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EFFECT OF MECHANICAL STIRRING ON BIOGAS PRODUCTION EFFICIENCY IN LARGE SCALE DIGESTERS

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ABSTRACT

This research work aims to study the effect of mechanical stirring at different speeds and interval stirring periods on the biogas production yield and productivity and the energy balance in large scale biogas digesters. This investigation was conducted on two fixed dome digesters with 20 m3 total volume. The study includes 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 equal to 6, 3, 2 and 1.5 hr/day, respectively. The obtained results 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) was 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) was gave the lowest energy consumption at different speeds and high net energy gained at stirring speeds of 60 rpm.

INTRODUCTION

Stirring of the fermentable material of biogas reactor is often recommended to ensure intimate contact between the micro-organisms and particle organic material to increase 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. The purpose of stirring is to distribute the nutrients in the biogas digester uniformly, to form a suspension of liquid and solid particles, to avoid sedimentation of particles, to ensure uniform heat distribution, to prevent foam formation and to enable gas lift from the fermentation substrate at high dry matter contents (Abdel-Hadi, *and Abd El-Azeem*. (2008) and Brehmer, *et al*. (2012)

Mixing is usually accomplished through various methods, including mechanical mixers, recirculation of digester contents, or by recirculation of the produced biogas using pumps. The importance of mixing in achieving efficient substrate conversion has been reported by several researchers (McMahon *et al*., 2001; Stroot *et al*., 2001; Kim *et al*., 2002; and Vedrenne *et al*., 2007). The main factors affecting digester mixing are the mixing strategy, intensity and duration and also the location of the mixer. However, the effect of mixing duration and intensity on the performance of anaerobic digesters are contradictory. Adequate mixing was shown to improve the distribution of substrates, enzymes and microorganism throughout the digester (Lema *et al*., 1991), whereas inadequate mixing was shown to result in stratification and formation of floating layer of solids. Continuous mixing was shown to improve biogas production compared to unmixed. Nevertheless, intermediate mixing appears to be the most optimal for substrate conversion. Mixing intensity was also shown to affect digester performance and biogas production (Vavilin and Angelidaki, 2005). Minimal mixing was found to be sufficient to distribute the feed adequately and stimulate the formation of new initiation centers that are required for autocatalytic reactions.

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.

The continuously stirred tank reactor (CSTR) is a very common digester design where the content is mixed continuously to maintain the solids in suspension and to form a homogenous mixture. Mixing mode and intensity are important control measures for the CSTR and many investigations have shown that they have direct effects on the biogas yield, even though there are conflicting views on how the mixing should be designed. Positive effects on the biogas yield have been achieved both by increasing and decreasing mixing in the anaerobic digestion process (Angelidaki, 2005).

Despite the importance of mixing in achieving efficient substrate conversion, there is no clear picture about the effects of mixing on anaerobic digestion of manure. Therefore, there is a need for further research on evaluating the optimum mixing strategy and/or duration (Wu and Chen, 2007).

Kissel and Effenberger (2013) mentioned that the central agitators and submersible motor agitators are continuously operated, while all other agitators are operated intermittently between 8 and 28 min per hour. However, Hopfner-Sixt and Amon (2007) found that the average mixing time at 3–4 h per day in Austrian biogas plants. Desai, *et al*. (1994) found that continuous stirring showed marginal improvement, while occasional stirring (total time of 4 hr/day at 120 rpm) improved the total gas production with reduction in volatile acid concentration and low BOD and COD values, indicating high process performance and process stability.

Kaparaju, *et al*. (2008) evaluate the effect of mixing on anaerobic digestion of manure in lab-scale and pilot-scale experiments at 55 C. They investigated the effect of continuous (control), minimal (mixing for 10 min prior to extraction/feeding) and intermittent mixing (withholding mixing for 2 h prior to extraction/feeding) on methane production in three lab-scale continuously stirred tank reactors. They found that the intermittent and minimal mixing strategies improved methane productions by 1.3% and 12.5%, respectively as compared with continuous mixing. In addition, the pilot scale supported the lab-scale results with an average of 7% increase in biogas yields during intermittent mixing compared to continuous mixing. The results also, indicated that mixing schemes and intensities have some effect on anaerobic digestion of manures

