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STUDY ON BIOGAS UNIT USING DAIRY CATTLE DUNG DURING WINTER IN EGYPT

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ABSTRACT

Anaerobic digestion (AD) become a crucial method for obtaining a green energy that represented in biogas from organic wastes particularly the animal wastes in rural areas instead of its incineration. This study aims to investigate the biogas yield of a constructed Indian type biogas unit with an approximately volume of 3m^3 at Faculty of Agriculture, Zagazig University, Sharkia Governorate, Egypt for biogas generation from dairy cattle dung under cold climate conditions during winter season of 2015. The results revealed that, the dairy cattle dung proved a suitable substrate for the installed biogas digester and produced an average 105L biogas per day for one cubic meter of dairy cattle slurry (8% of TS) without any feedstock for 30 days in winter season in Egypt under psychrophilic conditions of 16.3 to 20.5^{o}C temperature range. Therefore, the environmental affordability of the biogas technology, as a zero-waste engineering and unsound waste management system warrants further study in Egypt.

Key words: Anaerobic digestion (AD), biogas unit, psychrophilic conditions, cattle dung, organic wastes, winter season.

INTRODUCTION

Energy plays an important role and considered as the corner stone for pushing the development wheel into civilization in any country. The renewable energy resources are very vital to reduce the dependence on the depleted fossil fuel and conserve the environment from pollution. Biomass constitutes a major energy resource for the rural population of Egypt, which includes the agricultural residues and dry animal dung cakes that are directly burnt in primitive stoves and ovens to provide thermal energy to households for purposes of cooking, baking, and water and space heating. This causes many health problems and indoors local environmental pollution during its collection, transportation and burning processes. Biogas energy is obtained by anaerobic digestion (AD) of biodegradable materials like agricultural wastes due to the activities of methanogenic bacteria. It is an environmental solution instead of burning these wastes. AD is one of the common technologies to convert these wastes to combustible gas. The gas is produced from multi-phase process namely, hydrolysis, acid-forming and methane-forming phases. It is a biological engineering process in which a complex set of environmentally sensitive micro-organisms are involved.

Zieminski and Frac (2012) mentioned the benefits of biogas production technology through anaerobic digestion as it offers an alternative fuel, heat and electricity, waste management system, good fertilizer, complete recycling of wastes, greenhouse gas reduction and environmental protection from pollutants.

Cheng (2009) mentioned that, the use of biogas has attracted attention worldwide as it offers several environmental advantages compared to fossil fuels. He mentioned that, biogas consists of mixture of 50-80% of CH_4, 20-40% CO_2, N_2, and trace elements. Also, he reported that, 1 m^3 of methane can generate heat of about 8570 kcal and mentioned that, the energy from biogas needs a

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year to be reproduced, while fossil fuel needs millions of years to be renewed .

El-Shimi and Arafa (1995) reported that, the average production rate of fresh cattle dung of a big animal head is about 18.875 kg/day. Production $1m^3$ of biogas produced from 5.26 kg dry cattle dung which equivalent to 31kg fresh cattle dung. The $1m^3$ of biogas equivalent to conventional energy sources of : 0.4kg Butane gas; or 0.6liter Kerosene; or 0.79 liter Natural gas; or 7.45 kg dry dung cakes; or 6.84 kg crop residues; or 7.9kg water hyacinth; or 2 kW.hr electricity.

AD can take place at three temperature ranges: The psychrophilic temperature range lies between 10^oC and 20^oC, the mesophilic temperature range between 20^oC and 40^oC, and the thermophilic temperature range between 45^oC and 60^oC (Cheng, 2009; and Bouallagui *et al.,* 2005).

Rashwan *et al.* (2013) investigated the biogas production from cattle dung with loading rate of 21kg volatile solids (VS) per day under mesophilic operating conditions of 22 to 27 ^oC temperature range for one month. The study was conducted for farmer family scale biogas digester with $7m^3$ of volume. The results revealed that, the biogas production rate was about of $1.85m^3$ per day at average 6% of total solids concentration. Thus, temperature is the most important factor affecting biogas production and subsequently the low temperatures in cold winter season will reduce the biogas yield.

However, the main activities in biogas technologies started since 1978 in Egypt, so the implementation still quite limited. The most commonly types of the household biogas plants are of the Indian type with a floating gas storage drum and the Chinese fixed dome type. The main advantages of the floating drum biogas plant are: no problem of gas leakage; higher gas production; scum problem is less; pressure is naturally equalized; and no danger of mixing between biogas and external air, Hence no danger of explosion (Saeed and Sharma 2012). Therefore, the main objective of this study is to investigate the daily biogas yield from dairy cattle dung of a constructed Indian type biogas unit under cold climate of winter season in Egypt; for promoting the sustainable energy development of the rural communities in Egypt.

