with improvements in biogas production.

Average production rate of fresh cattle dung of a big animal head is about 18.875 kg/day. Biogas Production 1.0 m^3 is produced from 5.26 kg dry cattle dung which equivalent to 31.0 kg fresh cattle dung. The 1.0m^3 of Biogas equivalent to the following conventional energy sources: 0.40 kg Butane gas, or 0.60L Kerosene, or 0.79 L Natural gas, or 7.45 kg dung cakes, or 6.84 kg crop residues, or 7.90 kg water hyacinth, or 2 kwh electricity **El-shimi S. and S. Arafa (1995).**

In depth; study of technically, economically and new approaches for biogas digester development were highly required (**Widodo et. al., 2006**). One of the most important challenges that our world will face in the twenty-first century will be continuing to meet the ever increasing energy needs of its citizen. Along with the need to find a renewable long term energy source is the need to find a more environmental friendly one **(Budiyono, et al., 2010)**. The rate and efficiency of the anaerobic digestion process is controlled by the type of waste being digested, concentration, temperature, the pH and alkalinity, the Hydraulic Retention Time (HRT), the Solids Retention Time (SRT), the ratio of Food to Microorganisms, the rate of digester loading and the rate at which toxic end products of digestion are removed (**Burke, 2001**). **Ahmed, S. F et al. (1999)** investigated the digester performance and methane production using four reactors 75 liter capacity for each. They used some simple mathematical models to validate their results.

Amarely Santana and Pound (1980) studied the effect of 1, 3, 5, 8 % TS concentration on biogas production from cattle slurry. They found that there was a linear increase in the gas production between 1% and 8% total solids. It is suggested that under commercial conditions 8% TS may be nearer the optimum from economic and management points of view. **Hilkiah et al. (2008)** investigated various concentrations of the TS of municipal solid waste in an anaerobic continuously stirred tank reactor and corresponding a mounts of biogas produced, in order to determine conditions for optimum gas production. Their results show the amount of biogas produced as a power function of the % TS concentration, indicating that as the process continues, a time comes when any marginal increase in the %TS concentration would no longer contribute to the increasing volume of biogas produced.

Nusara et al. (2011) had studied the effect of the total solid content on biogas production from *Jatropha curcas* seed cake. Their results revealed that *Jatropha curcas* seed cake is a good source of biogas production when using appropriate solid content of seed cake for biogas production from a batch process should be a ratio in the range between 1:20 to 1:10 in order to promote rapid CH_4 production and to obtain high CH_4 yield. In the current work, a continuous flow family scale biogas digester was designed and investigated to examine the effect of TS on biogas production.

MATERIALS AND METHODS

Biogas digester is classified as continuous flow of floating drum based on the type of gas collector. It was constructed from cement, stone, brick, sand, and waterproof coating materials. The strength of the digester is highly depended on material quality. Construction steps of biogas digester consist of building foundation, setting walls, and coating the walls with a mixture of cement and waterproof materials.

Parameters of Design and Capacity of Biogas Digester

1- Design considerations of biomass processing unit:

(1) Estimation of basic energy needs of the rural family and kinds of their needs in terms of methane gas volume. **(2)** number of cattle which will produce cattle dung and urine quantity, as well as amount of required diluted water as filling materials; **(3)** hydraulic retention time; and **(4)** estimation of methane gas pressure produced to keep good biogas flow rate through biogas pipe line. The parameters which used in the biogas digester design were based on literatures study and research institutes, as well as the related institutions to obtain data and information related to technical problems in utilizing biogas energy from cattle manure. In addition to the parameters that were important in determination of biogas digester type and designing the biogas digester.

2- Design steps:

The digester capacity was estimated by using quotient (1), (2), (3) and (4) as following:

Biogas production rate = 0.3 m^3 biogas per $m^3$of digestion materials (**Sabry S., 1998**).

Average daily consumption for one person is = 0.4 m^3 biogas/day (**Sabry S., 1998**).