There are a number of different types of mixing equipments used in the anaerobic digester industry. These include mechanical mixing, hydraulic mixing and pneumatic mixing (Deublein and Steinhauser, 2008). Mechanical mixing is the most common mixing type being used in Europe today, and uses different types of propellers and agitators to homogenize the digester content. Mechanical mixing has also been reported as having the highest power efficiency per volume unit mixed. The digester can either be mixed continuously, using an intermittent mixing mode, or not be mixed at all. Intermittent mixing means that mixing is turned on and off according to a preset time interval that can range from a few seconds of mixing per day to an almost continuous mixing mode. The power demand of the mixer motor increases during start up of mixing, and this increase needs to be considered when considering energy optimization of the process. Kowalczyk, *et al*. (2013) reported that a 2.5% average increase in power consumption by the mixer motor for the first 13 min following startup in their laboratory-scale setup. They also, added that the energy demand for mixing in a full-scale digester is substantial and can vary from 14% to 54% of the total energy demand of the plant

Kowalczyk, (2012) found that the energy demand of mixing could be reduced by12–29% if intermittent mixing was used instead of continuous mixing. By applying an intermittent regime, mixing for 2 h and pausing mixing for 1 h, the energy demand was reduced by 29% compared to a continuous mixing mode, and when mixing for 7 h and pausing mixing for 1 h, the energy demand was reduced by 12%. Gas release from the liquid digestate in intermittently mixed digesters has been shown to increase by up to 70% during mixing periods (Ong, *et al*., 2002). This implies that gas release is impeded in the unmixed condition and that mixing increases the mass transfer of the gas from the liquid phase to the gas phase. Depending on the type of substrate treated in the anaerobic digester process the feed can have different properties. Light materials such as feathers and straw have a tendency to float on the surface (Carlsson and Uldal, 2009), while heavier materials like eggs hell and other heavy particles sink to the bottom. Foaming on the surface is also a problem that can occur in the absence of mixing or during mixing breaks, but no negative effect on the gas yield has been reported (Kowalczyk *et al*. 2013).

Laboratory scale research of anaerobic digestion of sewage water demonstrated that in continuous mixing systems, higher impeller speeds rising from 140 rpm to 1000 rpm did not improve total gas yields and even a slight reduction in gas production occurred (Stroot, *et al*., 2001). They also, added that continuous mixing was not necessary for good performance and was inhibitory at higher loading rates. Similar effects on biogas production rates and yields at steady-state conditions with treating animal manure at four different mixing intensities (50, 350, 500 and 1500 rpm) could be determined in continuously stirred bioreactors (Hoffmann, *et al*., 2008). Higher methane productions by 1.3% and 12.5% could be observed with intermittent and minimal mixing strategies of manure in anaerobic digestion compared to continuous mixing. An increase of 7% in biogas yields was found in pilot-scale studies comparing intermittent to continuous mixing. Gentle and minimal mixing before feeding proved to be advantageous compared to vigorous mixing by high substrate to inoculums ratio in laboratory scale research. In accordance to Kaparaju *et al*. (2007), it can be concluded that in biogas digesters fed with manure and solid substrates, mixing is indispensable. The mixing intensity had a small effect on biogas yield and mixing schemes proved to have an effect on anaerobic digestion of manure

The effect of mixing in anaerobic digestion of animal manure with 10% total solids was studied on a laboratory scale by Karim *et al*. (2005), who showed that mechanical, hydraulic and pneumatic accounted for 29%, 22% and 15% higher biogas yields compared to the unmixed digester.

The study of Naegele, *et al*., (2012) showed that mixing consumes up to 51% of total electric energy from biogas production process. Moreover, Kissel and Effenberger (2013) found that the electric energy consumption for agitation was 25% of total electric energy consumption which ranging from 6% to 58%.

A study of Lehner and Effenberger (2009) on 10 agricultural biogas plants over a period of one to two years, with an electric capacity ranging from 250 to 526 kW, showed that the total energy consumption varied from 3.7% to 17.4% with an average of 8.8% of the produced electricity. Also, Gemmeke, *et al*. (2009) added that the electric energy consumption ranged from 3.5% to 17.5% with an average of 8.2% from the total energy production from six biogas plants.

There is little information on hand about the optimal choice of agitators and their setup in digesters, mixing intervals and the time required for optimal homogenization . So, the main objective of this work is to study the effect of mechanical stirring at different speeds and interval mixing periods on the biogas production yield and productivity and the energy balance in large scale biogas digesters. The study includes three speeds of stirrer (30, 45 and 60 rpm) and four stirring interval periods (15 min/hr, 15 min/2 hr, 15 min./3 hr and 15 min./4hr) ‘which equal to 6, 3, 2 and 1.5 hr/day, respectively.

MATERIALS AND METHODS

This research work is one outputs of the “Development of Biogas Production and Utilization Systems Project” financed of the Agricultural Development Program (ADP). It was implemented at the Tractors and Machinery Research and Test Station, Alexandria city- Agricultural Engineering Research Institute. Through the period of April to September 2014.

