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Effect of High Total Solids Concentration on Biogas Production from Cattle Dung

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ABSTRACT

This study aimed to evaluate the effect of high total solid concentrations on biogas production from cattle dung. The evaluation process was achieved using four laboratory biogas digesters fed with fresh cow dung at three concentrations; 10 %, 15% and 20% of total solids, three different retention times of 20, 25, and 30 days and three different stirrer speeds of 80, 100, and 120 rpm. The stirring period was 15 minutes every 4 hours. The digesters have been installed inside a water bath to keep the digestion temperature at 40 ± 2ºC. The evaluation also, includes the estimation of energy production, energy consumption, and the net energy gained. The obtained results showed that increasing total solid concentration increase the biogas production rate (V/V/day) while the biogas productivity (V/kg TS_{add}) was decreased. The optimal conditions which gave the maximum biogas production and energy gained were; 15% of total solids (TS), 20 days of retention times, and 120 rpm of stirring speed. The maximum average biogas production rate and energy production at the optimal conditions were; 1.44 m^3/m^3/day and 28.881 kWh respectively. The energy consumption represents about 13.84% from the maximum energy production at stirring speed of 120 rpm and 28.66% from the minimum energy production at the non stirring digester, (control).

INTRODUCTION

Biogas as an alternative source of energy is gaining more recognition throughout several nations of the world. In Egypt methane emissions are produced at a level of 1.58 and 20.82 Giga-grams from cattle and buffalos, respectively (FAO, 2015).

Shaban and Omaima, (2010), added that the agricultural wastes can be utilized as animal feed production, or in compost production Also it can be used to produce biogas. On the other hand it may be Saied that producing of biogas from agricultural wastes by anaerobic digestion (AD) gives a new and clean source of energy and good organic fertilizer as a method to protect environment from pollution by wastes.

The benefits of biog as fuel are; it mixes simply with the air; it is high octane number and calorific value; and it reduces pollution (Shah, 2011).

Yu *et al*., (2011) Reported that high solid anaerobic digester (HSAD) has great potential for efficient conversion of agricultural, municipal and household wastes into green energy. Increasing solids concentration in the digester provides an option to substantially reduce the size of the reactor, thus reducing the footprint of the system. If the reactor volume could be reduced significantly, the economics of anaerobic digestion of these materials could also be improved. Sadaka and Engler, (2003) evaluated the biogas production at different solids concentration. They concluded that cumulative gas production decreased as TS increased, regardless of the type of animal manure. Biogas yield for whole dairy manure was from 0.2 to 0.6 m^3/kg as TS decreased from 43.7 to 13.7%. In addition, they found that high solids concentrations in suspended growth system negatively affected biogas quality by reducing its methane content.

The anaerobic digestion process is normally classified into three different temperature ranges, namely psychrophilic (<20ºC), mesophilic (20-40ºC) and thermophilic (>40ºC) El-Mashad *et al*., (2004). Temperature for fermentation also significantly affect biogas production. Methane can be created through varied range of temperature. The optimum temperature range for methane generating bacteria is (29- 41°C) (Sorathia *et al*., 2012).

Yingyuad, (2007) and Abdel-Hadi, and Abd El-Azeem, (2008) Saied that stirring of the fermentable material of biogas reactor is required to make sure of all contact between the micro-organisms and particle organic material to raise the rate of breakdown and degradation of organic compounds and increasingly the gas production rate, as well as breakdown the flouting material as scum to help the gas storage in gas space of biogas reactor. El-Tawil and Belal, (2009) studied the effect of mixture type, stirring and dry oxidation and water scrubbing process on biogas generation He found that biogas increased by stirring with 60.33% compared to control.. El-Bakhshwan *et al*., (2015) studied the effect of mechanical stirring at different speeds and interval stirring periods on the biogas production yield and productivity and the energy balance. Two large scale fixed dome biogas digesters with 20 m^3 total volume were used. Included three speeds of stirring (30, 45 and 60 rpm) and four stirring periods (15 min / hr, 15 min/2 hr, 15 min /3 hr and 15 min / 4hr) 'which is equal to 6, 3, 2 and 1.5 hr / day, respectively. The results showed that increasing the stirring speed increase the biogas yield with about 23.95, 46.75 and 61.71% at stirring speeds of 30, 45 and 60 rpm respectively. While, the increasing ratio of biogas productivities per digester unit (m3/m^3/day), per total solids added (m3/kg TS add) and per volatile solids consumed (m3/kg VS consumed) were; 23.95, 29.41 and 28.78% respectively at speed of 30 rpm, 46.97, 42.33 and 34.39% at speed of 45 rpm and 61.71, 68.99 and 76.86% at speed of 60 rpm as compared with the non stirring condition. The obtained data also showed that the stirring speed of 60 rpm was gave the high values of biogas production rate (0.423 m^3/m^3/day), biogas productivity (0.423 m^3/m^3/day, 0.106 m^3/kg TS add and 0.707 m^3/kg VS consumed), energy production (9.379 MJ/m^3/day), energy consumption in the stirring process (3.430 MJ/m^3/day) and net energy gained (8.448 MJ/m^3/day). However, the stirring period of 15 min /2 hr

(3 hr/day) gave the maximum biogas production rate and energy production at different stirring speeds and net energy gained at stirring speeds of 30 and 45 rpm. Meanwhile, the stirring period of 15 min/4 hr (1.5 hr/day) gave the lowest energy consumption at different speeds and high net energy gained at stirring speeds of 60 rpm. Kaparaju and Angelidaki, (2007) reported that, mixing creates a homogeneous substrate preventing stratification and formation of a surface crust, and ensures solids remain in suspension. Further, mixing also enables heat transfer, particle size reduction as digestion progresses and release of produced gas from the digester contents. Biogas increased by up to 70% through stirring periods from the liquid slurry in discontinuously stirred reactors Ong, *et al*., (2002). Foaming on the surface is a problem which may take place in the absence of stirring or during non-mixing periods, but the biogas production rate not effected (Kowalczyk *et al*., 2013)

MATERIALS AND METHODS

The main experiments were carried out through the year of 2015 in the biogas laboratory of "Development of Biogas Production and Utilization Systems Project" at Test and Research Station of tractors and farm machinery (Alexandria) - Agricultural Engineering Research Institute. The Biogas Production and Utilization Systems Project was financed by Agricultural Development Program (ADP), Agricultural Research Center), Ministry of Agriculture.

