Misr J. Ag. Eng., 26(1): 534- 560

EVALUATION AND SCRUBBING OF BIOGAS GENERATION FROM AGRICULTURAL WASTES AND WATER HYACINTH

Eltawil M. A.[1], E.B. A. Belal[2]

ABSTRACT

This study aimed to characterize anaerobic batch biodegradation of five co-digested mixtures in terms of methane yield and energy production as follows: Mixture 1 (potato waste + sugar beet leaves), mixture 2 (cattle dung), mixture 3 (water hyacinth + cattle dung), mixture 4 (rice straw + cattle dung + poultry droppings) and mixture 5 (bagasse + cattle dung). Effects of stirring, dry oxidation and water scrubbing processes on the biogas quality were also examined. The peak values of gas generation reached up to 0.344 and 0.476 L/L/day for control and handle stirring in case of mixture 5. The results showed significant differences in biogas production between control and stirring for different mixtures. The biogas generation increased by stirring with 60.33% compared to control. The highest values of CH_4 were 75, 69.7 and 68.6% for mixtures 1, 5 and 3, respectively. The average CO_2 ranged from 31.65 to 37.46%, while H_2S contents ranged from 2017.6 to 2622.4 ppm. Average removal efficiencies of CO_2 and H_2S reached up to 94.84 and 97.2%, respectively. Upgrading biogas enriched it with methane content up to 95.71% and increased its calorific value up to 31.28 MJ/m^3. It could be concluded that, the mixing and stirring as well as dry oxidation and water scrubbing processes have an important role and efficacy in the biogas production quantity and quality. Recycling of wastes and biogas production requires strong governmental support to be successful.

Keywords: Anaerobic digestion; Biogas; Water hyacinth; Potato wastes; Sugar beet leaves; bagasse; cattle dung; Scrubbing

---

[1]Assistant Prof. of Agric. Eng., Dept of Agric. Eng. of Faculty of Agric., Kafrelsheikh Univ. Egypt.

[2]Assistant Prof. of Agric Microbiology., Dept of Agric. Botany, Branch of Agric. Microbiology Faculty of Agric., Kafrelsheikh Univ. Egypt.

INTRODUCTION

Biomass and agricultural wastes represent a large potential renewable energy source, which could benefit society with a clean fuel in the form of methane (Chanakaya et al., 1997; Chynoweth et al., 2001 and Jagadish et al., 1998). Biogas technology is being seriously promoted as an important option to meet the growing energy demand of rural areas in developing countries. It provides a clean and efficient fuel for several end uses such as cooking, lighting, water pumping and other motive power applications. It also ensures the recycling of nutrients in the bovine dung and other biodegradable feed stocks to the soil. One of the promising applications of biogas is for mechanical power generation through internal combustion engines to drive pumps, generators, grinding mills and other equipment in rural areas.

Applications of anaerobic digestion have increased during the past 30 years. The process involves the treatment of agricultural and industrial wastes of varying types in the production of biogas. Interest in the anaerobic treatment of agro-industry wastes is increasing because it is economical, has lower energy requirements and is ecologically sound, may lead to environmental benefits, pollution reduction, energy production and improvements in agricultural practices among several other advantages, compared with aerobic treatment processes (Landine et al., 1982 and Borja et al., 1994). The process produces digested sludge, which is mainly used as fertilizer for crop production since the nutrients in the raw material remain in the mineralized sludge as accessible compounds (Francese et al., 2000). Treating wastes to yield fuel while, recycling nutrients constitutes a sustainable cycle.

Anaerobic digestion is a complex, natural, multi-stage process of degradation of organic compounds through a variety of intermediates into methane and carbon dioxide, by the action of a consortium of microorganisms (Gujer and Zehnder, 1983; Noykova et al., 2002; Tafdrup, 1994 and Tafdrup, 1995). The interdependence of the bacteria is a key factor in the anaerobic digestion process. Instability during both the start-up and operation of the anaerobic degradation process can be problematic due to the low specific growth rate of the methanogenic microorganisms involved (Bjornsson et al., 1997).

Anaerobic digestion of waste and wastewater can be performed in batch, or as continuous processes. In normal batch digestion, reactors are filled once with fresh waste, with or without the addition of inoculum, and allowed to go through the degradation process leading to the formation of biogas. Anaerobic batch digestion experiments are useful because they can be performed quickly with simple, inexpensive equipment, and are useful in assessing the rate at which a material can be digested (Lissens et al., 2001 and Stewart et al., 1984).

There is significant potential for anaerobic batch digestion in developing countries, which have substantial amounts of biomass. However, African nations are not the only ones with such resources. In Europe, particularly Denmark and Germany, large amounts of waste biomass are being utilized for energy production.

There is a lack of information on methane yield from various organic substrates including potato and on the influence of different operating parameters such as TS (Total solids) and ISR (Inoculum substrate ratio). The ISR shows the effect of substrate concentration during anaerobic digestion as well as the effect of inoculum concentration on anaerobic degradability and methane productivity (Fernandez et al., 2001).

The amount of one type of organic waste generated at a particular site at a certain time may not be sufficient to make anaerobic digestion cost-effective all year round. Co-digestion then becomes an interesting alternative as it is a well-established concept (Ahring, 1992; Kaparaju et al., 2002 and Misi and Forster 2001) and it has many advantages (Mata-Alvarez et al., 2000). Co-digestion as a process has been examined for a wide range of waste combinations (Tafdrup, 1994 and Rushbrook, 1990). However, much of the information in the literature involves co-digestion of cattle manure with other agro-waste where the manure provides nitrogen for the system (Francese et al., 2000; Ahring et al., 1992; Callaghan et al., 1997 and Callaghan et al., 2002).

Most industrial co-digestion plants treat the organic fraction of municipal solid waste plus sewage (Mata-Alvarez et al., 2000). However, no scientific reports were found on co-digestion of potato waste and sugar beet leaves under Egyptian conditions. The beet leaves provide additional nitrogen to the system.

The anaerobic mesophilic process (at about 35 ºC) is that most widely used. Generally, the anaerobic process is the subject of current research, as a result of the biogas evolved as a by-product of such a process. Degradation of volatile suspended solids (VSS) in the conventional mesophilic anaerobic process is about 40% at retention times between 30 and 40 days (Cook, 1986 and Owen and Parkin,1986). In the thermophilic range (about 50–60 ºC) sludge degrades at a much higher rate (50% of VSS degradation in 10 days retention time).

Under conditions of unstable operation, intermediates such as volatile fatty acids (VFAs) and alcohols accumulate at different rates depending on the cause of the instability (Gujer and Zehnder, 1983). The most common causes of imbalance are hydraulic or organic overloading, the presence of toxins and changes in the substrate concentration. Several parameters are used as indicators of stress, such as variations in gas production rate, gas composition, pH, partial alkalinity and VFA concentration (Powell and Archer, 1989; Jenkins et al., 1991 and Bjornsson et al., 2001). Increased stability and performance in anaerobic reactors can be achieved if the microbial consortium is retained in the reactor. The high organic content and degradability of potato waste make it one potential source of renewable energy from agricultural and market wastes in Egypt. The raw material can, however, be seen as representative of many other kinds of starch-rich biomass for conversion to biogas.