Average daily consumption of the family which consists of five persons is = 5 × 0.4 = 2 m^3/day

So the digester volume is = 2/0.3 = 6.67 ~ 7 m^3

And data on: (1) highest methane gas production capacity per kg volatile solid added; (2) concentration of volatile solid in materials; and (3) hydraulic retention time. Based on this estimation, biogas reactor design can be drawn as shown in **Figures 1 and 2**.

Fig. (1): A photo of the digester and gas holder

3- Performance testing

Performance test was done through several steps:

3-1. Digester filling:

Digester was filled with mixture of cattle dung and water depends on total solids desired. The filling was conducted until the digester was full and remained until gas produced was stable. The filling was then carried out every day. Some measuring tools were used in performance testing, such as water manometer to measure gas pressure, flow meter gas to measure gas quantity, pH meter to measure pH of mixture, and quick silver thermometer to measure temperature.

3-2. Laboratory analysis:

Laboratory analysis before starting every experiment consisted of: Cattle dung conditions including pH, moisture content, total solids,

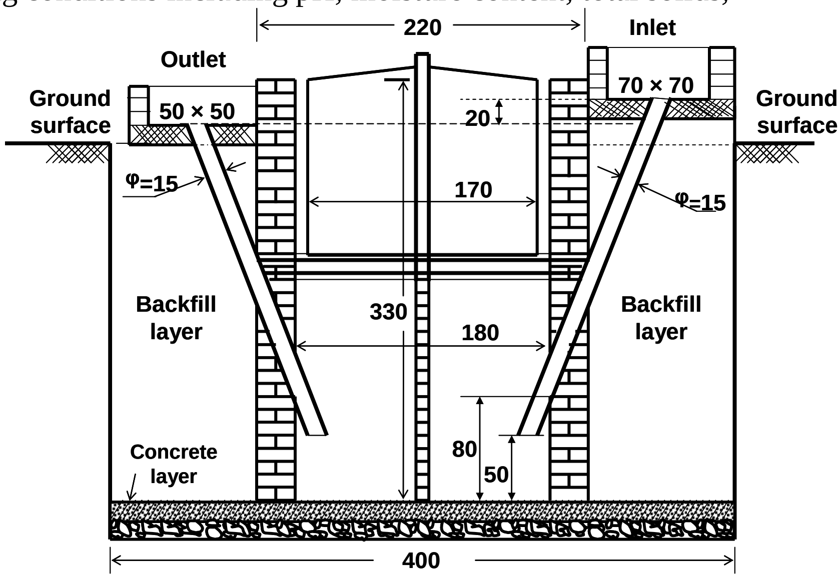

Fig. (2): Elevation of the family scale digester (Dimensions in cm.)

volatile solids, total carbon, total Nitrogen and C/N ratio. During working conditions and producing gas, the laboratory analysis consisted of: Chemical composition of biogas (CH_4 and CO_2**)** as shown in **Table 1.**

Table 1: The composition and characteristics of fresh Cattle manure

Parameter	First Experiment	Second Experiment	Third Experiment
pH	8.2	8.2	8
Moisture Content (MC %) w.b.	85	81	84
Average (TS %)	(4~8) =6	(8~12) =10	(14~20) =17
Volatile Solid (VS %)	81	87	91
Total Organic Carbon (TOC %)	43.3	48.33	50.55
Total Kjeldahl Nitrogen (TKN %)	1.68	1.91	1.83
C/N ratio	25.8:1	25.3:1	27.6:1
CH^4 (%)	58	77	71
CO^2 (%)	37	20	27

3-3.Wastes sources and characteristics:

The cattle manures used in this research were taken randomly from animal shelter (animal holding pen unit) located on Abiss 8/2 village located in Alexandria governorate.