Materials:

Cattle dung:

Fresh cattle dung was obtained from the dairy animal of agriculture faculty farm, Alexandria University, Alexandria Governorate. The wastes were taken directly after excretion from animals and analyzed for chemical characteristic such as total solids, volatile solids, organic carbon, and total nitrogen as shown in Table (1). Then the cattle dung was mixed with water to arrive the desirable total solid (TS) content of (10, 15 and 20 %) using the following formula (Lo *et al*., 1981):

$$Y = \frac{X(Ts_1 - Ts_2)}{Ts_2} \text{.......... ......(1)}$$

Where:-

Y: amount of water added, L

X: amount of raw cattle dung added, kg.

Ts_1: total solids of raw cattle dung, (%).

Ts_2: total solids of digested material, (%).

Table 1. Chemical analysis of raw cattle dung.

Parameters	Range of Measured value	Average of Measured value
Total solids, (T.S) % by weight	25.64 - 31.28	28.46
Total volatile solids (T.V.S) , % by weight	70.96 – 73.80	72.38
Total organic carbon , (T.O.C) % by weight	40.58 – 43.38	41.98
Total nitrogen,(T.N)%by weight	1.24 – 2.05	1.65
Carbon/Nitrogen ratio (C/N ratio)	23.68 :1 - 27.20 :1	25.44 : 1
pH	7.78 – 8.36	8.07

The digesters specifications:

Four laboratory biogas digesters with total volume of 35 Liters/ digester were manufactured. Each digester consists of digestion chamber, inlet and outlet tube, mechanical stirring system and biogas tube as shown in Figs. (1a and b). The digestion chamber was made from steel sheet of 3 mm thickness. It has a cylindrical shape with dimensions of 50 cm height and 30 cm diameter. Every digester was equipped with inlet and outlet pipes (feeding and discharging pipes). The two pipes diameter was 5.08 cm, the inlet pipe length was 35 cm and it passed from the digester cover. The lower end of this pipe was at a height of 12 cm from the bottom of the digester. This pipe was used to feed the digester with organic wastes (influent). However, the outlet pipe was installed on the opposite side of the digester at a high of 32 cm from the bottom of the digester and it was used to discharge the digested material (effluent).The inlet and outlet pipes were equipped with valves to control the feeding and discharging process and also to increase the digesters tighten.

Stirring system:

Every digester was equipped with a mechanical stirrer to keep the digester contents homogenous and to maintain uniform distribution of temperature as much as possible inside the digestion chamber. Each stirrer consists of a steel shaft with diameter 2.5 cm and 78.2 cm Length and it was operated using 0.060 kW electric motor (model of YYG 60, 220 V, 50 Hz, and 1 A) as shown in Fig. (1a).

Heating system:

The four digesters were installed inside a heated water bath to keep the digesters temperature at a level of 40°C ± 2 (El-Ashmawy, 2004). The water bath was made from steel sheet with 0.3 cm thickness, and its dimensions were; 200 cm Length, 60 cm Width and 60 cm Height. An electric heater of 1200 Watt was fixed in the lower end of the water bath to heat water. The water bath temperature was controlled using an electric thermostat (model WRC 90 TU, 30-90 ºC, and 250V/16A) to keep temperature at a certain degree (Fig. 1b). The upper surface of water bath was insulated using polystyrene slabs (foam) 25 mm thickness to reduce the temperature loss.

Measurements:

1 Biogas yield and compositions:

The daily biogas production was volumetrically measured two times a day then cumulated per day under laboratory condition using water displacement metering system (Angelidaki *et al*., 1992) as shown in Fig. (2). Then the daily biogas production was recalculated at the standard conditions (0 °C and 1 bar) to adjust the volume of biogas production under standard conditions as mentioned by Gosch *et al*. (1983) using the following equation:

$$V_{tr} = \frac{V_f[273.15(P_1 - P_2 - P_3)]}{[273.15 + T]\ (1013)} \quad m^3..(2),$$

Where, V_{tr}, is the volume of gas under standard condition, V_f, is the volume of wet gas at pressure P and temperature T, P_1, is the atmospheric pressure at temperature T, P_2, is the pressure of wet gas at temperature T, P_3, is the saturation steam pressure of water at temperature T, 1013, is the absolute pressure in milli-bar and 273.15, is the standard temperature at 0 °C (K). The average temperature inside the digesters through the anaerobic digestion period was about 40ºC. While, the gas pressure (P_2) ranged from 18.95 to 36.83 milli-bar with an average of 29.33 milli-bar. In addition, the atmospheric pressure (P_1) ranged from 1011 to 1018 milli-bar with the range of 1014 milli-bar at 25ºC.

The biogas compositions (methane content (CH_4), carbon dioxide (CO_2), hydrogen sulfate (H_2S), Oxygen (O_2) and Hydrogen (H_2)), the gas pressure (P_2) and the atmospheric pressure (P_1) were measured directly using a portable gas analyzer model of GA5000 (Geotechnical, UK). The measuring range of GA5000 analyzer were; CH_4: 0-100 (±0.5% - ±1.5% vol accuracy), CO_2: 0-100(±0.5% - ±1.5% vol. accuracy), O_2 : 0-25 (±1) and H_2S : 0-10000 (0-5000 (±1.5% - ±2% FS accuracy), 5000-10000 (±2% - ±5% FS accuracy). The relative pressure measurement: ±500 mbar, barometric pressure: 500 to 1500 mbar, (±5 mbar accuracy), and temperature measurement: 10°C to +75°C with (±0.5°C accuracy).