Water hyacinth a native of South America is abundantly found in Egypt and South East Asia etc. Due to vegetative reproduction it spreads rapidly clogging drainage, ditches, shedding out other vegetations and interfering with shipping and recreation. The concept of using aquatic plants for conversion to energy (methane) is gaining attention in tropical and sub topical regions of the world where warm climate is conductive to the plant growth through out the year (Shoeb and Singh, 2000).

Production of biogas could be a continuous process. However, its use is limited near to the site of the biogas plant. The presence of uncombustible gases like CO_2, H_2S and water vapour reduce its calorific value and make it uneconomical to compress and transport to longer distances. It is therefore necessary to remove these gases before compression (Kapdi et al., 2005).

Bhattacharya et al. (1988) developed one such water scrubbing system. The process provides 100% pure methane but is dependent on factors like dimensions of scrubbing tower, gas pressure, composition of raw biogas, water flow rates and purity of water used. Dubey (2000) tried three water scrubbers having diameters 150 mm (height: 1.5 m), 100 mm (height: 10 m) and 75 mm (height: 10 m) to absorb CO_2 present (37–41%) in the biogas. He found that the CO_2 absorption is influenced by the flow rates of gas and water than different diameters of scrubbers.

Water scrubbing method is popular for CO_2 removal in sewage sludge based biogas plants in Sweden, France and USA. The results show that 5–10% CO_2 remains in biogas after scrubbing (Wellinger and Lindeberg, 1999).

The contradictory findings reported in the literature about the effect of mixing on the performance of anaerobic digesters bring the need of extensive research in this direction. This paper describes some initial studies to characterize the anaerobic batch biodegradability and methane generation potential of cattle dung and a mixture of different agricultural wastes, kitchen wastes and water hyacinth in terms of methane yield and energy production. Furthermore, handle stirring and scrubbing the produced biogas to minimize its contamination were also examined.

MATERIALS AND METHODS

1. Experimental set-up

An experimental biogas pilot plant was constructed and installed at the experimental farm of the Faculty of Agriculture, Kafrelsheikh University during the period of 2005-2006. The biogas plant consists of 10 polyethylene tanks (Cylindrical in shape), each one having a gross volume of about 120 liter. These polyethylene tanks were used as inoculum in the batches. Five digesters were equipped with a handle stirrer, a shaft of 2.5 cm diameter and 125 cm length. The stirrer provided with 8 blades fixed at two levels 4 near the tank bottom and 4 near to the substrate surface. Each blade has 1.5 cm thickness, 5 cm width and 35 cm length. The cover was secured to the reactor by means of steel belt, and a rubber gasket was fitted between the cover and the vessel to provide a gas-tight seal. The other five digesters were used as control without stirring. To minimize the variation of slurry temperature and maintain conditions close to the mesophilic, the digesters were operated under plastic house which could be semi-shaded during summer and without shade during winter. Figure 1 shows one digester used for control (A) and another used for stirring (B), while the remaining digesters having the similar mechanism.

2. Substrates

To prepare the slurry for mixing testes, some of the raw materials were collected from the research and experimental farm of the Faculty of Agriculture, Kafrelsheikh as follows: Cattle dung and poultry droppings were collected from the livestock barns (with concrete floor). The required quantities of rice straw and bagasse were air dried and chopped to small pieces (3-5 cm). Sugar beet leaves was collected from the farm, while water hyacinth (*Eichornia crassipes*) was collected from irrigation channel (to avoid heavy metals) and the fresh materials were chopped also to small pieces 3-5 cm. Potato residues (kitchen wastes) were collected from the student restaurant, Kafrelsheikh University. Different combinations of the materials were manually homogenized before setting it in the digesters. The chemical composition of different materials is presented in Table 1.

Water was added to the different prepared raw materials to form slurry of desired total solids concentration (7.9-10%). The amount of water required to adjust the total solids of slurry was calculated as follows according to (Lo et al., 1981).

$$D_w = R_m \left[\frac{\left(TS_{rm} - TS_{dig}\right)}{TS_{dig}} \right] \quad (1)$$

Where:

D_W = dilution water required, L (kg);

R_m = amount of raw materials added, kg;

TS_{rm} = total solid friction of raw materials; % and

TS_{dig} = total solids of fermentation materials, %.

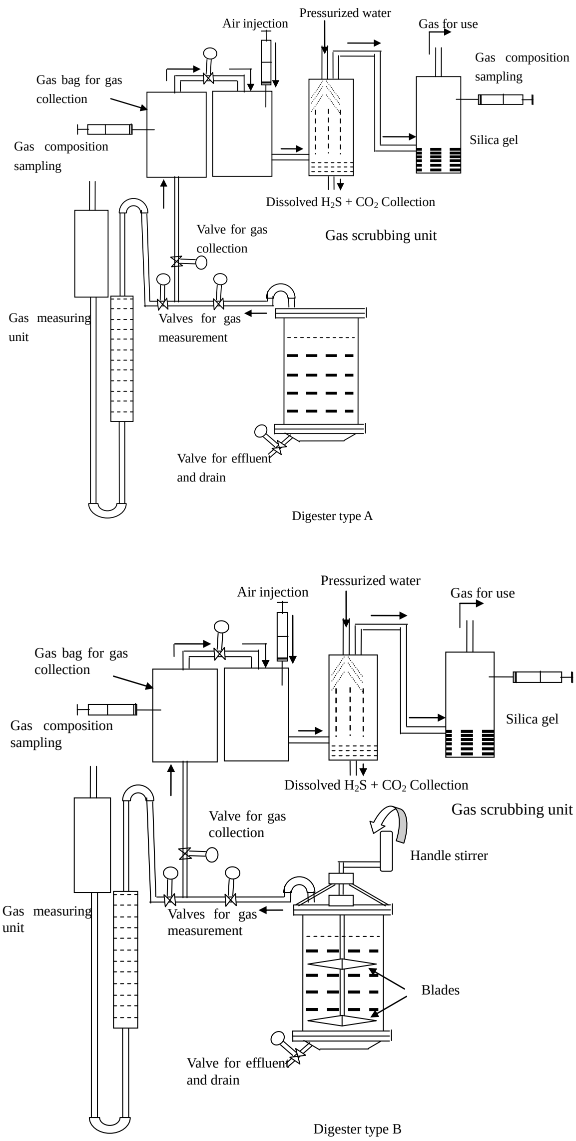

Fig. 1. Schematic diagram of the experimental set-up: Digester type A used as control, while digester type B was equipped with handle stirrer.

2.1. Preparation of the starter (inoculum) for the digester

Enrichment cultures of methanogenic microorganisms capable of producing CH_4 were established as follows: Starter (inoculum) for the

Table 1. Initial chemical composition of agricultural-animal and water hyacinth mixtures used for biogas production.