MATERIALS AND METHODS

The experimental study was conducted in December 2015 at Faculty of Agriculture, Zagazig University, Sharkia Governorate, Egypt.

Fresh Dairy Cattle Dung and Characteristics

Fresh dairy cattle dung was collected from animal farm in Abu-Kabir, Sharkia Governorate. The fresh wastes were taken directly after excretion from animals and analyzed for chemical and physical compositions such as total solids, volatile solids, organic carbon, and total nitrogen. The initial moisture content of manure was determined in three replicates by drying the samples in an oven furnace at temperature of 105^oC for 24 hours.

The slurry was obtained by adding tap water to fresh dung and homogenized by feeding mixer to achieve the desired moisture content for preparing the required total solids (8%) using the following formula (Anonymous*,* 1998):

$$m_{wa} = m_m \frac{(TS_f - TS_s)}{TS_s}$$

Where:

m_m : initial mass of manure, kg.

m_{wa} : the mass of water added to manure, kg.

TS_f: initial total solids content of fresh dung (%).

TS_s: desired total solids content of substrate slurry (8%).

The biogas unit

An approximately $3m^3$ constructed biogas unit (Indian type) including: digestion chamber; gas holder; feeding chamber; and outlet chamber as seen in Fig. 1 was operated to investigate its performance for daily biogas production in cold winter under psychrophilic conditions (lower than 20^oC). The body of digester was cylindrical in shape and it has an inlet and outlet ports. The gas holder is to collect the produced gas until use.

Digestion chamber was filled with mixture of cattle dung and water depends on total solids desired by feeding chamber provided with a hand mixer. The filling was conducted until the digester was full and the gas holder put down until was floated up digestion chamber. The unit was tested for 30 days without any feeding after filling in start-up. The agitation was performed 4 times/day for 5 minutes/time. Some measuring instruments were used in performance testing, such as gas flow meter to measure daily produced gas quantity with resolution of 1 liter, pH meter to measure pH degree with resolution of 0.01, K-type calibrated thermocouple sensors to measure temperature inside the digester and ambient temperature using digital thermometer with resolution of 0.1°C.

Laboratory and Analytical Methods

The samples taken were analyzed for total solids (TS), volatile solids (VS), and C/N ratio in the Land Sciences and Animal Production Laboratories at Faculty of Agriculture, Zagazig University.

TS was estimated using an oven furnace at 105°C for 24 hr. In addition, VS was estimated using a muffle furnace at 650°C for 3 hours. Total nitrogen was obtained using Kjeldahl method while, total organic carbon of feedstock is measured by considering the VS that was expressed as a percentage using an empirical equation as reported by (Badger *et al.,* 1979):

$$\text{Carbon}(\%) = \text{VS}\%/1.8$$

Hence, the carbon to nitrogen ratio for samples was calculated by dividing the carbon percentage with nitrogen percentage.

RESULTS AND DISCUSSION

The discussion will cover the obtained results under the following topics:

Fresh Dung and Slurry Characteristics

The obtained results of physical and chemical characteristics of cattle dung and digested slurry are illustrated in Table 1.

The anaerobic digestion process and biogas production in the digester depend on both process configuration and waste characteristics. Nutrients and C:N ratio are crucial parameters to ensure a stable digestion process and fertilizer quality (Crolla *et al.,* 2013). The cattle dung had a high total solids (TS) content compared with digested slurry. Compared to analytical results of cattle dung and anaerobic slurry, the C:N ratios were 25.3 and 23.7, respectively. The volatile solids (VS) were 13.9 and 6.12, respectively, indicating a stable anaerobic digestion process with no potential for acidification. The pH values were 7.5 and 7.4, respectively, before beginning the experiment. Then, during the start-up operation to the end, it was recorded lower pH and arrived to a stable pH of 6.78. These results indicated sufficient nutrients for the anaerobic process.