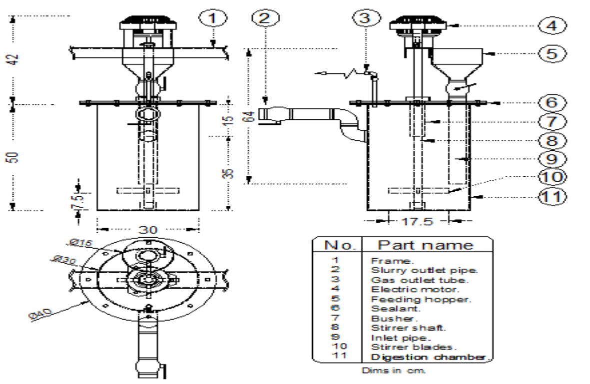


Figure 1a. Elevation, side view and plan of one digester

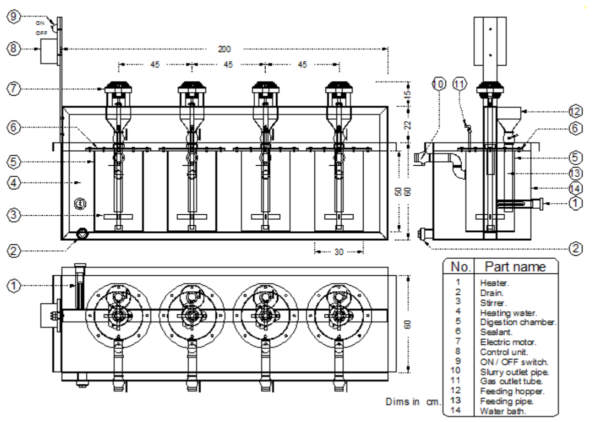


Figure 1b. Elevation, side view and plan of four digesters

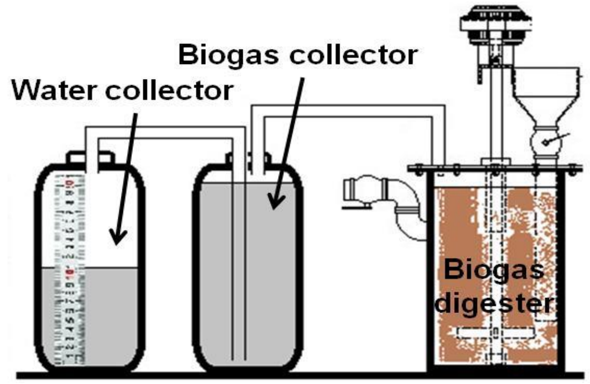


Fig. 2. The biogas measuring method using water displacement system.

The temperature inside the water bath around digesters was measured and adjusted by using a digital thermometer, while the stirring speed was measured and adjusted using digital hand tachometer (Testo 470), Model of T465 (0563 0465), maximum speed of 100000 rpm and accuracy range from -0.01% to -0.003%.

The power consumption of different stirring and heating systems was measured using the digital clamp meter (Kew SNAP model 2007A, Made in THAILAND). All measurements of biogas rate, and energy were recorded daily.

2 Chemical analyses:

Total solids:

Samples of the fresh cattle dung to be used in the digestion test and digested slurry were oven-dried at 105 ± 2 °C to constant weigh (APHA, 1989) using An electric oven model of WS 200, type 117-0200 with temperature range from 30 to 300 °C.

Volatile solids.

The dried sample from the total solids determination was ignited at 600°C in a digital Muffle Furnace Model of F-14 (korea), with temperature range of 100 to 1200^{0}C for two hours. The loss in weight was taken as the volatile solids fraction of the total solids. (APHA, 1989). The volatile solids (VS) mass in kg was determined using the following formula (Wittmaier, 2003)

$$\mathbf{VS\ (kg) = M_{fresh} \times VS\%\ \ldots\ldots\ (3)}$$

Organic matter and organic carbon (O.M & O.C):

The percentage of organic matter was estimated from the percentage of ash using the following equations (Black et. al., 1965):-

$$\mathbf{Organic\ matter\ (\%) = 100\ (\%) - ash\ (\%) \ldots\ldots\ (4)}$$

$$\mathbf{Organic\ carbon(\%) = Organic\ matter(\%)/1.7421 \ldots\ (5)}$$

Studied factors:

Factors investigated in this work include:

(1) Total solid concentrations with three different ratios: 10 %, 15 % and 20% TS.

(2) Stirring speed of mechanical stirring with four different levels: Without stirring (0 rpm), 80, 100, and 120 rpm

(3) Retention time with three different periods: 20, 25, and 30 days.

- The stirring period was automatically adapted at 15 min. every 4 hr daily using an electrical timer (according to El-Bakhshwan, 1998 and El-Hadidi, 1999).
- The stirring speeds for different digesters were adjusted as follow: first digester (1) was operated without stirring (0 rpm), the second digester (2) was operated with stirring speed of 80 rpm, the third digester (3) was operated with stirring speed of 100 rpm and, the fourth digester (4) was operated with the speed of 120 rpm.

Experiments procedure:

The experiments conducted in this work were divided into two stages:

First stage: the batch operation process:

The objective of this experiment is to achieve the steady state condition of the digesters under batch digestion process. To achieve this objective, the active volume of every digester (33 L) was filled by about 90% of diluted cattle dung with 11% TS and 10% of inoculum material with 3.4 % TS. The final initial mixture had a total solids of 10 % TS. The inoculum was obtained from an old operated biogas digester fed with cattle dung.

The amount of water to be added to reach the desirable total solid within the biogas digesters was calculated using equation No (1).

After loading the digesters with the organic wastes, the anaerobic reactors were sealed to maintain anaerobic conditions and sited within a heated water bath to reach the mesophilic temperature of 40 ± 2˚C (El-Ashmawy, 2004). The stirring speeds were adjusted at 0, 80, 100, and 120 rpm and stirring period of 15 minutes every four hours.

The gas production was collected at room temperature and then it was calculated at standard conditions (STP). The biogas yield and the gas pressure were measured daily, while; the gas compositions were evaluated every five days. The batch operation period was 30 days.

Second stage: the continuous operation process.

After 30 days of batch operation, the digesters were reached the steady state condition and the loading rate of different digesters was started at the same stirring speeds and stirring interval (15 min. /4 hr daily). The digester loading rate was calculated using the formula of Lo, *et al*. (1981) as follows:

$$HRT = \frac{V}{LR} \quad \text{day} \; ....(7)$$

Where:

LR = loading rate (m^3 /day).

V = digester Volume (m^3).

HRT = Hydraulic Retention Time (day).

The daily loading rate of digesters was calculated based on the active digestion volume of 33 liters and hydraulic retention times of 20, 25, and 30 days. The applied loading rates were 1.650, 1,320, and 1.1 liter per day at the same hydraulic retention times respectively. The different experiments period was 15 days. methane content (CH_4) and the carbon dioxide (CO_2) in biogas were measured every five days.