Constituent	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5
PH	8.2 ± 0.1	7.5 ± 0.1	7.7 ± 0.1	7.5 ± 0.1	6.5 ± 0.1
Total solids (%)	16.5 ± 0.2	18.4 ± 0.2	15.3 ± 0.2	23.3 ± 0.2	16.45 ± 0.2
Volatile solids (% of TS)	89.3 ± 0.1	81.6 ± 0.2	82.1 ± 0.2	76.18 ± 0.1	88.65 ± 0.1
Total Kjeldahl nitrogen (% of TS)	2.25 ± 0.1	1.76 ± 0.1	1.6 ± 0.1	1.99 ± 0.1	1.13 ± 0.1
Organic carbon (% of TS)	53.6 ± 0.2	46.7 ± 0.1	41.82 ± 0.2	43.7 ± 0.1	51.5 ± 0.1
Carbon: Nitrogen ratio (C/N)	23.82	26.5	26.14	21.96	45.57

digester was prepared using the reactor broth of running cattle dung based biogas plant. A 50 ml from cattle dung was suspended in 10 flasks of 1000 ml capacity containing 450ml medium no. 119 (Methanobacterium medium), medium 120 (Methanosarcina medium) and medium no. 141 (*Methanococcus sp*. medium) according to (DSMZ. 2004) which were used to enriched methanogenic bacteria, and were incubated for 4 days at 40^{o}C under anaerobic conditions (incubation was in closed desiccators which was free from O_2). This procedure was repeated four times.

To allow the culture of each enriched culture to be adapted to the actual conditions of the digesters and increase the methanogenic bacterial concentration it was inoculated with the mixture suspended bacterial culture grown in the previous medium (with ratio 1:1:1). Then, it was transferred to size digester of 20 liter capacity and mixed with grinded rice straw to increase the reactive area. Smaller particles provide a large surface area available for the microorganisms resulting in increased microbial activity, thus the anaerobic biodegradability could be increase. Enrichment was done by repeating the inoculation in the selective medium for five times. The ultimate culture, adapted to the actual slurry condition was used as the seed culture to inoculate the digesters feed.

Using the pour plate method, dry weight analysis and by microscopic analysis the concentration of acidogenic and methanogenic bacterial consortia was always determined to be 0.10 and 0. 64 mg/ml in the seed culture, respectively. The volume of inoculum was always kept at 10% (v/v) of the reactant volume. The culture was thoroughly mixed and filtered through a 1 mm pore size screen before use.

Initially the digesters were fed with influent slurry and starter to fill 80% of the reactor volume. The burnt lime was added to each digester to buffer the digesting slurry at pH close to 7.

The following samples (mixtures) of sludge were tested to determine the methane yield productivity:

- Digesters A_1 and B_1 (mixture 1): 50% sugar beet leafs + 50% potato (kitchen wastes) + starter + water,
- Digesters A_2 and B_2 (mixture 2): 100% cattle dung + starter + water,
- Digesters A_3 and B_3 (mixture 3): 40% water hyacinth + 60% cattle dung + starter + water,
- Digesters A_4 and B_4 (mixture 4): 20% rice straw + 60% cattle dung + 20% poultry droppings + starter + water, and
- Digesters A_5 and B_5 (mixture 5): 50% bagasse + 50% cattle dung + starter + water.

The reactors denoted A was used to evaluate the digestion control, while B was equipped with handle stirrer to evaluate the stirring performance. The slurry in the digesters was stirred manually for 10 min, three times daily (at about 7.00 am, at 13.00 pm and 6.00 pm). All the reactors were operating under the same conditions from the beginning to the end of the experiment. The digestion was carried for about 60 days and terminated when the gas production almost ceased.

3. Analytical methods

The anaerobic digestion process was evaluated by measuring the following parameters: Total solids (TS), volatile solids (VS), pH and daily biogas production. Total volume of the biogas generated was measured by displacement technique and the gas composition was determined by using gas chromatography. The compounds detected were methane, carbon dioxide and hydrogen sulfide. All analyses were performed per standard procedures (APHA, 1998), unless otherwise mentioned. Total Kjeldhal nitrogen (TKN) was estimated by the kjeldahl method.

4. Energy production

The daily biogas production was measured at atmospheric pressure by means of the acidified water displacement technique to prevent the dissolution of carbon dioxide contained in the biogas. It was then converted into standard conditions (0°C and 1.013 bar) as mentioned by Gosch et al. (1983) using the following equation:

$$V_{tr} = \frac{V_f \left[273.15\left(P_1 - P_2 - P_3\right)\right]}{\left[273.15 + T\right] x1013} \quad (2)$$

Where:

V_{tr} = volume of dry gas under standard condition, liter;

V_f = volume of wet gas at pressure P and temperature T, liter;

T = temperature of wet gas, °C;

P_1 = air pressure at temperature T, millibar;

P_2 = pressure of wet gas at temperature T, millibar;

P_3 = saturation steam pressure of water at temperature T, millibar; and

1013 = absolute pressure in (mill bar).

The actual calorific value (kJ/m³) of produced biogas was calculated using the following equation according to Shannon (2000):

$$H_{act} = (V_{CH4}/ V_{tot}).\ \rho_{CH4,\ act}\ .\ H_u \quad 3)$$

Where: H_{act} = actual calorific value of produced biogas, kJ/m³;

V_{CH4}/ V_{tot} = methane proportion in biogas, %;

$\rho_{CH4,\ act}$ = actual biogas density, kg/ m³; and

H_u = calorific value of biogas at standard condition, kJ/ kg (assumed as 50000 kJ/kg or 36000 kJ/m³).

The actual biogas density was calculated as follows:

$$\rho_{CH4,\ act} = [\rho_{CH4,\ std}.\ (P_{act}/ P_{std})\ (T_{std}\ /T_{act})] \quad (4)$$

Where: P_{act} = actual biogas pressure, Pa;

$\rho_{CH4,\ std}$ = biogas density at standard conditions, kg/m³ (assumed as 0.72 kg/m³);

P_{std} and T_{std} = pressure, Pa, and temperature, °C, at standard conditions; and

T_{act} = ambient temperature, °C.

The total energy production for control and handle stirring digesters was estimated according to Mitzalff (1983) as follows:

Total energy = The rate of biogas production (m^3/m^3/day or m^3/kg TS add/day) x CH_4 (%) x 36000 (kJ/m^3 of CH_4) (5)

5. Biogas scrubbing

Gas produced in the digester was flushed through a hydrogen sulfide scrubber and collected in a gas storage bag. In this system, by injecting a small amount of outside air (about 3.5%) into the biogas produced (Fig. 1), the hydrogen sulfide content was biologically oxidized into sulfur and H_2S concentration is lowered (Hagen et al., 2001).

$$2H_2S + O_2 \rightarrow 2S + 2H_2O \quad (6)$$

However, care should be taken to avoid overdosing of air, as biogas in air is explosive in the range of 6–12%, depending on the methane content (Wellinger and Lindeberg, 1999).

One of the easiest and cheapest methods involves the use of pressurized water as an absorbent. The biogas collected in the storage bag was fed into a packed bed column from bottom; pressurized water (shower) is sprayed from the top. The absorption process is, thus a counter-current one. The dissolved CO_2 as well as H_2S in water were collected at the bottom of the bed column (Shannon, 2000). Biogas output contain amount of water vapour, which caused some trouble when using the biogas. So it is very important to remove this water vapour from biogas before inlet to the used device. This operation was chemically executed using silica gel filter.

6. Statistical data analysis

Average steady-state data and the standard error presented in the present study have been calculated as a mean value over days of observations. Statistical significance of the experimental data was tested using one way ANOVA statistical program (Microsoft Excel 2002).

RESULTS AND DISCUSSION

Biogas generation from different mixtures of agricultural-animal residues and water hyacinth by anaerobic digestion was monitored through 60 days of batch operation and all the experiments started in the same time.