The main substrate used in this research work was cow dung. To determine the cow dung properties, a periodically samples were taken and analyzed. Periodically chemical analyses of the used cow dung samples were done at Land, Water and Environmental Research Institute, Nobaria Research Station and Biogas Laboratory of the Project to determine its properties before and after the digestion process. The cow dung properties include; the total solids (TS), total nitrogen (TN), organic carbon (OC), organic matter (OM), carbon to nitrogen ratio (C/N), and PH.

Two digesters were be constructed with the total volume of 20 m^3 for each one. The specifications and dimensions of the digester were illustrated in **Fig. (1)**. The produced gas was collected in separated floating gasholder volume of 20 m^3 with inner diameter of 3.2 m and high of 2.8 m. The floating gasholder was made from fiber glass materials which have of many advantages such as low maintenance cost, don't reacted with gas or liquid, non-corrosive and increase of the life span which reached to 25 years. The diameter of floating gasholder is 3 m with high of 2.8 m and 1.2 cm thickness. The specifications of biogas digesters were listed in table (1).

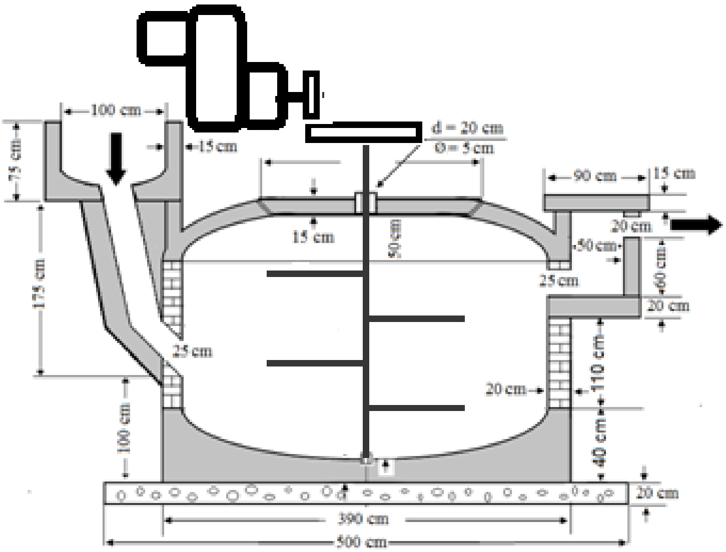

Fig. (1): Biogas digester unit diagram

Table (1): The specifications of biogas digesters.

parameter	specification
Number of digesters	2
Total volume of every one (V_t)	20 m^3
Active volume (V_a)	19 m^3
Inlet basin volume (V_{inlet})	1m^3
Outlet basin volume (V_{outlet})	0.8 m^3
Loading Rate (LR)	0.76 m^3 /day
Hydrolytic Retention Time (HRT)	25 day
Gas storage system	Separate movable gas holder
Volume of gas holder	20 m^3, floating on water
Digestion system	Continuous stirring reactor
Digestion temperature	Mesophilic reaction (27 ± 2 °C).
Mixing system	Mechanical stirring

The two digesters were provided with mechanical stirring system. This system consists of a variable speed electric motor power of 5 hp with the minimum and maximum speeds of 230 and 1820 rpm respectively (**Fig. 2**) used to operate a stainless steel stirring with the axis diameter of 5 cm and 3 m length, four blades each 5 cm width, 85 cm length and 1.2 cm thickness are fixed on the axis with the distance of 40 cm between each other. The stirring system was operated at different speeds and interval periods. The stirring speeds and periods were selected according to the conclusions of several researchers (Elbakhshwan, 1998, El-Hadidi, 1999, Lins, and Illmer, 2012, and Lindmark, *et al*., 2014). The stirring speeds were 30, 45, and 60 rpm while the stirring periods were; 15 min/hr, 15 min / 2 hr, 15 min / 3 hr, and 15 min / 4 hr. Every treatment period was 15 days. The stirring speeds were adjusted using Digital Hand tachometer type of testo 470, while the stirring interval periods were controlled by electrical timer.

The biogas production rate and the methane content were being measured at different stirring speeds and interval periods. The loading rate of biogas digesters was estimated according to the following equation, (El-Hadidi, 1999):

$$\mathbf{V = HRT * LR} \qquad \mathbf{(1)}$$

Where:

V = Digester volume (m^3)
HRT = Hydraulic retention time (day)
LR = Digester loading rate (m^3/day)

Fig. (2): The variable speed motor connected with the transmission gearbox

Since, the active digester volume was 19 m^3; and the retention time is 25 days, the digesters loading rate was; 0.76 m^3/day (760 L/ day).