Energy balance at the standard conditions (0 ˚C and 1 bar):

1 The daily energy production:

The energy production from digesters was determined using the following equation:

$$E_p = B_{PR} \times CV, \quad (MJ/m^3/day)....... (8)$$

Where:

E_p = Energy production, (MJ/m^3 digester /day)

B_{PR}=Biogas production rate, (m^3gas/m^3digester/day)

CV = Calorific value of biogas, (MJ/m^3 gas)

$$B_{PR} = B_p / D_v \; (m^3/m^3/day) .... (9)$$

Where:

B_p = Biogas production (m^3/day), and

D_v = Digester volume (m^3).

2 The total energy consumption.

a) The energy consumption for agitation was calculated using equation (10):

$$P_t = \frac{p \times t \times n}{60} \quad ,\text{kWh/day} \; ...(10)$$

Where:

P_t= Total power (kWh)/day.

P = The power of motor (kW).

t = time of agitation at once (minute).

n = number of agitation per day.

b) The energy consumption for heating was directly measured.

3 Net energy gained:

The net energy gained is the difference between biogas production rate and biogas consumption.

Data analysis:

Excel spreadsheet was used to determine the averages of biogas production rate, biogas compositions, influent and effluent characteristics at different factors affecting biogas production throughout the experimental work.

RESULTS AND DISSCUION

The biogas production rate, productivity and its content of methane (CH_4) during anaerobic digestion of cattle dung, under three different total solids percentage (10, 15 and 20%), three different retention times (20,25 and30 days) and four different stirring speed (0,80,100 and 120 rpm) were investigated and discussed.

1 Biogas production through the batch stage at 10 % total solids (TS):

The biogas production rate (m^3/m^3/day) and cumulative (m^3) during the batch stage were illustrated in Fig. (3a and b). The results revealed that the biogas was produce through the first day after the digesters feeding. This production may be due to the active inoculum which added through the digester feeding with fresh cattle dung. The results illustrated in Fig. (3a) showed that the biogas production rate was increased with the time reached the maximum values of 0.961 and 1.009 m^3/m^3/day at stirring speeds of 100 and 120 rpm respectively and 24 days of retention time. While, the maximum values of biogas production rate at stirring speed of 0 and 80 rpm were; 0.859 and 0.895

m^3/m^3/day respectively and it's occurred at 26 days of retention time. The stirring speed of 120 rpm gave the maximum cumulative biogas production (0.810 m^3) and maximum biogas production rate (0.630 V/V/day) followed by stirring speeds of 100, and 80 rpm respectively. These results were higher than that obtained by Hamad *et al*. (1984) who recorded 0.15 m^3/m^3 day and El-Awady *et al*. (1988) who recorded 0.02-0.027 m^3/m^3/day for cattle dung, and El-bakhshwan (1998) who recorded that the average values of biogas production rate through the batch phase at 10 % total solids was; 0.362 V/V/day with mechanical stirring.

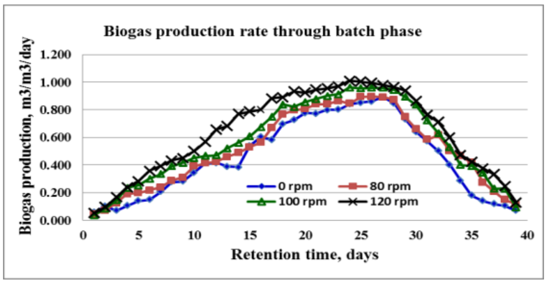


Fig. 3a. Biogas production rate m^3 /m^3 /day through batch phase

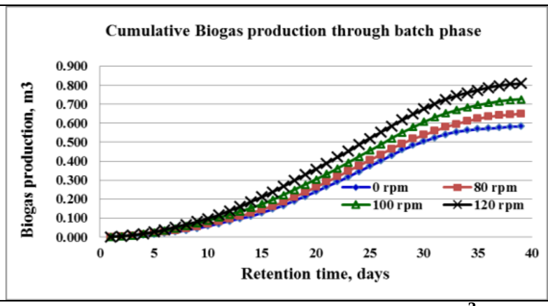
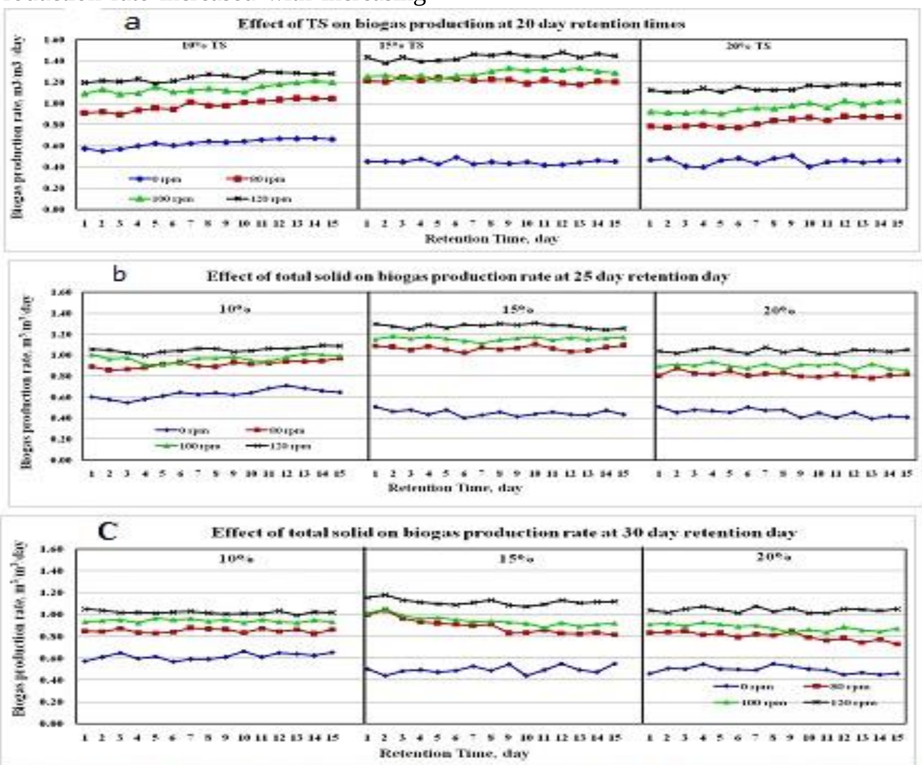


Fig. 3b. Cumulative Biogas production (m^3) through batch phase

2 Biogas production rate at continuous feeding conditions:

Effect of total solids (TS) on biogas production rate (m^3 /m^3 /day) at different retention times and stirring speeds:

The results illustrated in Figs. (4 a, b and c) showed that the biogas production rate increased with increasing the stirring speed from 80 to 120 rpm for all total solid concentrations. While the biogas production was increased with increase the total solids from 10 to 15% then it was decreased as the total solids increased from 15 to 20%.