1. Effect of stirring system and mixture materials on biogas production rate

The daily biogas production (volume /volume /day) throughout the fermentation of 5 treatment (described in materials) are illustrated in Fig.2. It can be noticed that the biogas production rate was very low for the control and handle stirring through the first days and thereafter started to increase with increasing the detention period and reached the peak or several peaks then decreased. The peaks and detention period differed according to the digested materials. The detention periods were 33, 36, 44, 48 and 60 days for mixtures 1, 2, 3, 4 and 5, respectively. The biogas production during this study was in the mesophilic range where temperature ranges between 30 to 35ºC under plastic house. The thermophilic sludge digestion is much faster than the mesophilic. Therefore, this system can be run in thermophilic digestion during summer season, and in this case the thermophilic digestion would be only up to 30% of the size of mesophilic digestion (Zupancic and Ros. 2003).

The average gas production rates were 0.203, 0.169, 0.205, 0.197 and 0.206 L/L/day for control, while for handle stirring the average values were 0.296, 0.27, 0.297, 0.293 and 0.301 L/L/day with respect to mixtures 1, 2, 3, 4 and 5, respectively. The peaks of gas production occur on 13, 21, 23, 25, 29 days for mixtures 1, 2, 3, 4 and 5, respectively. The peak values of gas generation were 0.328, 0.295, 0.34, 0.339 and 0.344 L/L/day for control, while for handle stirring the peak values were 0.421, 0.418, 0.457, 0.45 and 0.476 L/L/day with respect to mixtures 1, 2, 3, 4 and 5, respectively. For the ignition test, it was found that, the flammable gas started earlier in case of mixtures provided with fibrous residues.

Water hyacinths have a high content of hemicellulose and cellulose, but the existing hemicellulose has a rather strong association with the lignin in the plant, which makes it unavailable for the microorganisms. Due to that, the cattle dung and the starter is used to provide enough microorganisms to serve as inoculum. The low bulk density of water hyacinths could result in large voids with poor compaction and low feed rates as a result.

The results obtained from the experiments showed a significant difference of the biogas production between different mixtures in case of

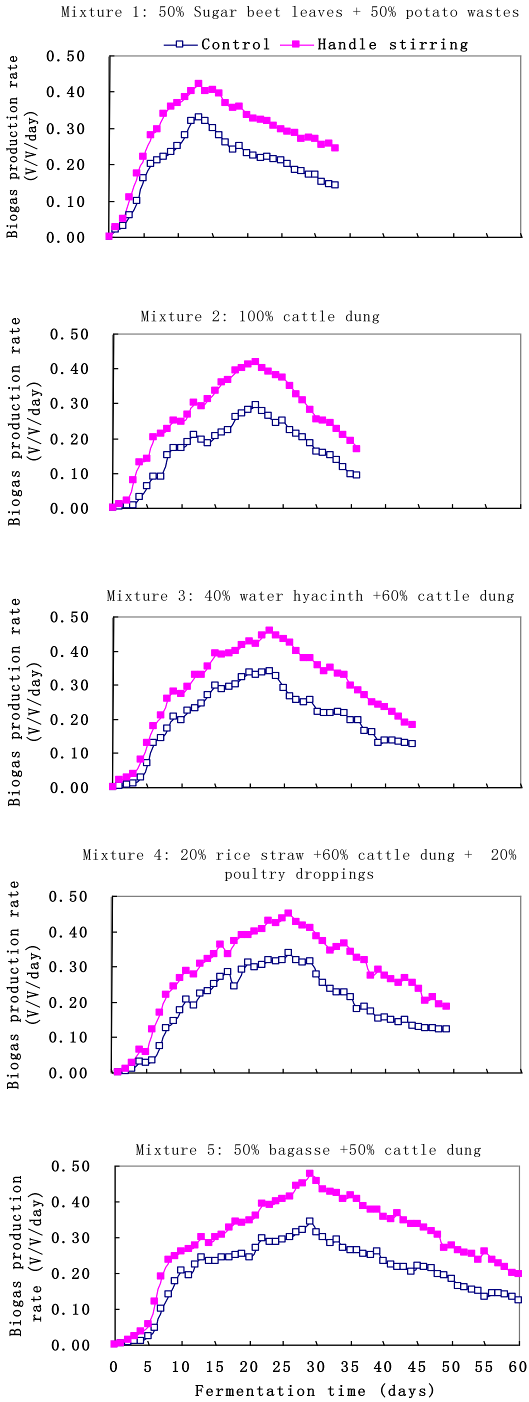

Fig. 2. The daily biogas production (volume /volume /day) throughout the fermentation time of the 5 mixtures.

control and handle stirring digestions. It was found that using the handle stirrer increased the rates of generated gas by 45.38, 60.33, 45.01, 48.85 and 46.40% compared with control one for mixtures 1, 2, 3, 4 and 5, respectively.

The fermenting materials during fermentation process settles into three layers: the top layer formed as scum with a high content of fresh material, the middle layer composed of a clear fermented material containing little solids, while the bottom layer containing sediment and low in fresh material. The digesting materials in the lower layer are under a high hydrostatic pressure and therefore, the produced gas is dissolved in the fermenting liquid and is not easy to up taking (or release).

Therefore stirring of the fermented material of biogas reactor is recommended to ensure the intimate contact between the micro-organisms and particle organic material to increase rate of breakdown and degradation of organic compounds, hence increasing the gas production rate, as well as breakdown the flouting material such as scum to help the gas storage in gas space of biogas reactor. Also, the role of mixing (stirring) becomes more important with an increase in total solid concentration in the feed slurry. These results are in agreement with Alaa EL-Din (1978); El-Hadidi (1999) and Karim et al. (2005).

2. Composition of biogas

Methane yield is an important economic factor in anaerobic digestion. The biogas composition in terms of methane, carbon dioxide and H_2S contents for different mixtures during batch digestion is shown in Fig. 3. The methane production rate varied from 54 to 75% based on type of mixtures and stirring process. The highest values of CH_4 were 75, 69.7, 68.6, 66.5 and 65.2% for mixtures 1, 5, 3, 2 and 4, respectively. Average values of CH_4 were 65.2, 60.74, 63.39, 61.1 and 62.94% with standard deviation of 5.03, 3.16, 3.0, 3.34 and 3.28 for control, while it were 66.74, 63.04, 65.04, 62.16 and 64.56% with standard deviation of 4.91, 2.89, 3.21, 3.48 and 3.45 for handle stirring with respect to mixtures 1, 2, 3, 4 and 5, respectively.

The average recorded values of CO_2 were 33.36, 37.46, 35.13, 37.36 and 35.39% for control, while it were 31.65, 35.43, 33.52, 36.31 and 33.84%

for handle stirring with respect to mixtures 1, 2, 3, 4 and 5, respectively. It was noticed that the stirring process caused an increase in the CH_4 content while CO_2 decreased. Results showed that there is no significant difference between control and handle stirring regarding to the CH_4 and CO_2 contents. The H_2S contents ranged from 2017.6 to 2622.4 ppm and 2179.29 to 2292 ppm for control and stirring, respectively.

The highest CH_4 was produced in the first two weeks in case of first mixture (potato and beet leaves), thereafter the CH_4 production slowed down. This could be explained by the fact that the more easily degradable compounds were finished during the first 2 weeks and slow degradation of complex material taking place after that period (Parawira et al., 2004). It was found that the co-digestion of different materials used in this study enhanced methane yields comparing with other literatures. Also, it should be noted that, comparisons of methane yields reported in the literature cannot be precise because of possible differences in the feedstock and in the experimental conditions. The properties of the co-digestion mixtures at the end of the experiments are given in Table 2.