The amount of water required to adjustment the total solid fraction in biogas digester to 10% was calculated using the following formula (LO, *et al*., 1981).

$$Y = X\left[\frac{Ts_m - Ts_d}{Ts_d}\right] \quad liter \qquad (2)$$

Where:

Y = Dilution volume (L).
X = Amount of raw material added (kg).
TS_m = Total solids of raw material, % and
TS_d = Total solids of digestion material %.

Accordance of this formula, the loading rate (LR) equal to the amount of raw dung (X) and amount of water added to the digester (Y), then:

$$\mathbf{LR = X+Y} \qquad \mathbf{(3)}$$

$$LR = X\left[1 + \frac{Ts_m - Ts_d}{Ts_d}\right] \quad m^3 \qquad (4)$$

The amount of raw dung added to the digesters was 237 kg/ day with average total solids of 32.11%, this amount of dung was diluted in 523 liter of water to give the loading rate volume of 760 liters daily added to the digesters with average total solids of about 10% (recommended by Sorathia, *et al*., 2012).

Analytical methods and Instrumentation

Total solids (TS) and volatile solids (VS) determination:

The total solids percentage (TS%) and its contents of volatile solids percentage (VS%) of the fresh dung and after the digestion process were determined. To determine the volatile solids contents percentage in the dry solids of each sample, the dry solids were dried at 560 °C in muffle oven type of Wise Therm for 2 hours; the TS% and VS% were calculated from the following formula (DEV, 1971):

$$TS\% = \frac{M_{TS}}{M_{fresh}} \times 100 \qquad (5)$$

$$VS\% = \frac{M_{ash} - M_{TS}}{M_{fresh}} \times 100 \qquad (6)$$

Where: M_{fresh} is the fresh mass, M_{TS} is the mass of total solids and M_{ash} is the ash mass

Meanwhile, the volatile solids (VS) mass in kg was determined as mentioned by Wittmaier, (2003)

$$\mathbf{\mathit{VS}\ (kg) = M_{fresh} \times VS\%} \qquad \mathbf{(7)}$$

Daily biogas production:

The daily biogas production was collected in separated floating gasholder volume of 20 m^3. This gas holder was provided with scaling ruler to measure the amount of gas produced (m^3/day). The daily biogas production was recorded at atmospheric to standard conditions (0°C and 1.013 bar) as mentioned by **Gosch, *et al*. (1983)** using the following equation:

$$V_{tr} = \frac{V_f\,[273.15\,(P_1 - P_2 - P_3)]}{[273.15 + T] \times 1013} \quad m^3, \qquad (8)$$

Where:

V_{tr} = Volume of gas under standard condition, m^3
V_f = Volume of wet gas at pressure P and temperature T, m^3
T = Temperature measured in °C.
P_1= atmospheric pressure at temperature T. , millibar
P_2 = Pressure of wet gas at temperature T. millibar
(P_1 and P_2 were measured directly by GA5000 gas analyzer)
P_3 = Saturation steam pressure of water at temperature T.,(millibar), and
1013 = Absolute pressure in (millibar).

The biogas production rate (m^3 gas/m^3digestion volume/day), (m^3_{gas}/kg TS_{added}) and (m^3_{gas}/kg $VS_{destroyed.}$) was determined by divided the daily biogas production (m^3_{gas}/day) on the digestion volume (m^3), the total solids added to the digester (kg $TS_{add.}$) and the volatile solids destroyed (kg $VS_{destroyed.}$) respectively.

Methane content

The biogas compositions (methane content, carbon dioxide and hydrogen sulfate) were measured using GA5000 gas analyzer, and periodically, samples of biogas were chemical analysis at the Gases Analysis Laboratory of Petroleum Research Institute to determine the methane percentage, the gross and net calorific value and the density of biogas.

Temperature and pressure

The temperature inside the two digesters was measured and recorded hourly using DataTaker DT85 U.S.A. The average temperature through the anaerobic digestion period was about 27 ºC while, the gas pressure(P_2) ranged from 18.95 to 36.83 millibar with the average of 29.33 millibar. In addition, the atmospheric pressure (P_1) ranged from 1011 to 1018 millibar with the range value of 1014 millibar at 27 ºC. as measured directly by GA5000 gas analyzer

Energy production and consumption:

-The daily energy production was determine using the following equation:

$$E_p = B_{PR} \times C_V, \qquad (\mathrm{MJ/m^3/day}) \qquad (9)$$

Where:

E_p = Energy production, (MJ/$m^3_{digester}$ /day)
B_{PR} = Biogas production rate, (m^3_{gas}/$m^3_{digester}$/day)
C_V = Calorific value of biogas, (MJ/m^3_{gas}) which measured by Gas Chromatograph(Laboratory of Petroleum Research Institute).

$$B_{PR} = B_p / D_v \qquad (\mathrm{m^3/m^3/day}) \qquad (10)$$

Where:

B_p = Biogas production (m^3/day), and
D_v = Digester volume (m^3).