Figs. (5a, b and c) The effect of total solids concentration on Biogas production rate (m^3 / m^3/day) at 20, 25 and 30 day retention time after steady state phase

Moreover, increasing the stirring speed from 0 to 120 rpm resulted in increase the average biogas production rates at different total solids and retention times. In addition, the stirring speed of 120 rpm was gave the maximum average biogas production rate compared with the other two speeds of 80 and 100 rpm. The average biogas production rates at 120 rpm and 20 days retention time were; 1.24, 1.44, and 1.14 m^3/m^3/day at 10, 15, and 20% TS respectively with increasing ratios of 100, 220, and 153.3% as compared with nun stirring digester. The same values at 25 days retention times were; 1.05, 1.28, and 1.04 m^3/m^3/day at the same total solids respectively, with increasing ratios of 66.67, 184.44 and 133.33%. While, at30 days retention times these values were; 1.02, 1.12, and 1.04 m^3/m^3/day respectively, with increasing ratio of 64.52, 124, and 112.24%. These results were higher that obtained by Ong, *et al*., (2002) who reported that biogas increased by up to 70% through stirring periods as compared with unstirred reactor, El-Tawil and Belal (2009) found that biogas increased by stirring with 60.33% compared to control and El-Bakhshwan *et al*. (2015) recorded that the increasing ratio of biogas production rate (m^3/m^3/day) was; 61.71% at stirring speed of 60 rpm as compared with the non stirring condition. In addition, increasing the total solid from 10 to 15% increase the biogas production rates at different retention times. The average increasing ratios were; 16, 21.9, and 9.8% at 20, 25, and 30 days RT respectively. These results were in the range of that obtained by El-Housseini (1983) who reported that the increasing of the total solids concentrations fed to the digester from 2-16 % increased the biogas production rates from 0.316 to 2.409 V/V/day with increasing ratio of 662.3%. On the other hand increasing the total solids from 15 to 20% decrease the biogas production rates with the average ratios of; 20.8%, 17.97%, and 7.14% at 20, 25, and 30 days RT respectively. These results were in agreement with that obtained by Vandervivere *et al*., (2002), who suggested that the suitable total solids for a one stage anaerobic wet system digestion ranged from 10 -15%. While there were difference from the results obtained by Raheman and Mondal (2012) who, found that the maximum biogas production was; 0.17 m^3 at 20% TS followed by 15, 25 and 10% respectively.

In general the total solids concentration of 15% gave the higher rate of biogas production at all retention times and different stirring speed. Moreover, the stirring speed of 120 rpm was gave the maximum biogas production rate followed by stirring speed of 100 and 80 rpm respectively. The maximum average biogas production rates at 15% TS and 120 rpm were; 1.44, 1.28, and 1.12 m^3/m^3/day with increasing ratios of; 220, 184.44, and 124% at 20, 25, and 30 days RT respectively as compared with non-stirring digester. These results were higher that that obtained by Karim *et al*., (2005) who concluded that the mechanical stirring accounted for 29%, higher biogas yields compared to the unmixed digester.

Effect of retention time on biogas production rate (m^3/m^3/day) at different total solids (TS) concentrations and stirring speeds:

The data plotted in Fig. (5 a, b and c) revealed that biogas production rate increased with increasing the stirring speed from 80 to 120 rpm at different retention times. While it decreased as retention time decreased from 20 to 30 days at total solids concentration of 10 and 15%, but at 20% TS the biogas production rate was decreased with increasing the retention time from 20 to 25 days, then it was slightly increased as the retention time increased to 30 days.

The effect of retention time on biogas production at 10% TS and different stirring speeds was illustrated in Fig. (5a). The results showed that, the retention time of 20 days gave the higher biogas production rates at different stirring speeds as compared with the other two retention times of 25 and 30 days. The stirring speed of 120 rpm was gave the highest biogas production rates of 1.24, 1.05, and 1.02 m3/m3/day at retention times of 20, 25, and 30 days respectively. The increasing ratios at 20 days RT were; 18 and 21.6% as compared with 25 and 30 days respectively.