The recorded results showed that the hydrogen ion concentration (pH) in the digested slurries for all digested materials initially ranged between 6.5 and 8.2. None of the co-digestion batches was acidified except mixture 5 (bagasse) which was little acidified at the beginning of digestion due to the high content of sugars. The observed inhibition of methanogenesis was supported by the low pH levels recorded in this reactor, which was below the range for methanogenic activity. Therefore, the starter is added since it has a high concentration of methane bacteria which capable to increase the gas production. The pH values slightly decreased during the fermentation time and reach the final values that ranged between 7.1 and 7.8. There was no significant difference in pH between control and stirring digesters.

The C:N ratios of the digested and co-digested materials ranged between 23.82 and 45.57. The recorded results indicated that, both of pH and C:N ratios are within the values required for stable anaerobic digestion of organic waste. The well-balanced anaerobic digestion in the co-digestion was also evidenced by the neutral pH observed at the end of the digestion period. Data presented in Table 2 indicated that, both of total solids and

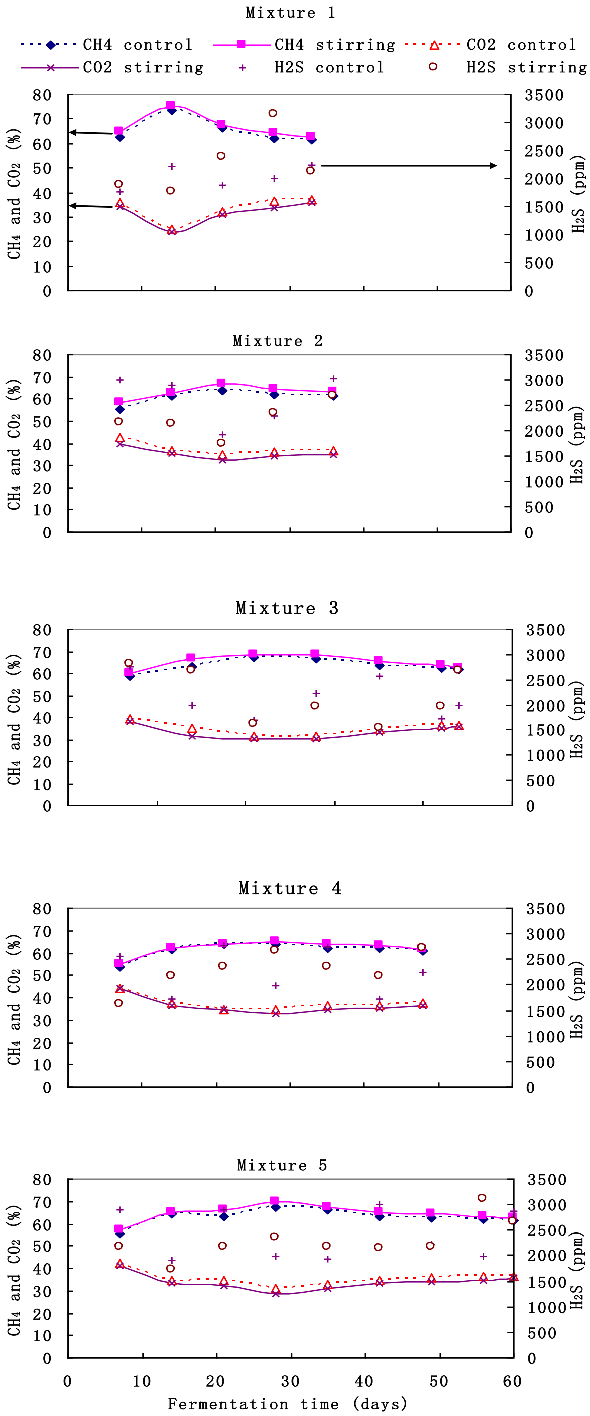

Fig. 3. Biogas composition in terms of methane, carbon dioxide and hydrogen sulfide contents for different mixtures of digestion materials.

volatile solids contents decreased due to destruction of organic material to produce CH_4 and CO_2. The total solid decreased in the digesters by variable percentages ranged from 21.82- 35.15, 16.85- 19.56, 18.30- 23.53, 21.9- 25.32 and 28.26- 34.95% for control and handle stirring with respect to mixtures 1, 2, 3, 4 and 5, respectively. While the volatile solids decreased in the digesters by variable percentages ranged from 30.12- 32.6, 13.6- 16.31, 21.68- 26.31, 15.07- 19.27 and 22.95- 26.21% for control and handle stirring with respect to mixtures 1, 2, 3, 4 and 5, respectively.

Table 2. Final chemical composition of agricultural-animal and water hyacinth mixtures used for biogas production.

Constituent		Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5
pH	Control	7.8 ± 0.1	7.3 ± 0.1	7.4 ± 0.1	7.1 ± 0.1	7.3 ± 0.1
	Stirring	7.7 ± 0.2	7.1 ± 0.1	7.2 ± 0.1	7.0 ± 0.2	7.2 ± 0.2
Total solids, (%)	Control	12.9 ± 0.2	15.3 ± 0.2	12.5 ± 0.2	18.2 ± 0.2	11.8 ± 0.2
	Stirring	10.7 ± 0.3	14.8 ± 0.1	11.7 ± 0.2	17.4 ± 0.1	10.7 ± 0.2
Volatile solids (% of TS)	Control	62.4 ± 0.2	70.5 ± 0.1	64.3 ± 0.3	64.7 ± 0.2	68.3 ±0.2
	Stirring	60.2 ± 0.3	68.3 ± 0.2	60.5 ± 0.2	61.5 ± 0.2	65.41 ±0.3
Total Kjeldahl nitrogen (% of TS)	Control	1.86 ± 0.1	1.4 ± 0.1	1.15 ± 0.1	1.52 ± 0.1	0.91 ± 0.2
	Stirring	1.8 ± 0.1	1.2 ± 0.2	0.95 ± 0.1	1.43 ± 0.1	0.7 ± 0.1

Nutrient concentration will increase slightly during digestion because of the loss of volatile solids, associated with methane generation. The high concentration of nutrients gives the sludge a high potential as fertilizer that can be used for soil improvement. Due to the anaerobic conditions, most of the nitrogen in the sludge will be found in organic form, followed by ammonium and a very small part as nitrate (Hons et al., 1993).

3. Energy production

The average daily production of energy ($MJ/m^3/day$) and biogas characteristics in fermentation process as a function of experimental variables before and after scrubbing were tabulated in Table 3. The results indicated that the average calorific values of produced biogas were 28.56, 27.97, 28.68, 27.86 and 28.67 MJ/m^3 for control, while it were 28.75, 28.4, 28.85, 28.19 and 28.79 MJ/m^3 for handle stirring with respect to mixtures 1, 2, 3, 4 and 5, respectively. These results are higher than mentioned by EREC (2003) which indicate that biogas composed of 65% methane yields 24.5 MJ/m^3. This difference may be due to different conditions and different digestion materials used and the methane concentration was considered after one week from staring the experiments.