Ambient and AD temperatures

Fig. 2 shows the variation of average ambient temperature in the experimental site and temperature inside the biogas digester for 30 days (the study period). The ambient temperature ranged from 13.5°C to 19.7°C with an average temperature of 17.3°C while, the slurry temperature inside the biogas digester ranged from 16.3°C to 20.5°C with an average temperature of 17.9°C. A little difference was observed in temperature values inside and outside the biogas digester. Generally, temperature inside the digester was found 0.8-2.8°C more which is nearly equal in day. This means that, the underground biogas digester can be more stable and needn't to insulate for maintaining temperature stable.

pH values of cattle slurry during AD

Fig. 3 illustrate that, the pattern of pH was typical of a digester operating under stable condition; where the optimum pH for methanogenic bacteria is in the neutral to slightly basic range. So, the average values of pH for operating period ranged between 6.78 to 7.41 which are agreed with (Cheng, 2009). A decrease in the pH value was observed in the first few days of the digestion and this is due to high volatile fatty acid (VFA) formation and this confirm and agree with (Rao *et al.,* 2000). Then, the pH stabled to its normal operating value after VFA metabolism.

Daily and cumulative biogas yield

The daily and cumulative biogas production during the study period is shown in Fig. 4. It was observed that biogas production was actually slow at starting and the end of observation. During the first week of observation, there was less biogas both daily or cumulative production and this mainly due to the lag phase of microbial growth. Whereas, in the range of 7 to 17 days of observation; biogas

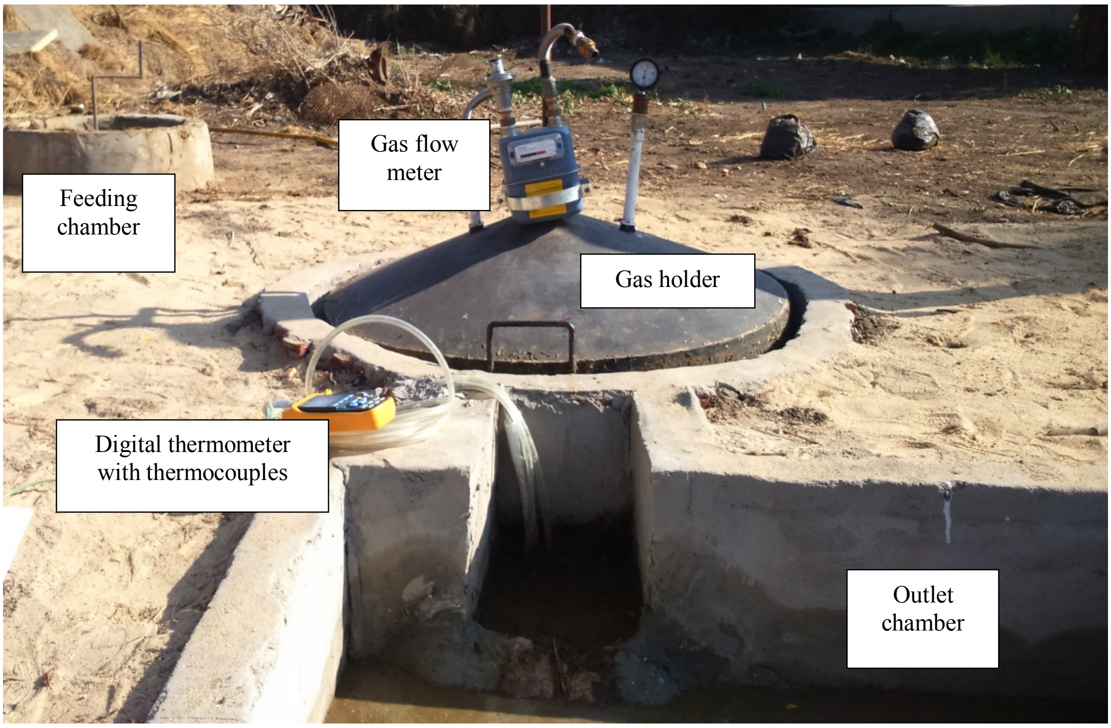

Fig.1. A view of the investigated biogas unit

Table 1. The chemical composition of fresh cattle dung and slurry

Parameter	Fresh dung	Slurry
Moisture content (%) (MC)	81.8	91.9
Total solids (%) (TS)	18.2	8.1
Volatile solids (%) (VS)	13.9	6.12
VS (%) (from TS)	76.42	75.6
Ash (%)	4.3	1.98
Ash (%) (from TS)	23.6	24.4
Total organic carbon (%) (C)	44.33	43.85
Total Nitrogen (%) (N)	1.75	1.85
Carbon/Nitrogen (C/N ratio)	25.3:1	23.7:1
pH value	7.5	7.4