The initial moisture content of the manure was determined in three replicates by drying of the samples in the oven at temperature 105 ˚C for 24 hours. The moisture content was determined according to **Eq.1** in terms of wet basis (**Anonymous 1998**).

$$MC\,(w.b.)\% = \frac{m_w}{m_w + m_d} \times 100 \qquad (1)$$

Where:

MC ($w.b.$) % = Moisture content of fresh manure (%), m_w = mass of water in the manure (g)

m_d = mass of dry matter in the manure (g)

To achieve the desired moisture content for preparing the required total solid, an amount of water was added to the manure based on the following equation (**Anonymous 1998**):

$$m_{wa} = m_m \frac{\left(TS_f - TS_S\right)}{TS_S} \qquad (2)$$

Where:

TS_f = initial total solid content of fresh manure (%, w.b.), TS_s = desired total solid content of substrate manure (%, w.b.), m_m = initial mass of manure (kg), m_{wa} = the mass of water added to manure (kg).

4- Family scale digester

Family scale digester was established at Abiss village 8/2, Alexandria governorate. It consists of two main parts, the body of the digester which is cylindrical in shape and has internal diameter of 1.80m and a depth of 3.3 m and it has an inlet tank and outlet port. The second part is a gas holder which has a diameter of 1.70 m and a depth of 1.5 m to collect the produced gas until use.

Methods to determine physical and chemical properties of the feedstock

Total solids (TS) and volatile solids (VS)

The total solid (TS) was estimated using the oven at 105°C for 24 h and the volatile solids (VS) was estimated using the furnace at 650°C for 3 h, respectively.

C/ N ratio

The Nitrogen content was obtained in laboratory using kjeldahl method while, carbon content of the feedstock is measured by considering the volatile solids content that was expressed as a percentage and the total carbon content were obtained from volatile solids data using an empirical equation as reported by **Badger et al. (1979)**:

$$Carbon\,\% = VS\,(\%)/1.8 \qquad (3)$$

Hence, the carbon to nitrogen ratio for each treatment is calculated by dividing the carbon percentage with nitrogen percentage.

Continuous digester

The experimental work was carried out through 2 years from May 2012 to June 2013. The first experiment (10 % TS) was started on May 2012. The second experiment (6 % TS) was started on July 2012, while the third experiment (17 % TS) was started on May 2013.

Measuring quantity and quality of biogas

The gas production was daily measured by flow meter gas whereas the quality, which is the percentage of methane from the biogas, was estimated by the displacement of sodium hydroxide, with a process held one next to the other. A mount of gas volume produced in the digester was captured in a bottle filled with water, which was kept under pressure. The gas coming out of the digester is stored in the displaced bottle.

Adding back the displaced water to the displacement bottle would push out the biogas stored before; and passing it through 5 % Sodium hydroxide (NaOH) solution. The Carbon dioxide (CO_2) from the biogas would be retained in the solution whereas the methane would displace its equivalent volume of NaOH. Collecting the displaced solution and measuring its volume using a measuring cylinder would give the volume of methane from the produced biogas (**Veeken and Hamelers, 1999**). Hence, it would be possible to estimate the percentage of methane in the biogas, using the following simple equation.

$$CH_4\,\% = \frac{Displaced\ NaOH}{Displaced\ Water} \times 100 \qquad (4)$$

RESULTS AND DISCUSSION

BIOGAS PRODUCTION

The digester was operated in mesophilic conditions where the temperature of the mixture inside the digester ranged between 22 and 27 °C. The average pH values of the mixture inside the digester during the experiments were within the range of 7–8 as shown in **Fig. 3**. The pH was slightly decreased during the experiments due to the daily feeding of fresh manure. The average values of pH agreed with **El-Mashad et al. (2004)** where reported that, the optimum pH for methanogenic bacteria is in the neutral to slightly basic range.