In addition to, in the present study the inoculum was rich with the methanogenic bacterial and a good contact between the microorganism and organic solid surfaces that generate high CH_4 contents. The total energy production ranged from 3.828 to 5.122 MJ/m^3/day for control and 6.494 to 7.468 MJ/m^3/day for stirring, as shown in Fig. 4.

The minimum and maximum values were recorded for control of mixture 2 and stirring of mixture 1, respectively. The energy consumed by handle stirring was neglected in the current study. It is recommended to use mechanical or hydraulic stirring system for agitating the digestion materials. Meanwhile the net energy can be calculated by subtracting the consumed energy from the total energy.

4. Scrubbing efficiency

Carbon dioxide is the second most abundant constituent in biogas. There is a great need to make biogas transportable. This can be done by compressing the gas in cylinders which is possible only after removing its CO_2, H_2S and water vapour components. For certain applications, CO_2 and H_2S must be removed from the biogas as they are not flammable, lowers the energy value of biogas and cause corrosive and harmful properties. The generated biogas from different mixtures goes through a two step process. The first step, known as "cleaning", removes hydrogen sulfide. The second step, "upgrading", removes carbon dioxide, which lowers the energy value of the biogas. As shown in Table 3, the average CO_2 removal efficiency ranged from 91.88 to 93.54 and 92.49 to 94.84% for control and stirring, respectively with standard division ranged from

Table 3. The average daily energy production and biogas characteristics before and after scrubbing process during the fermentation period for different digestion mixtures.

Type of mixture	Biogas characteristics	Before scrubbing		After scrubbing		Removal efficiency, %	
		Control	Stirring	Control	Stirring	Control	Stirring
Mixture 1	CH_4, %	65.2	66.74	95.64	95.67	-	-
	CO_2, %	33.36	31.65	2.16	1.63	93.54	94.84
	H_2S, ppm	2017.6	2257	56.49	97.05	97.2	95.7
	Density, kg/m^3	0.867	0.866	0.642	0.639	-	-
	Calorific value, MJ/m^3	28.56	28.75	30.7	30.57	-	-
	Total energy production, MJ/m^3/day	5.122	7.468	-	-	-	-
Mixture 2	CH_4, %	60.74	63.04	94.36	95.26	-	-
	CO_2, %	37.46	35.43	3.04	2.49	91.88	92.98
	H_2S, ppm	2622.4	2206.2	123.25	86.04	95.3	96.1
	Density, kg/m^3	0.921	0.901	0.663	0.651	-	-
	Calorific value, MJ/m^3	27.97	28.4	31.28	31.01	-	-
	Total energy production, MJ/m^3/day	3.828	6.494	-	-	-	-
Mixture 3	CH_4, %	63.39	65.04	95.35	95.71	-	-
	CO_2, %	35.13	33.52	2.45	2.14	93.03	93.63
	H_2S, ppm	2137.71	2179.29	68.41	76.28	96.8	96.5
	Density, kg/m^3	0.905	0.887	0.648	0.64	-	-
	Calorific value, MJ/m^3	28.68	28.85	30.89	30.63	-	-
	Total energy production, MJ/m^3/day	4.77	6.94	-	-	-	-
Mixture 4	CH_4, %	61.1	62.16	94.67	94.92	-	-
	CO_2, %	37.36	36.31	3.03	2.73	91.9	92.49
	H_2S, ppm	2251	2287.43	92.29	97.67	95.9	95.73
	Density, kg/m^3	0.912	0.907	0.659	0.653	-	-
	Calorific value, MJ/m^3	27.86	28.19	31.19	30.99	-	-
	Total energy production, MJ/m^3/day	4.59	6.91	-	-	-	-
Mixture 5	CH_4, %	62.94	64.56	94.94	95.03	-	-
	CO_2, %	35.39	33.84	2.66	2.17	92.48	93.59
	H_2S, ppm	2409.11	2292	103.59	99.7	95.7	95.65
	Density, kg/m^3	0.911	0.892	0.65	0.652	-	-
	Calorific value, MJ/m^3	28.67	28.79	30.86	30.98	-	-
	Total energy production, MJ/m^3/day	4.774	7.246	-	-	-	-

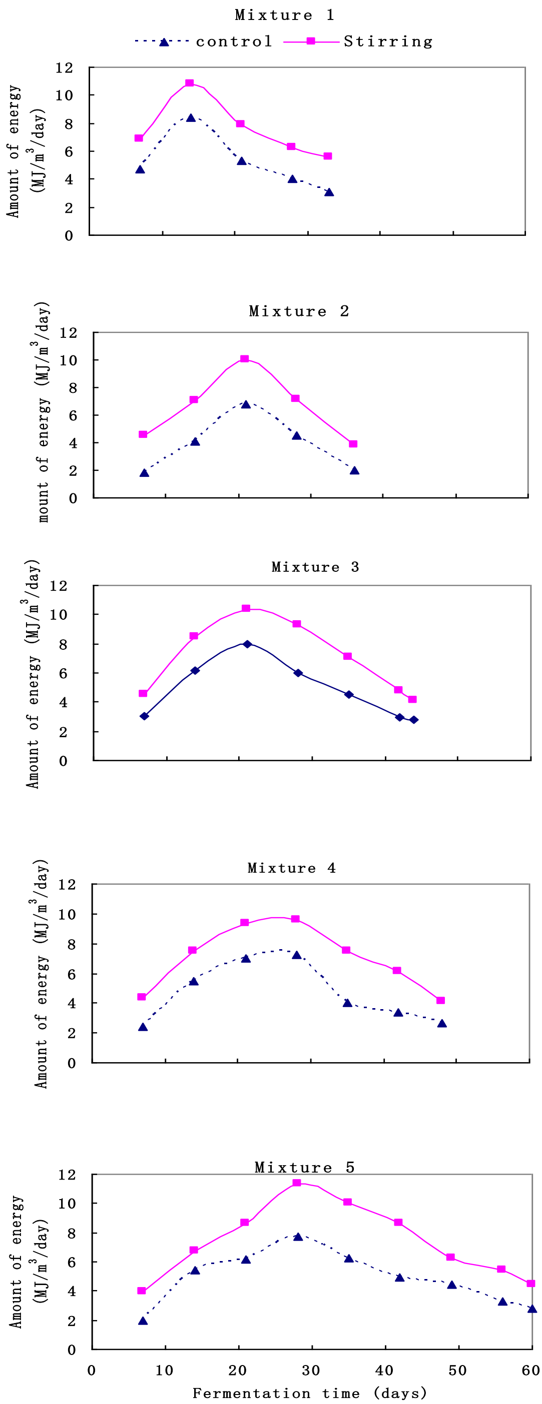

Fig. 4. Energy production throughout digestion of five different mixtures for control and stirring during steady state.

0.86 to 1.79. These results are in agreement with Wellinger and Lindeberg (1999).

The average amount of H_2S remaining in the biogas after scrubbing ranged from 56.49 to 123.25 ppm with removal efficiency ranged from 95.3 to 97.2% for control, while it ranged from 76.28 to 99.7 ppm with removal efficiency ranged from 95.65 to 96.5% for stirring. The removal efficiency depends on the amount of CO_2 and H_2S entered to the scrubbing unit. The remaining amount of H_2S is more than 50 ppm as mentioned by Wellinger and Lindeberg (1999). The reason for that may be due to the amount of air used is not such that (5-10%) used by Hagen et al. (2001). Removal of H_2S by this method is cheaper than chemical cleansing, but it depends on several factors, including temperature, reaction time, amount and location of air injection. If pipeline quality gas is the goal, further treatment and adjusting amount of injected air is necessary to bring H_2S levels to less than 4 ppm.