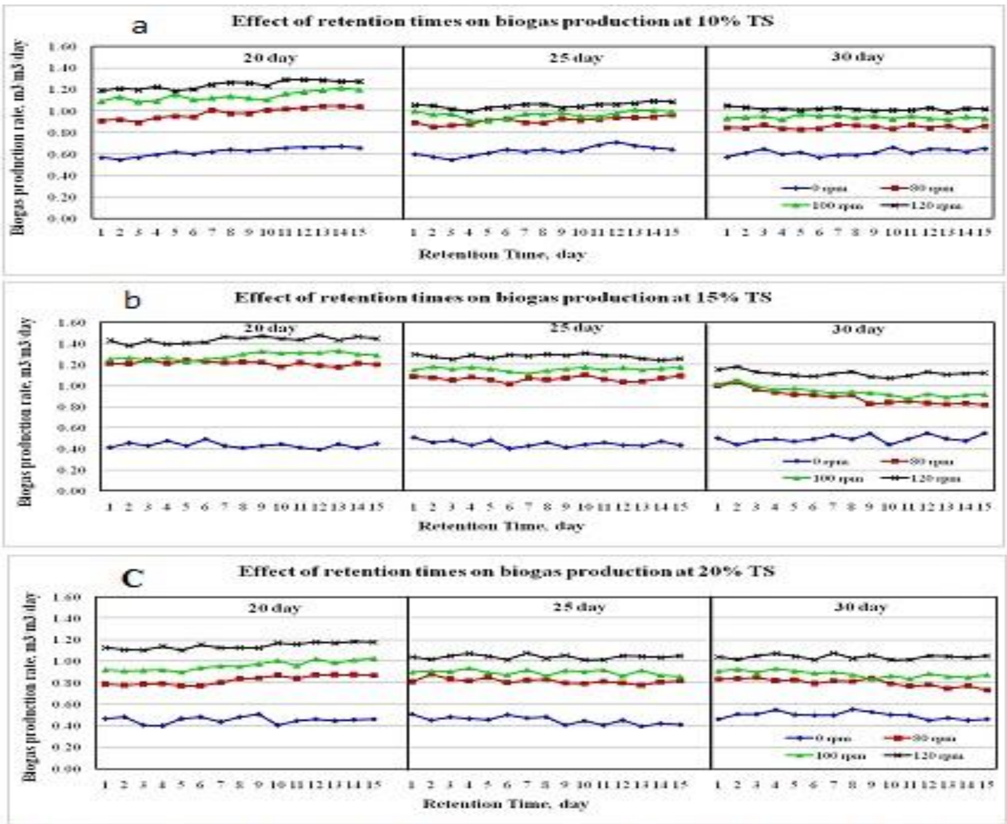
Fig. (5b) showed the effect of retention time on biogas production at 15% TS and different stirring speeds. The average biogas production rates at 20 days retention time were; 0.43, 1.21, 1.28 and 1.44 m^3/m^3/day at 0, 80, 100 and 120 rpm respectively. The biogas production rates were increased with about; 181.4, 197.67 and 234.88 % at 80, 100 and 120 rpm respectively as compared with the control (0 rpm). While the same values at 25 days were; 0.45, 1.06, 1.16 and 1.28 m^3/m^3/day with average increasing ratio of; 135.56, 157.78 and 184.44 % at 80, 100 and 120 rpm respectively as compared with the control. In addition, the biogas production rates at 30 days were; 0.50, 0.89, 0.95 and 1.12 m^3/m^3/day, with the average increasing ratio of; 78, 90 and 124% at stirring speeds of; 80, 100 and 120 rpm respectively as compared with non stirring digester.

The retention time of 20 days also, gave the higher biogas production rates at different stirring speeds as compared with the other two retention times of 25 and 30 days. The average increasing ratios at 20 days and 120 rpm were; 12.5% and 28.57% as compared with retention times of; 25 and 30 days respectively.

Fig. (5c) illustrated the effect of retention time on biogas production at 20% TS and different stirring speeds. The average biogas production rates at 20 days retention time were; 0.45, 0.82, 0.96 and 1.14 m^3/m^3/day at 0, 80, 100 and 120 rpm respectively. The biogas production rates were increased with about; 82.22, 113.33 and 153.33 % at 80, 100 and 120 rpm respectively as compared with the control (0 rpm). While the same values at 25 days were; 0.45, 0.81, 0.90 and 1.04 m^3/m^3/day with average increasing ratio of; 80, 100 and 131.11 % at the same stirring speeds respectively. In addition, the biogas production rates at 30 days were; 0.49, 0.80, 0.88 and 1.04 m^3/m^3/day, with the average increasing ratio of; 63.27, 79.59 and 112.24% at stirring speeds of; 80, 100 and 120 rpm respectively as compared with the non-stirring digester.

The retention time of 20 days was gave the higher biogas production rates at different stirring speeds as compared with the other two retention times of 25 and 30 days. The average increasing ratios at 20 days was; 9.62% as compared with 25 and 30 days RT.

The obtained results showed that, the retention time of 20 days gave the higher biogas production rates at different total solids concentrations and stirring speeds. The average biogas production rates at 10% TS were; 1.24, 1.05, and 1.02 m^3/m^3/day at 20, 25, and 30 days of retention times respectively. The increasing ratios at 20 days were; 18.1 and 21.6% as compared with retention times of 25 and 30 days respectively. While the same values at 15% TS were; 1.44, 1.28, 1.12 m^3/m^3/day at the same retention times respectively. The increasing ratios at 20 days were; 12.5 and 28.6% as compared with retention times of 25 and 30 days respectively. But at 20% TS there were; 1.14, 1.04, and 1.04 at the same retention times respectively. The increasing ratio at 20 days was; 9.6% as compared with both 25 and 30 days. These obtained results indicated that decreasing the retention time from 30 to 20 days resulted in increasing the average biogas production rate with about; 21.6, 28.6 and 9.6% at total solids of 10, 15, and 20% respectively. These results were in agreement with that obtained by El-Ashmawy (2004) who found that decreasing the retention times from 28 to 20 days resulted in increase the biogas production rate from 0.280 to 0.390 (m^3/m^3/day) with increasing ratio of 39.29% and Rico *et al*., (2011) who reported that, the biogas production rate increased from 0.66 to 1.47 m^3/ m^3/ day as the hydraulic retention times (HRTs) decreased from 20 to 10 days. However, increasing the retention time from 20 to 30 days led to decrease the average biogas production rate with about 17.7, 22.2 and 8.8% at total solids of 10, 15, and 20% respectively. These results were in agreement with that obtained by El-Shemi *et al*., (1992) who, concluded that biogas production from cattle dung was decreased from 0.638 to 0.482 m^3/ m^3.day (about 24.45%) as the retention time increased from 30 to 50 days HRT. The maximum average biogas production rate was 1.44 m^3/m^3/day, and it occurred at 20 days RT, 15% TS and 120 rpm, while the minimum value was; 1.02 m^3/m^3/day and it occurred at 30 days RT, 10% TS and 120 rpm.