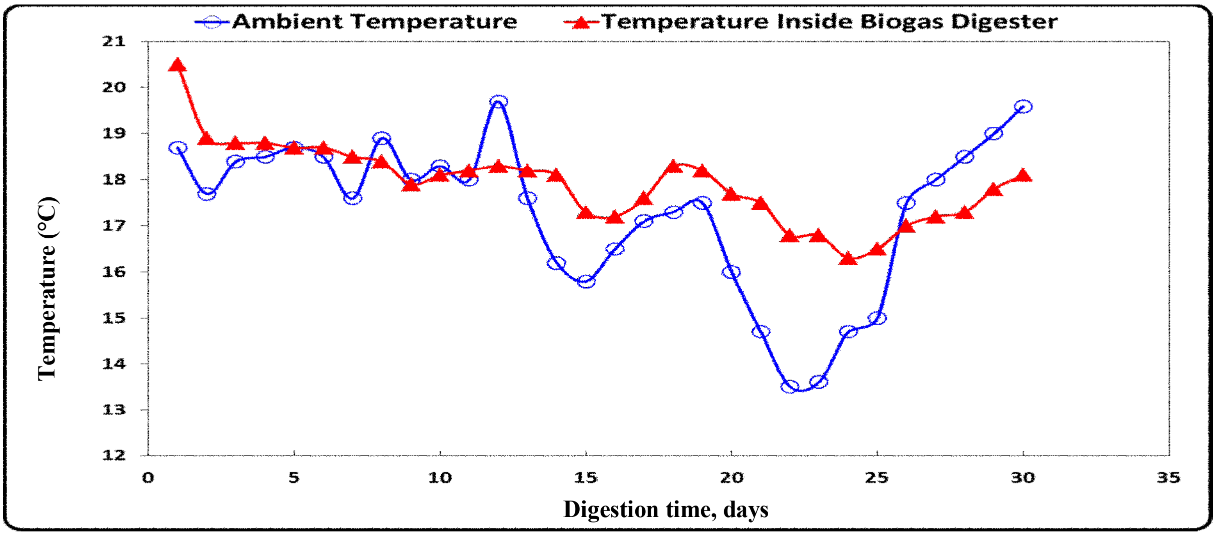

Fig. 2. Daily temperature variations of ambient and biogas digester

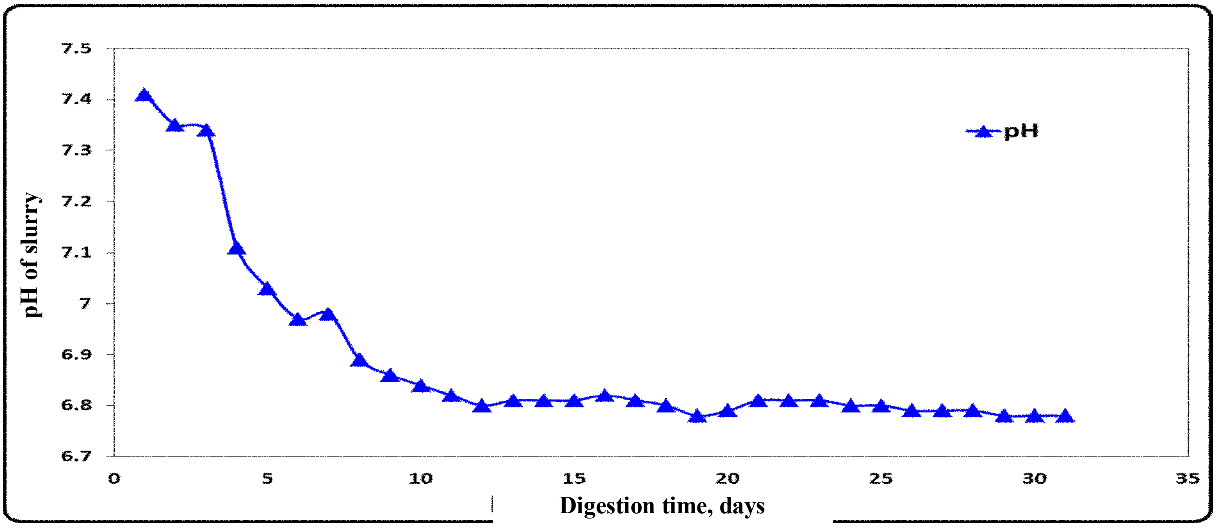

Fig. 3. pH profile during AD of cattle slurry

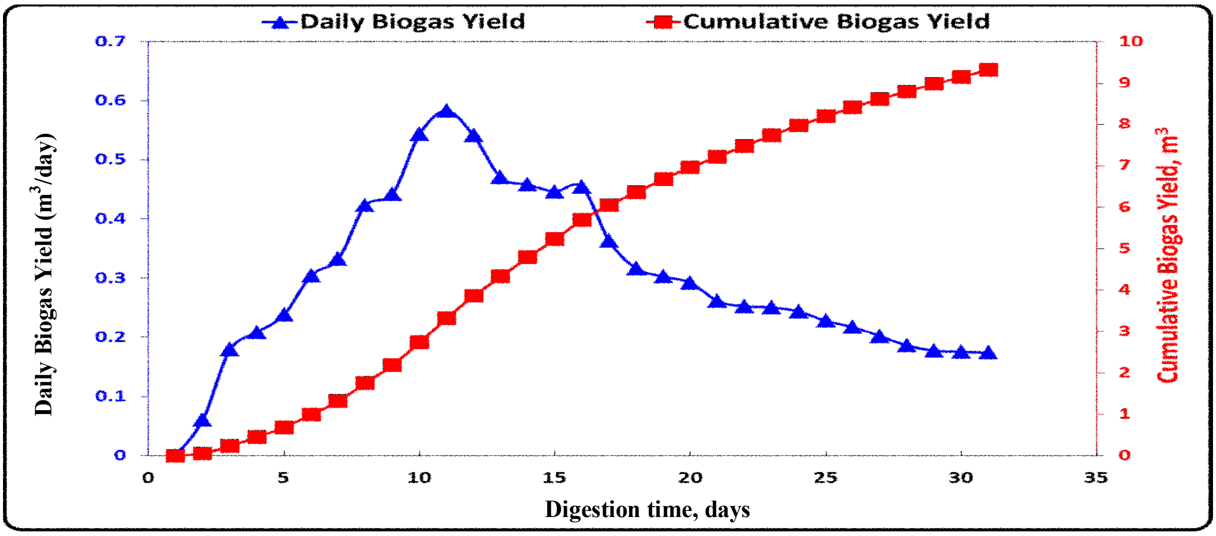

Fig. 4. Daily and cumulative biogas yield

production increases substantially due to exponential growth of methanogens. Highest biogas daily production rate of 0.6m^3 was measured on day 11. After the second week the yield was deceased until 0.17 m^3 to the end of the experimental period. The average daily yield of produced gas was about 0.34 m^3. The cumulative yield was 9.4 m^3 after one month. It is clear that cattle dung is an effective feedstock for anaerobic digestion and could significantly enhance the cumulative biogas production. Also, it could be produce biogas under cold climates in Egypt with an average yield of 105 L per day for one cubic meter of dairy cattle slurry (8% of TS) without any feedstock for one month.

Conclusion

The results showed that, the dairy cattle dung might be one of feedstock for efficient biogas production and waste treatment. It proved a suitable substrate for the installed biogas digester and produced on average 105 L biogas per day for one cubic meter of dairy cattle slurry (8% of TS) without any feedstock for 30days in winter season in Egypt under psychrophilic conditions of 16.3 to 20.5^{o}C temperature range.