After scrubbing process, the average percentage of methane content has been increased and ranged from 94.36 to 95.64% and 94.92 to 95.71% for control and stirring, respectively. Also the calorific value of purified gas increased and ranged from 30.57 to 31.28 MJ/m^3. The biogas density has been decreased after scrubbing process. The average density ranged from 0.866 to 0.921 kg/m^3 and from 0.64 to 0.663 kg/m^3 before and after scrubbing process, respectively.

Batch digestion is however, suitable when the material to be digested is cumbersome to handle or when it is produced in large amounts at intervals, as for instance crop residues (Stafford et al., 1980). Small-scale digester designs exist that, with proper implementation, could work very well in the rural areas.

Based on the above discussion, this research can also be applied to solid potato waste like peeling wastes and potato chunks culled from food processing lines, also vegetable market waste, bagasse, cattle dung and water hyacinth, etc can be used to meet the ever-growing energy demand. Recycling of wastes and biogas production requires strong governmental support to be successful, investments and technological skills that would impose great problems in developing countries.

CONCLUSION

This study aimed to evaluate the anaerobic batch biodegradation of agricultural wastes and water hyacinth as well as stirring and scrubbing effect on the generated quantity and quality ob biogas. The potato waste and sugar beet leaves; water hyacinth and cattle dung; rice straw, cattle dung and poultry droppings, and bagasse and cattle dung were co-digested successfully resulting in improved methane yield compared with separate cattle dung digestion. Stirring or mixing improved the performance of the digester and increased the biogas production by up to 60.33% compared with control. Results from this study suggest that the co-digested materials are potential substrates for anaerobic digestion for the production of biogas and could provide additional benefits to farmers. Water scrubbing and dry oxidation processes are simple and cheap and achieved a good results for removal efficiency of CO_2 (up to 94.84%) as well as H_2S (up to 97.2%) form biogas. Upgrading biogas enriched it with methane content up to 95.71% and increased its calorific value up to 31.28 MJ/m^3. The batch anaerobic digestion can be applied in developing countries where low and cheap technology is needed most.

REFERENCES

Ahring, B., I. Angelidaki and K. Johansen. 1992. Anaerobic treatment of manure together with industrial waste. Water Science Technology, 25(7):311–8.

Alaa EL-Din, M.N. 1978. Biogas technology with respect to Chinese experience. Paper presented at the FAO/ Sida workshop on the use of organic materials for improving soil productivity in the near east, Alex., Egypt.

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, DC.

Bhattacharya, TK, T.N. Mishra and B. Singh. 1988. Techniques for removal of CO2 and H2S from biogas. Paper presented at XXIV annual convention of ISAE, held at PKV, Akola.

Bjornsson, L., B. Mattiasson and T. Henrysson. 1997. Effects of support material on the pattern of volatile fatty acid accumulation at overload in anaerobic digestion of semi-solid waste. Appl Microbiol Biotechnol, 47:640–4.

Bjornsson, L., M. Murto, T.G. Jantsch and B. Mattiasson. 2001. Evaluation of new methods for the monitoring of alkalinity, dissolved hydrogen and the microbial community in anaerobic digestion. Water Res, 35: 2833–40.

Borja, R., A. Martin, M. Luque and V. Alonso. 1994. Kinetics of methane production from wine distillery wastewater in an immobilized cell bioreactor using sepiolite as support medium. Resour Conserv Recycl 1994;10:317–27.

Callaghan, F.J., D.A.J. Wase, K. Thayanithy and C.F. Forster. 2002. Continuous co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure. Biomass Bioenergy, 27:71–7.

Callaghan, F.J., K. Luecke, D.A.J. Wase, K. Thayanithy and C.F. Forster. 1997. Co-digestion of cattle slurry and waste milk under shock loading conditions. Journal of Chemical Technology and Biotechnology, 68:405–10.

Chanakaya, H.N., R. Venkatsubramaniyam and J. Modak. 1997. Fermentation and methanogenic characteristics of leafy biomass feed stocks in a solid phase biogas fermenter. Bioresource Technology, 62:71–8.

Chynoweth, D.P., J.M. Owens and R. Legrand. 2001. Renewable methane from anaerobic digestion of biomass. Renewable Energy, 22:1–8.

Cook, E.C. 1986. Anaerobic Sludge Digestion: Manual of Practice No. 16. Alexandria, VA: Water Pollution Control Federation: Task Force on Sludge Stabilization.

DSMZ. 2004. catalogue media No.119, 120 and 141. http://www.dsmz.de/microorganisms/html/media/medium000027.html.

Dubey, A.K. 2000. Wet scrubbing of carbon dioxide. Annual report of CIAE, Bhopal, India.

El-Hadidi, Y.M. 1999. Effect of mechanical mixing on biogas production from livestock manure. Misr J. Ag. Eng.,16 (4): 625-635.

EREC. 2003. Energy Efficiency and Renewable Energy Clearinghouse, brief. Methane (Biogas) from Anaerobic Digesters. Biogas review \ biogas from anaerobic digestion and some web .htm. Voice (USA only): 800-DOE-EREC (363-3732).

Fernandez, B., P. Porrier and R. Chamy. 2001. Effect of inoculum–substrate ratio on the start-up of solid waste anaerobic digesters. Water Science Technology, 44(4):103–8.

Francese, A.P., G. Aboagye-Mathiesen, T. Olesen, P.R. Co´rdoba and F. Sineriz. 2000. Feeding approaches for biogas production from animal wastes and industrial effluents. World J Biotechnol, 16:147–50.

Gosch A., M. Hildegart, W. Ursula and J. Walter. 1983. The anaerobic treatment of poultry manure, Animal Res. and Dev., 17: 62-73.

Gujer, W. and A.J.B. Zehnder. 1983. Conversion processes in anaerobic digestion. Water Sci Technol, 15:127–67.

Hagen M., E.Polman, A. Myken, J. Jensen, O. Jönsson and A. Dahl. 2001. Adding Gas from Biomass to the Gas Grid. Swedish Gas Centre, Report SGC 118.

Hons F.M., J.T. Cothren, J.C. Vincent and N.L. Erickson. 1993. Land application of sludge generated by the anaerobic fermentation of biomass to methane. Biomass and Bioenergy; 5 (3–4), 289–300.

Jagadish, K.S., H.N. Chanakaya, P. Rajabapaiah and V. Anand. 1998. Plug flow digesters for biogas generation from leaf biomass. Biomass Bioenergy, 14(5/6):415–23.

Jenkins, S.R., J.M. Morgan and X. Zhang. 1991. Measuring the usable carbonate alkalinity of operating anaerobic digesters. Res J Water Pollut Control Fed, 63: 28–34.

Kaparaju, P., S. Luostarinen, J.Kalmari and J. Rintala. 2002. Co-digestion of energy crops and industrial confectionery by-products with cow manure: batch-scale and farm-scale evaluation. Water Science Technology; 45(10):275–80.

Kapdi, S.S., V.K. Vijay, S.K. Rajesh and R. Prasad. 2005. Biogas scrubbing, compression and storage: perspective and prospectus in Indian context. Renewable Energy, 30: 1195–1202.