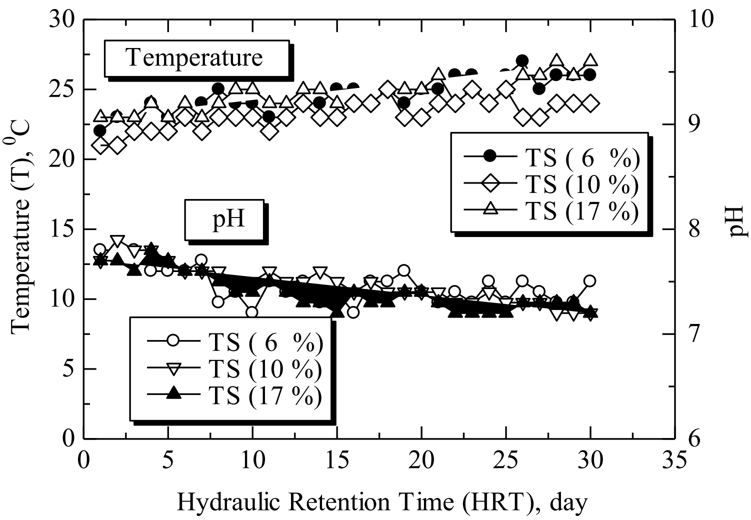

Fig. (3): Temperature and pH of the mixture with hydraulic retention time

Fig. 4. shows the biogas production rate at three levels of total solids during 30 days hydraulic retention time. The total biogas production from each treatment was measured daily using flow meter gas until the period of digestion. The average gas production is located between 1.7 and 3.2 m^3/day as shown in **Fig. 4.** There are relatively high volume of total biogas production was recorded in the total solids (TS) of 10 % of cattle manure (0.43 L/L/day) compared with 6 % (0.2631 L/L/day) and 17 % (0.333 L/L/day) of total solids in average as shown in **Fig. 5**. The increase in gas production with TS concentration is in agreement with previous work by **Hobson et al. (1977).** While the decrease in gas production with TS more than 10 % due to the possibility of scum formation and buildup of toxic chemicals such as ammonia, volatile fatty

acids, heavy metals and microbial by-products are more likely as concentrations increase, particularly for unmixed systems (**Albertson 1961; Levi 1951; McCarty 1964; Mosey et al., 1971**).

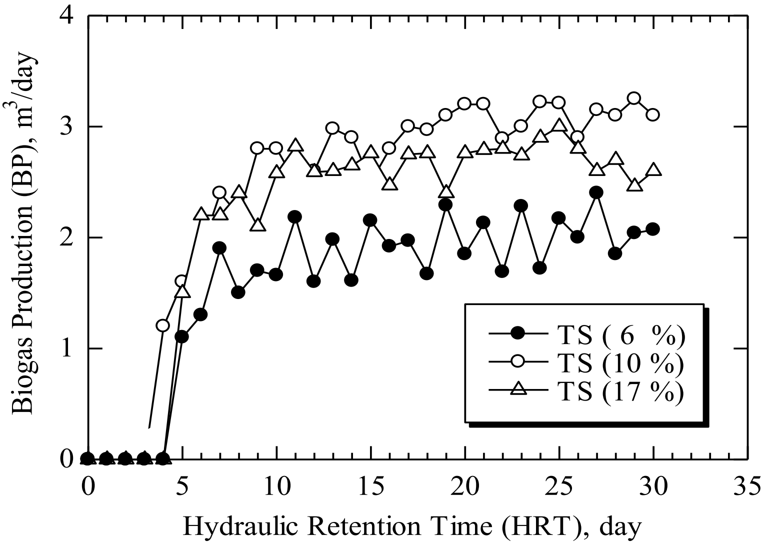

Fig. (4): Biogas production rate at three levels of TS during 30 days HRT.

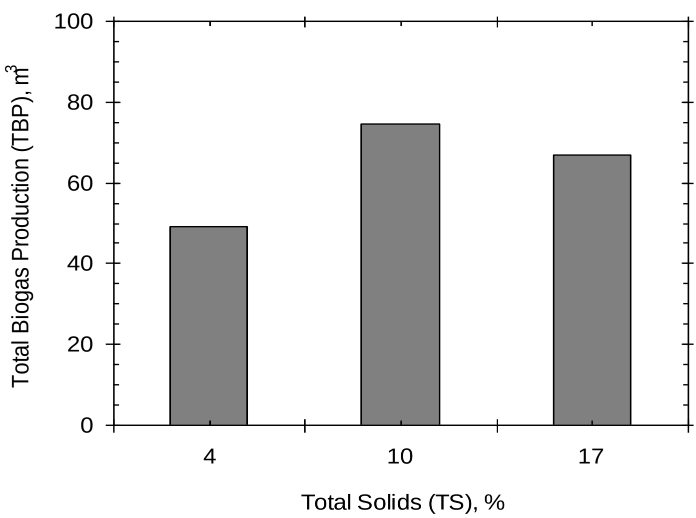

Fig. (5): The relationship between total biogas production and TS concentration after 30 days.