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دراسة على وحدة لإنتاج الغاز الحيوي بإستخدام روث ماشية اللبن خلال فصل الشتاء فى مصر

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أصبحت تقنية الهضم اللاهوائي وسيلة حاسمة للحصول على الطاقة الخضراء التي تتمثل في انتاج الغاز الحيوي من المخلفات العضوية وخاصة المخلفات الحيوانية المتراكمة في المناطق الريفية بدلاً من حرقها، لذا تم تجريب وتشغيل وحدة البيوجاز- طراز هندي عائلي - سعة حوالي ٣ متر مكعب، والمنشأة بكلية الزراعة ، جامعة الزقازيق ، بمحافظة الشرقية ؛ بغرض دراسة إمكانية إنتاج الغاز الحيوي من روث ماشية اللبن ، وذلك فى ظروف الأجواء الباردة خلال شتاء عام ٢٠١٥، ولقد أثبتت النتائج المتحصل عليها : أن هذا الروث يناسب جداً إنتاج متوسط يومي ١٠٥ لتر من الغاز لكل متر مكعب واحد من الروث الطازج المخفف لتركيز ٨% من محتوى المواد الصلبة الكلية، لمدة ٣٠ يوم (بدون أى تحميل يومي إضافي من الروث في هذه الفترة) تحت الظروف السيكروفيلية لنشاط بكتيريا الميثان في مدى درجات حرارة تخمر منخفضة (من ١٦,٣ إلى ٢٠,٥ مْ)، ونظراً لمميزات تقنية البيوجاز البيئية توصي الدراسة بضرورة زيادة الوعى نحو هذه التقنية وإنتشارها فى مصر لحسن إدارة المخلفات الزراعية والإستفادة منها.

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