-The energy consumption in the stirring process was determined using the following equation:

$$E_C = (P_C \times S_T)/D_v \qquad (\mathrm{MJ/m^3/day}) \qquad (11)$$

Where:

E_C = Energy Consumption, (MJ/m^3/day);
P_C = Power Consumption, (MJ/hr);
S_T = Stirring Time, (hr/day), and

D_v = Digester Volume, (m^3).

The power consumption of different electric motors was measured using the electric digital wattmeter type of Demo 96, USA.

RESULTS AND DISCUSSIONS

The results of chemical analyses for inlet cow dung and outlet sludge after biogas production are summarized in Table (2). The chemical analysis of the inlet cow dung illustrated that the average values of TS, TN, OC, OM, C/N and PH were; 10.09%, 1.33%, 38.98%, 67.20%, 30.47:1 and 6.89 respectively. Meanwhile, the chemical analyses of digested sludge after biogas production revealed that the values of TS, OC, OM, and C/N ratio were decreased with about; 40.18, 24.13, 24.14 and 56.6% compared with inlet cow dung. On the other hand, the values of TN and PH were increased with about; 67.83 and 4.18%. The reduction ratio of the total solids, organic carbon, organic matter and carbon to nitrogen ratio were due to the degradation of the cow dung as a result of the anaerobic digestion processes, it reflected the digestion process efficiency with applying the stirring process. The increasing ratio of total nitrogen may be due to the degradation of the total solids. This results mean that the biogas fertilizer is rich with nitrogen and the PH value is suitable for methanogenic bacteria (ranged from 6-8 (Sorathia, *et al*. (2012)).

Table (2): Chemical analysis of inlet cow dung and outlet digested sludge after biogas production through the period from April to September 2014.

Parameter	Digested dung	Months						Average	Increase/
		April	May	June	July	Aug.	Septem.		Decrease ratio
TS %	Inlet	9.88	10.16	10.24	9.98	9.95	10.3	10.09	-40.18
	Outlet	6.25	5.35	6.2	6.42	5.96	6.02	6.03	
TN %	Inlet	1.44	1.94	1.06	1.13	1.27	1.15	1.33	67.83
	Outlet	2.01	2.52	2.01	2.22	2.41	2.24	2.24	
OC %	Inlet	39.07	39.39	38.91	38.52	39.29	38.69	38.98	-24.13
	Outlet	30.47	29.03	29.29	28.64	30.57	29.26	29.57	
OM %	Inlet	67.36	67.91	67.09	66.41	67.74	66.71	67.20	-24.14
	Outlet	52.52	50.05	50.50	49.38	52.71	50.76	50.98	
C/N ratio	Inlet	27.13	20.3	36.71	34.09	30.94	33.64	30.47	-56.6
	Outlet	15.16	11.44	13.75	12.9	12.95	13.14	13.22	
PH	Inlet	6.91	7.02	6.86	6.79	6.95	6.81	6.89	4.18
	Outlet	7.26	7.24	7.38	7	7.01	7.18	7.18	

TS= Total Solids, TN= Total Nitrogen, OC= Organic Carbon, OM= Organic Mater, C/N = Carbon to Nitrogen ratio

Effect of stirring process on the biogas production:

The daily biogas production at Standard Temperature Pressure (STP) and methane content were determined. The obtained data revealed that the different stirring speeds and periods had the positive effect on the biogas production. It gave a higher biogas yield and biogas productivity. Moreover, the increase 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(m^3/m^3/day), per total solids added (m^3/kg

TS add) and per volatile solids consumed (m^3/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 results also, indicated that the stirring speed of 60 rpm was gave the highest values of biogas productivity (0.423 m^3/m^3/day, 0.106 m^3/kg TS add and 0.707 m^3/kg VS consumed) at stirring period of 15 min./2 hr. These highest values may be due to the complete homogenous of the digestion materials which led to increase the exposed surface area resulted in increasing the microbial growth and consequently increase the totals methanoginic bacteria. Moreover, the obtained biogas productivity per kg of the volatile solids (0.707 m^3/kg VS consumed) is twice that obtained by Rico,*et al*., (2011) (0.327 – 0.336 m^3/kg VS consumed) and Ferrer, *et al*., (2011) (0.35 m^3/kg VS). while it was agreement with the data obtained by Banks, *et al*., (2011) (0.642 m^3/kg VS).

On the other hand, Fig.(3) illustrated the effect of the stirring periods on biogas production rate at the standard temperature-pressure (STP). The results indicated that the period of 15 min./2 hr was the best option for biogas production in the large scale digesters at different stirring speeds. The biogas production rates at this period were; 0.361, 0.386, and 0.423 m^3/m^3/day with speeds of 30, 45 and 60 rpm respectively.