Karim, K., R. Hoffmann, T. Klasson and M.H. Al-Dahhan. 2005. Anaerobic digestion of animal waste: Waste strength versus impact of mixing. Bioresource Technology, 96:1771 – 1781.

Landine, R.C., T. Virarahgavan, A.A. Cocci, G.J. Brown and K.C. Lin. 1982. Anaerobic fermentation-filtration of potato processing wastewater. J Water Pollut Control Fed, 54:103–10.

Lissens, G., P. Vandevivere, L. de Baere, E.M. Biey and W. Verstraete. 2001. Solid waste digesters: process performance and practice for municipal solid waste digestion. Water Science Technology, 44(8):91–102.

Lo, K.V., W.M. Carson, K. Jeffers. 1981. A computer-aided design for biogas production from animal manure. Livestock Wastes. A Renewable Resource, p:133-135, 141.

Mata-Alvarez, J., S. Mace and P. Llabres. 2000. Anaerobic digestion of organic solid wastes: an overview of research achievements and perspectives. Bioresource Technology, 74:3–16.

Misi, S.N. and C.F. Forster. 2001. Batchco-digestio n of two component mixtures of agro-wastes. Process Safety and Environment Protection, 79(B6):365–71.

Mitzalff K. V. 1983. Engines for biogas. GATEREP. Braunschweig, Germany, p: 27-33.

Noykova, N., T.G. Muller, M. Gyllenberg and J. Timmer. 2002. Quantitative analysis of anaerobic wastewater treatment process: identifiability and parameter estimation. Biotechnol Bioeng, 78:89–103.

Owen, W.F. and G.F. Parkin. 1986. Fundamentals of anaerobic digestion of wastewater sludges. Journal of Environmental Engineering,112:867–920.

Parawira, W., M.Murto, R. Zvauya and B. Mattiasson. 2004. Anaerobic batch digestion of solid potato waste alone and in combination with sugar beet leaves. Renewable Energy, 29: 1811–1823.

Powell, G.E. and D.B. Archer. 1989. On-line titration method for monitoring buffer capacity and total volatile fatty acid levels in anaerobic digesters. Biotechnol Bioeng, 33: 570–7.

Rushbrook, P.E. 1990. Co-disposal of industrial wastes with municipal solid wastes. Resource Conservation Recycling, 4:33–49.

Shannon R. 2000. Biogas conference proceedings. http://www.rosneath.com.all/ipc6/ch08/shannon2/

Shoeb, F. and H.J. Singh. 2000. Kinetic studies of biogas evolved from water hyacinth. 2nd International Symposium on New Technologies for Environmental Monitoring and Agro-Applications. Proceedings, 18-20 October, Tekirdag, Turkey.

Stafford D. A., D. L. Hawkes, R. Horton. 1980. Methane production from waste organic matter. CRC Press. ISBNO 8493–52223–I.

Stewart, D.J., M.J. Bogue and D.M. Badger. 1984. Biogas production from crops and organic wastes 2. Results of continuous digestion tests. New Zealand Journal of Science, 27:285–94.

Tafdrup, S. 1994. Centralised biogas plants combine agricultural and environmental benefits with energy production. Water Science Technology, 30:133–41.

Tafdrup, S. 1995. Viable energy production and waste recycling from anaerobic digestion of manure and other biomass materials. Biomass Bioenergy,1–5:303–14.

Wellinger A. and A. Lindeberg. 1999. Biogas upgrading and utilization. Task 24: energy from biological conversion of organic wastes, p:1–19.

Zupancic G.D. and M. Ros. 2003. Heat and energy requirements in thermophilic anaerobic sludge digestion. Renewable Energy; 28: 2255-2267.

الملخص العربي

تقييم وتنقية الغاز الحيوي المنتج من المخلفات الزراعية وياسنت الماء

محمد عبد العزيز الطويل[١]   السيد بلال عبد المطلب بلال[٢]

تهدف هذه الدراسة إلى تقييم انتاج الغاز الحيوي (البيوجاز) من المخلفات الزراعية وياسنت الماء المتاحة في الريف المصري. بالاضافة إلى دراسة تأثير عملية التقليب للمخلوط المتخمر وتنقية الغاز المنتج من الشوائب على كمية الغاز المنتج وجودته. أجريت التجارب بالمزرعة البحثية التابعة لكلية الزراعة- جامعة كفر الشيخ خلال ٢٠٠٥/٢٠٠٦.

[١] مدرس الهندسة الزراعية – قسم الهندسة الزراعية - كلية الزراعة- جامعة كفر الشيخ

[٢] مدرس الميكروبيولوجي الزراعية- قسم النبات الزراعي- فرع الميكروبيولوجي- كلية الزراعة- جامعة كفر الشيخ

تم استخدام خمسة مخاليط من المخلفات وهى: مخلوط ١ (مخلفات البطاطس + أوراق بنجر السكر)، مخلوط ٢ (روث الماشية)، مخلوط ٣ (ياسنت الماء + روث الماشية)، مخلوط ٤ (قش الأرز + روث الماشية + مخلفات الدواجن)، مخلوط ٥ (قش القصب + روث الماشية). وضعت المخاليط السابقة في خمسة مخمرات منفصلة وتم تقليب كل منها بمقلب معدني تم تشغيله يدويا بالإضافة إلى خمسة مخمرات أخرى بدون تقليب. ويمكن تلخيص النتائج الرئيسية للدراسة فيما يلي:

- أعطت المخاليط المختلفة (١ ، ٣، ٤، ٥) زيادة في نسبة الميثان مقارنة بروث الماشية فقط (٢).
- بلغت أقصى قيمة للغاز المنتج حوالى ٠,٣٤٤ و ٠,٤٧٦ لتر/لتر/يوم بدون تقليب وباستخدام التقليب على التوالي في حالة المخلوط ٥.
- أوضحت الدراسة وجود تأثيرًا ملحوظاً لعملية التقليب على كمية الغاز المنتج، حيث أدت عملية التقليب إلى زيادة كمية الغاز المنتج بحوالي ٦٠,٣٣٪ مقارنة بدون تقليب.
- كانت أعلى قيم لغاز الميثان المنتج هي ٧٥,٠ ، ٦٩,٧ و ٦٨,٦ ٪ في حالة المخاليط ١ ، ٥ و ٣ على التوالي.
- تراوحت نسبة CO_2 من ٣١,٦٥ إلى ٣٧,٤٦٪، بينما تراوحت نسبة H_2S من ٢٠١٧,٦ إلى ٢٦٢٢,٤ جزء في المليون (ppm) .
- بلغت كفاءة إزالة (تنظيف) كل من CO_2 و H_2S حوالي ٩٤,٨٤ و ٩٧,٢ ٪ على التوالي.
- أدت عملية تنقية الغاز الحيوي إلى زيادة نسبة غاز الميثان إلى ٩٥,٧١٪ ورفع قيمته الحرارية إلى ٣١,٢٨ ميجاجول/م^3 .
- أوضحت الدراسة أن عملية خلط وتقليب المخلفات المختلفة مهمة لإنتاج الغاز الحيوي وأن عملية التنقية باستخدام الماء والأكسدة الجافة ذات كفاءة و فاعلية في رفع جودة الغاز المنتج بالإضافة إلى قلة تكلفتها.