The volume of biogas production generated during the digestion period is shown in **Fig. 6**. The graph also shows that, the average total solid content of 10 %, produced more gas than other total solids.

The relationship between total solids content and hydraulic retention time for each treatment are shown in **Fig. 7.** The samples were taken and analyzed every 5 days. The graph showed a linear decreasing in the rate of total solid during the period of digestion. The decreasing rate of the total solids approximately similar in all treatments and ranged between 2~3 % during the retention time.

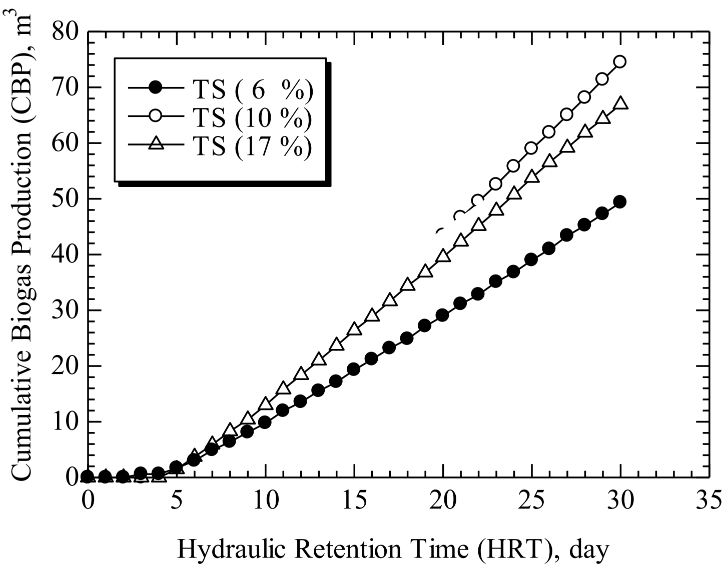

Fig. (6): Cumulative biogas production during 30 days hydraulic retention time.