However, the mechanical stirring had a slight effected on the methane content in biogas production as shown in Fig.(4). In this Figure, it can be noted that the methane content (CH_4) was increased with a little values at different stirring speeds and periods. The average percentage of CH_4 without stirring process was 60.1% while it was 62.11, 62.51 and 62.5% at 30, 45 and 60 rpm stirring speeds respectively. The average of increasing ratios in CH_4 using mechanical stirring method were; 3.3, 3.8 and 4% at stirring speeds of 30, 45, and 60 rpm respectively.

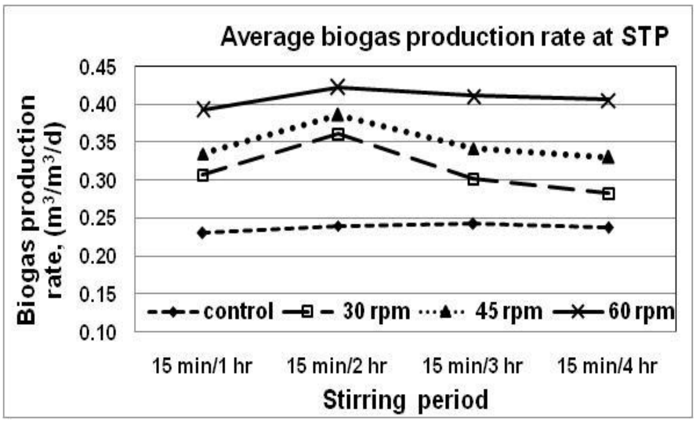

Fig. (3): Effect of stirring periods on biogas production rate at different speeds

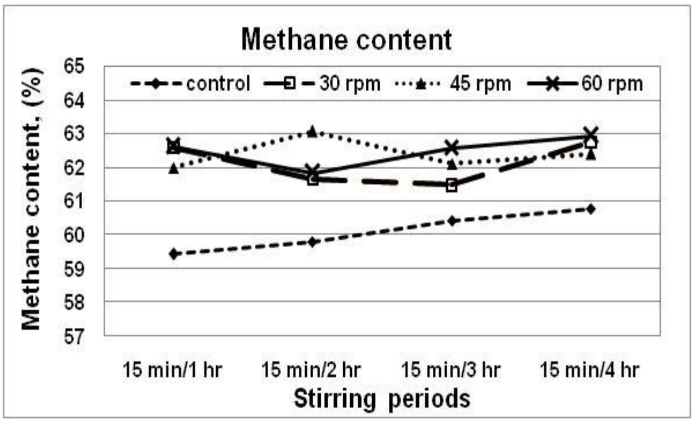

Fig. (4): Methane content in biogas production under different stirring factors

Energy balance of biogas digesters:

The biogas production, total energy production, energy consumed in the stirring process and net energy gained were determined and evaluated. It was mentioned that, the total energy production increased as the stirring time decreased and the stirring speed increase. The maximum energy production was 9.379 MJ/m^3/day at stirring speed of 60 rpm and stirring period of 3 hr/day with increasing ratio of about 72.2% as compared with non-stirring digester. Moreover, the stirring speed of 60 rpm gave the highest energy production at different stirring period flowed by stirring speed of 45 and 30 rpm respectively (Fig. 5). In addition, the highest energy production was occurred at stirring interval period of 3 hr/day at different stirring periods. The average energy production at different stirring speeds were; 7.075, 7.928 and 9.291 MJ/m^3/day at 30, 45 and 60 rpm stirring speed respectively with increasing ratios of 28.05, 43.49 and 68.16% as compared with the non-stirring digester.