Figs. (6a, b and c) The effect of retention time on Biogas production rate (m^3 / m^3/day) at 20, 25 and 30 day retention time after steady state phase

Effect of total solids (TS) concentrations and retention time on biogas productivity (m^3/kg $TS_{add.}$/day) at different stirring speeds:

The effects of total solids and retention times on biogas productivity were investigated and the obtained data were listed in Table (2). The results revealed that increasing the retention time increase the biogas productivity at 10%TS at different stirring speeds reached the maximum values at stirring speed of 120 rpm. The average maximum biogas productivity with 10% TS; 0.249, 0.263, and 0.306 m^3/kg $TS_{add.}$/day at retention times of 20, 25, and 30 days respectively. The increasing ratios at 30 days retention time were; 22.9 and 17.5% as compared with other retention times of 20 and 25 days respectively. While, at 15 and 20% TS, the biogas productivity was decreased as the retention times increased from 20 to 25 day, then it was slightly increase at 30 days retention time. The average values of biogas productivity with 15% TS were; 0.287, 0.213, and 0.223 m^3/kg $TS_{add.}$/day at 20, 25, and 30 days RT respectively. The average decreasing ratios were; 25.8 and 22.3% at 25 and 30 days respectively. But with 20% TS the average biogas productivity were; 0.229, 0.130, and 0.156 m^3/kg $TS_{add.}$/day at the same retention times respectively, with decreasing ratios of; 43.2, and 31.9% at 25 and 30 days respectively.

The results also, indicated that increasing total solids concentrations decrease the biogas productivity at different retention times and stirring speeds except at 15% TS and 20 day retention time it was increased and then decreased again with the increase in the TS up to 20%. The stirring speed of 120 rpm gave the highest values of biogas productivity as compared with the other speeds of; 0, 80 and 100 rpm. At 20 days retention time, increasing the total solids from 10 to 15% increase the biogas productivity with about; 23.5, 12.7 and 15.3% at stirring speed of 80, 100, and 120 rpm respectively. While increasing the TS from 15 to 20% decrease the biogas productivity with about; 31.8, 25.3, and 20.2% at the same stirring speed respectively. While at 25 days retention time, increasing the total solids decrease the biogas productivity at different stirring speeds. The decreasing ratios at 15% TS were; 52.5, 22.4, 20.2, and 19.01% at 0, 80, 100, and 120rpm respectively. While at 20% TS there were; 64.6, 55.3, 53.7, and 50.6% at the same stirring speed respectively. The decreasing ratios at 30 days retention times and 15% TS were; 46.5, 29.8, 33.2, and 27.1% at 0, 80, 100, and 120 rpm respectively. While at 20% TS these ratios were; 60, 52.9, 53.4, and 49.02% at the same stirring speed respectively.

The obtained results revealed that the total solids concentration of 15% was gave the highest biogas productivity at different stirring speeds and retention time of 20 days as compared with 10 and 20% TS. The maximum average value was 0.287 m^3/ Kg TS added/day. While at higher retention times of 25 and 30 days, the total solids concentration of 10% was gave the highest values of biogas productivity as compared with 15 and 20% TS at different stirring speeds. The highest average value of biogas productivity was 0.306 m3/ Kg TS added/day and it was occurred at 30days RT, 10% TS, and 120 rpm and these results were higher than that obtained by El-bakhshwan, (1998) who found that the amount of biogas productivity (m^3/ Kg TS added/day) was; 0.109 m^3/Kg TS added/day using mechanical stirring at 120 rpm, and El-Bakhshwan *et al*., (2015) who recorded that the stirring speed of 60 rpm was gave the highest values of biogas productivity 0.106 m^3/kg TS add./day.

On the other hand, the stirring speed of 120 rpm gave the highest biogas productivity at different total solids and retention times. The increasing ratio at the maximum productivity (0.306 m^3/ Kg TS added/day) was 65.4%, as compared with non-stirring digester and these results are in agreement with that obtained by El-Bakhshwan *et al*., (2015) who recorded that increasing ratio of biogas productivities (m^3/kg TS add) was; 68.99 % at speed of 60 rpm as compared with the non-stirring condition.

Table 2. Biogas productivity at different total solids, retention times and stirring speeds:

RT	TS	Biogas productivity m^3/kg TS add/day Stirring speed, rpm			
day	%	0	80	100	120
20	10	0.125	0.196	0.228	0.249
	15	0.089	0.242	0.257	0.287
	20	0.090	0.165	0.192	0.229
25	10	0.158	0.228	0.242	0.263
	15	0.075	0.177	0.193	0.213
	20	0.056	0.102	0.112	0.130
30	10	0.185	0.255	0.283	0.306
	15	0.099	0.179	0.189	0.223
	20	0.074	0.120	0.132	0.156

3 Effect of total solids and retention times on methane content in biogas production:

The results illustrated in Table (3) showed that methane content in biogas production increased with the increasing in the total solids from 10 to 15 % then it was decreased with increasing the total solids from 15 to 20 % for all retention times. The average maximum value of methane content in biogas production was; 61.96 % and occurred at 15 % (TS), 30 days (RT) and stirring speed of 80 rpm. While the minimum value was; 59.45% which occurred at 20 days (RT), 10% (TS) and stirring speed of 80 rpm. The difference between maximum and minimum CH_4 content was 2.51% and it was not significant difference. So, the total solids and retention time were not significant effect on methane content in biogas. El-Shemi *et al*. (1992) recorded that the percentage of CH_4 were 64.6 and 66.53% for 30 and 50 days HRT.

Table 3. Effect of total solids and retention times on methane content in biogas production:

Retention Time	Total Solids	Methane content (%) Stirring speed (rpm)			
day	%	0	80	100	120
20	10	59.48	59.45	59.63	59.77
	15	60.03	60.7	60.33	60.93
	20	60.27	59.93	59.77	60.43
25	10	59.47	60.03	59.77	59.57
	15	59.85	61.39	60.67	60.13
	20	60.87	61.2	60.07	59.73
30	10	59.98	60.51	59.91	60.17
	15	60.89	61.96	61.89	61.88
	20	60.85	61.36	60.8	60.98

4 Energy balance for biogas production:

The total energy production and energy consumption through anaerobic digestion of 10, 15 and 20 % TS cattle dung with application of different stirring speeds were estimated (as showed in appendix). The energy production at different stirring speeds and total solids concentrations was calculated according to the equation of Klaus Von Mitzlaff (1988). The energy consumption for heating and stirring was calculated and listed in Table (4). Data listed in this table clear that the average total energy consumption for heating and stirring was 2.522, 2.959, 3.376 and 3.998 kWh at 0, 80, 100, and 120 rpm stirring speed respectively. It also, indicated that the maximum energy consumption was occurred with the stirring speed of 120 rpm followed by 100, 80, and 0 rpm respectively.