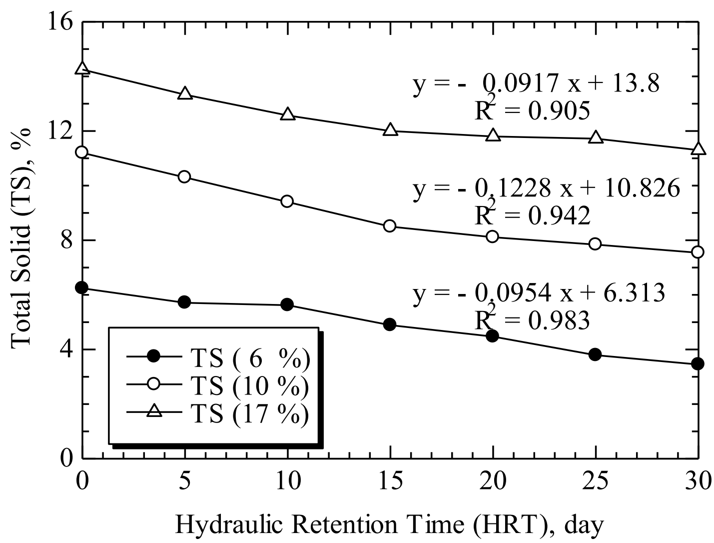

Fig. (7): Total solids during 30 days hydraulic retention time

CONCLUSIONS

In the current work, a continuous flow family scale biogas digester of floating drum was designed and constructed in Abiss 8/2 Village, Alexandria governorate. The experiments were conducted to investigate and develop the production of biogas from Cattle wastes by using anaerobic digestion process. It was designed with installed capacity of cattle manure from 5 to 6 heads or about 100.0 kg/day. The digester is operated at 3 levels of average TS: (6 %), (10 %) and (17 %) respectively under one month retention time for each treatment. It is found that, the biogas production rate is rather slow at the beginning of observation and increases gradually during the first week. The digester operates at mesophilic conditions of 22 to 27 °C temperature range and produced greater production of gas up to 3.0 m^3/day at average TS of 10% and it was about 1.85, and 2.33 m^3/day at average TS of 6% and 17% respectively. The biogas yield was 0.43 L/L/day (77 % methane) at average TS content of 10%, 0.264 L/L/day (58 % Methane) at average TS content of 6% and 0.333 L/L/day (71 % Methane) at average TS content of 17%. The digester showed stable performance with highest methane 77% and biogas yield (0.43 L/L/day) with VS reduction of around 90% during loading rate of 23.9 kg VS/.d. pH, TS and VS were measured and analyzed during the work. The pH started with the value of 7.8 and slightly decreased during digestion and the minimum measured vale found was 7. The degradation rate of the total solids approximately similar in all treatments and ranged between 2~3 % during the retention time.

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الملخص العربى

تأثير محتوى المواد الصلبة للمخلفات على انتاج البيوجاز فى مخمر عائلى

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فى هذا البحث تم تصميم وإنشاء مخمر مستمر من النوع الهندى العائلى ذو الخزان العائم سعة ٧ متر^{٣} بقرية أبيس ٢/٨ بمحافظة الاسكندرية. ولقد صمم هذا المخمر ليعمل على المخلفات الناتجة من عدد ٥ الى ٦ رؤوس من الحيوانات والتى تعطى مايقرب من ١٠٠ كجم يوميا. وقد تم تشغيل المخمر على ثلاث تركيزات من محتوى المادة الصلبة هى ٦ % و ١٠ % و ١٧ % ولكل منها تم التشغيل وتجميع الغاز لمدة ٣٠ يوم. وقد لوحظ أن:

- تشغيل المخمر عند تركيز ١٠ % مادة صلبة كان الأفضل على الاطلاق حيث كان متوسط انتاج البيوجاز حوالى ٣ متر^{٣} /يوم (٠,٤٣ لتر/لتر/ يوم) بينما كان متوسط الانتاج حوالى ١,٨٥ متر^{٣} /يوم (٠,٢٦٤ لتر/لتر/ يوم) فى حالة استخدام تركيز بمتوسط ٦ % وكان متوسط الانتاج ٢,٣٣ متر^{٣} /يوم (٠,٣٣٣ لتر/لتر/ يوم) فى حالة استخدام تركيز بمتوسط ١٧ %.
- تراوحت نسبة غاز الميثان المنوسطة بين ٧٧ % فى حالة استخدام تركيز ١٠ % بينما كانت النسبة ٥٨ % فى حالة استخدام تركيز ٦ % و بينما كانت النسبة ٧١ % فى حالة استخدام تركيز ١٧ %.
- المخمر شهد ثبات فى الأداء عند استخدام تركيز ١٠% من محتوى المادة الصلبة بنسبة غاز ميثان ٧٧% و محصول بيوجاز ٠,٤٣ لتر/لتر/ يوم وذلك باستخدام معدل تحميل يومى حوالى ٢٣,٩ كجم مادة صلبة متطايرة /يوم.
- تم قياس وتحليل بعض القياسات الهامة التى تعبر عن أداء وعمل المخمر مثل رقم الحموضة ومحتوى المادة الصلبة والمادة المتطايرة وتراوح معدل الانخفاض فى المادة الصلبة بين ٢ الى ٣ % على مدى فترة المكوث.
- رقم الحموضة للمخلفات داخل المخمر كان بين ٧ و ٨ وهى نسبة متعادلة تميل الى القاعدية قليلا ويرجع ثباته فى هذا المدى للتحميل اليومى بكمية محددة من المخلفات الطازجة المخففة بالماء.

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