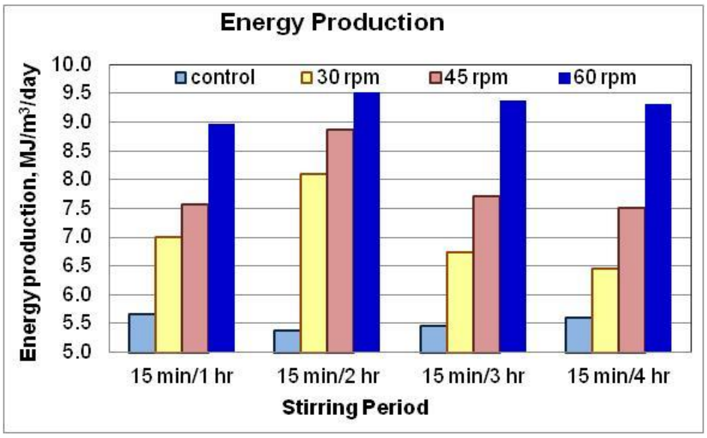

Fig.(5): The total energy production at different stirring speeds and periods

On the other hand, the energy consumption for stirring the digester contents was illustrated in Fig.(6). It can be noted that the energy consumption increased with increase the stirring time and the stirring speed. The minimum energy consumed was 0.591 MJ/m^3/day at stirring ‘speed of 30 rpm and stirring time of 1.5 hr/day. while the maximum one was 3.430 MJ/m^3/day with the stirring speed of 60 rpm and stirring time of 6 hr/day. The energy consumption increased by about 45.6 and 93.6% at the stirring speeds of 45 t0 60 rpm respectively as compared with 30 rpm. On the other hand, increasing the stirring time leads to duplicated the energy consumption at different stirring speeds. The highest energy consumption was occurred at stirring time of 6 hr/day and different stirring speeds flowed by 3, 2 and 1.5 hr/day respectively. Meanwhile, the stirring speed of 60 rpm was consumed the highest energy as compared with the other two speeds. The average percentage of energy consumption were; 13.04, 16.95 and 19.23% from the total energy production at stirring speeds of 30, 45 and 60 rpm respectively. The obtained results were 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. Also, the stirring time of 1.5 hr/day (15 min/4 hr) gave the minimal energy consumption at different stirring speeds, it was 6.86, 8.6 and 9.21% at 30, 45, and 60 rpm stirring speed respectively from the total energy production. These values were in agreement with that obtained by Kamarad, *et al*., (2013) who reported that the electric energy consumption by the biogas plants was in the range of 7–8 % of the total electric energy produced.

Moreover, the net energy gain was calculated and illustrated in Figurer (7). The results mentioned that the maximum net energy gained (8.448 MJ/m^3/day) was obtained at the higher speed (60 rpm) and lower stirring time (1.5 hr/day). while the minimum was 5.221 MJ/m^3/day and occurred at the stirring speed of 30 rpm and stirring time of 6 hr/day (15min/1 hr). The average increasing ratios were; 35.83, 19.16 and 11.35% at stirring speeds of 60, 45 and 30 rpm respectively as compared with the no stirring digester. Moreover, the stirring time of 6 hr/day (15 minl1 hr) is not recommended because it consumed the highest energy resulted in lower net energy gain which less than the non-stirring digester and such treatment must be excluded.

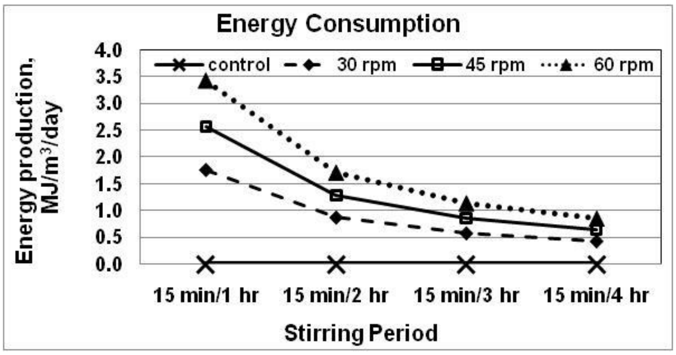

Fig.(6): The energy consumption at different stirring speeds and periods

The obtained results indicated that the stirring process was an important factor that increase the energy production from biogas digesters and increase its efficiency specially at the lower stirring time. The maximum increasing ratio of net energy production was 52.9% at stirring speed of 60 rpm and time of 1.5 hr/day flowed by 49.05% and 41.18% at the same speed and time of 2 and 3 hr/day respectively and 38.3% and 30.63% at stirring time of 3 hr/day and speed of 45 and 30 rpm respectively.