Moreover, the net energy production daily during anaerobic digestion of cattle dung with application of different stirring speeds are calculated and presented in Table (5). The maximum energy production was 28.881 kWh and it was occurred at stirring speed of 120 rpm, 20 day (RT) and 15% total solids followed by stirring speed of 100 rpm, 20 day (RT) and 15% total solids (25.538 kWh) and stirring speed of 120 rpm, 25 day (RT) and 15% TS (25.355 kWh). On the other hand, the minimum energy production was 8.801 kWh and it was occurred with control digester (0 rpm stirring speed, 25 day RT and 15% TS.

Table 4.The average energy consumption for heating and stirring of biogas digesters through different experiments.

Stirring speed (rpm)	Energy consumption (kWh/day) Stirring	Heating	Total energy consumption kWh/day
0	0.000	2.522	2.522
80	0.437	2.522	2.959
100	0.854	2.522	3.376
120	1.476	2.522	3.998

Table 5. The average energy production, energy consumption and net energy gained through the biogas production from cattle dung under the different experiments.

Retention Time	Total Solids	Energy production (kWh) Stirring speed, (rpm)				Energy consumption (kWh) Stirring speed, (rpm)				Net Energy gained (kWh) Stirring speed, (rpm)			
day	%	0	80	100	120	0	80	100	120	0	80	100	120
	10	12.257	19.257	22.409	24.545					9.735	16.298	19.033	20.547
20	15	8.828	24.256	25.538	28.881	2.522	2.959	3.376	3.998	6.306	21.297	22.162	24.883
	20	8.975	16.285	18.913	22.785					6.453	13.325	15.536	18.787
	10	12.459	18.090	19.071	20.684					9.937	15.131	15.695	16.686
25	15	8.801	21.566	23.163	25.355	2.522	2.959	3.376	3.998	6.279	18.606	19.787	21.357
	20	9.019	16.459	17.750	20.506					6.497	13.500	14.374	16.508
	10	12.205	16.993	18.630	20.246					9.683	14.034	15.254	16.247
30	15	9.955	18.259	19.301	22.769	2.522	2.959	3.376	3.998	7.433	15.300	15.925	18.771
	20	9.915	16.206	17.682	20.936					7.393	13.246	14.306	16.937

These results also, indicate that the stirring speed of 120 rpm was suitable stirring speed because it gave higher net energy production as compared with other stirring speeds, While the control digester was recorded a lower net energy production.

The energy consumption represents about 13.84% from the maximum energy production (stirring speed of 120 rpm) and 28.66% from the minimum energy production (control digester, (0 rpm)). These results are lower than that reported by Naegele, *et al*., (2012) who stated that, the electric energy consumption for agitation was 30%–50% from total energy production. While El-Ashmawy (2004) concluded that the total energy consumed for heating the biogas digester in winter and summer seasons were 54.92% and 77.54% respectively.

CONCULUSION

1- Total solids of 15% gave the maximum average biogas production rates at different retention times and stirring speeds.
2- Retention time of 20 days gave the maximum average biogas production rates at different total solids and stirring speeds.
3- The stirring speeds of 120 rpm gave the maximum average biogas production rates at different total solids and retention times.
4- The maximum average biogas production rate at the previous optimal conditions was; 1.44 m^3/m^3/day.
5- The maximum average biogas productivity was 0.306 m^3/kg TS_{add}./day and it occurred at 10% TS, 30 days retention times and stirring speed of 120 rpm.
6- The maximum energy production and net energy gained were; 28.881and 24.883 kWh respectively and they occurred at stirring speed of 120 rpm, 20 day (RT) and 15% total solids. While, the minimum energy production was 8.801 kWh and it occurred with control digester (0 rpm stirring speed, 25 day RT and 15% TS).
7- The energy consumption represents about 13.84% from the maximum energy production (at stirring speed of 120 rpm) and 28.66% from the minimum energy production (at control digester, (0 rpm))

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تأثير التركيزات المرتفعة للمادة الصلبة على الغاز الحيوى الناتج من روث الماشية

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تهدف هذه الدراسة الى تقييم تأثير التركيزات المرتفعة للمادة الصلبة على انتاج الغاز الحيوى من روث الماشية. وذلك باستخدام عدد اربعة مخمرات معملية سعة المخمر 35 لتر, تم وضع المخمرات داخل حمام مائى مزود بسخان كهربائى للحفاظ على درجة الحرارة عند (40 ± 2 م°). تم تجهيز كل مخمر بنظام تقليب ميكانكى يعمل بواسطة موتور كهربائى. تم تغذية المخمرات بالروث الحيوانى عند تركيزات مختلفة (10, 15, و20% مادة صلبة) ويتم تشغيل المخمرات عند ازمنة مكوث مختلفة (20, 25, و30 يوم) وعند سرعات تقليب مختلفة (0, 80, 100, و120 لفة/دقيقة) وتم تثبيت فترة التقليب عند 15 دقيقة/4 ساعات. وقد اظهرت النتائج المتحصل عليها ان تركيز المادة الصلبة 15% مع سرعة تقليب 120 لفة/دقيقة اعطى اعلي معدلات لإنتاج الغاز الحيوى بنسب زيادة 220 ، 184.44 ، 124 % عند زمن مكوث 20، 25 ،30 يوم على الترتيب مقارنة بسرعة تقليب صفر لفة/دقيقة (بدون تقليب) وكذلك الطاقة الكلية الناتجة, فى حين ان زمن المكوث 20 يوم مع سرعة تقليب 120 لفة/دقيقة اعطى اعلي معدلات لإنتاج الغاز الحيوى بنسب زيادة 21.6 ، 28.6، 9.6 % عند تركيز مادة صلبة 10، 15 ، 20 % على الترتيب. اظهرت النتائج ايضا ان ظروف التشغيل المثلى التى اعطت افضل انتاجية للغاز والطاقة هى: 15% مادة صلبة, 20 يوم زمن مكوث وسرعة تقليب 120 لفة/دقيقة. اقصى طاقة ناتجة بلغت 28.881 ك.واط. ساعة. وبلغت اقصى طاقة صافية 24.883 ك.واط.ساعة. وقد بلغت نسبة الطاقة المستهلكة حوالى 13.84% من اقصى طاقة ناتجة (عند سرعة تقليب 120 لفة/دقيقة) وحوالى 28.86% من اقل طاقة ناتجة (عند سرعة تقليب صفر).