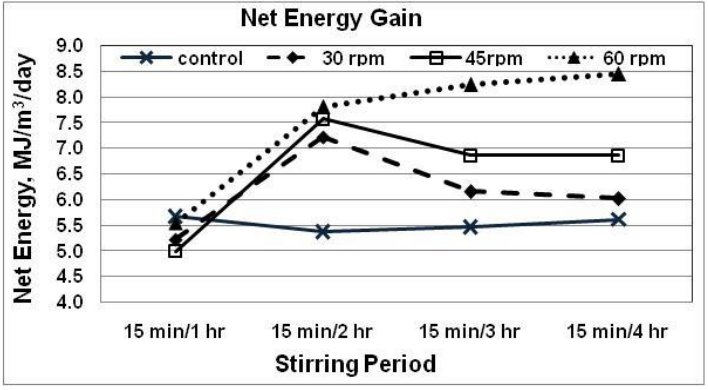

Fig.(7): The net energy gain at different stirring speeds and periods

Moreover, the average energy balance at different stirring speeds were illustrated in Fig. (8). The maximum net energy gained (8.448 MJ/m^3/day) was occurred at stirring speed of 60 rpm anf stirring period of 15 min./4 hr flowed by 7.641 and 7.218 MJ/m3/day at stirring speeds of 45 and 30 rpm respectively and stirring period of 15 min/2 hr. The average values of net energy gained were**;** 6.152, 6.584 and 7.505 MJ/m^3/day with increasing ratios of 11.35, 19.16 and 35.83% at stirring speeds of 30, 45 and 60 rpm respectively as compared with the non-stirring digester. These results were higher than that obtained by **Kaparaju, *et al*., (2008)** who found that the minimal mixing strategy improved methane productions by 12.5%, and increasing biogas yields with an average of 7% and **Karim *et al*. (2005)** who concluded that the mechanical stirring accounted for 29%, higher biogas yields compared to the unmixed digester.

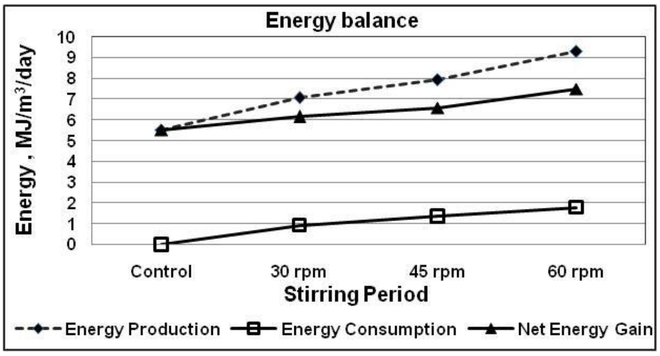

Fig.(8): The average energy balance at different stirring speeds

CONCLUSSION

The present results showed that the biogas production in large scale digesters can be optimized using the mechanical stirring. The obtained results can be summarized in the following conclusions:

1- The stirring speed of 60 rpm 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).

2- 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.

3- The stirring period of 15 min./4 hr (1.5 hr/day) was gave the lowest energy consumption at different speeds and high net energy gained at stirring speeds of 60 rpm.

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تأثير التقليب الميكانيكى على كفاءة انتاج الغاز الحيوى فى الهواضم كبيرة الحجم

مصطفى كامل البخشوان*، شعبان محمود عبد الغفار* ، مؤمن فرحات زايد* و أشرف السيد الشاذلى*

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يهدف هذا العمل البحثي لدراسة تأثير التقليب الميكانيكى عند سرعات وفترات تقليب مختلفة على محصول إنتاج الغاز الحيوي والإنتاجية وتوازن الطاقة في الهواضم كبيرة الحجم. وقد أجريت هذه الدراسة على اثنين هاضم ذات القبة الثابتة حجم الهاضم 20 م^{3}. وتشمل الدراسة ثلاث سرعات للمقلب (30 و 45 و 60 لفة / الدقيقة) وأربع فترات تقليب (15 دقيقة / ساعة، 15 دقيقة / 2 ساعة و 15 دقيقة. / 3 ساعة و 15 دقيقة. / 4ساعة) وهذه الفترات تعادل 6، 3, 2 و 1.5 ساعة / يوم، على التوالي.

وقد أظهرت النتائج أن سرعة المقلب 60 لفة / الدقيقة أعطت اعلى قيم لانتاج الغاز الحيوى, حيث بلغ معدل إنتاج الغاز الحيوي 0.423 م^{3} /م^{3} / يوم، وإنتاجية الغاز الحيوي 0.106 م^{3} / كجم مادة صلبة مضافة و0.707 م^{3} / كم مادة صلبة طيارة مستهلكة، ومعدل الطاقة الناتجة 9.379 ميجاجول/ م^{3} / يوم، ومعدل الطاقة المستهلكة في عملية التقليب 3.430 ميجاجول/ م^{3} / يوم وصافي الطاقة الناتجة 8.448 ميجاجول/ م^{3} / يوم.

كما اعطت فترة التقليب 15 دقيقة / 2 ساعة (3 ساعة / يوم) الحد الأقصى لمعدل إنتاج الغاز الحيوي وإنتاج الطاقة عند السرعات المختلفة للمقلب وكذلك صافي الطاقة المكتسبة عند سرعات المقلب 30 و 45 لفة /الدقيقة. بينما اعطت فترة التقليب 15 دقيقة / 4 ساعة (1.5 ساعة / يوم) أدنى استهلاك للطاقة عند السرعات المختلفة واعلى قيمة للطاقة الصافية عند سرعة تقليب 60 لفة / الدقيقة.