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Effect of Digestion Temperature and Stirring Time on Biogas Properties Using Vertical and Horizontal Units

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ABSTRACT

This work was carried out in order to compare the performance of two digesters types (horizontal and vertical) for biogas production from animal wastes as a source of renewable energy at the biogas laboratory of the Agricultural Engineering Department, Faculty of Agriculture, Mansoura University. Daily biogas production and its content of methane was recorded. The biogas production rate, productivity and the calorific value were determination during batch process anaerobic digestion of buffalo dung. Three different digestion temperatures (35 ºC, 40 ºC and 45 ºC) with stirring time of 15 minutes every 2 hours and total solid of 12% were investigated to identify the optimal digestion temperature (O.D.T). The optimal digestion temperature was used with two different stirring times (15 minutes every 3 hours and 15 minutes every 4 hours daily) to define the optimal condition for biogas productivity. The stirring speed for all experiments was adjusted at 120 rpm and hydraulic retention time of 60 days. Chemical analysis and biochemical oxygen demand (BOD) of influent and effluent slurries were also carried out. The obtained results indicated that, biogas production from vertical digester is more than that from horizontal one. It is recommended to use temperature of 40 ºC with stirring time 15 minutes every 3 hours at total solid of 12% and stirring speed of 120 rpm. According to chemical analysis, the effluent slurry of different experiments could be used as a good organic fertilizer. It contains high concentration of plant nutrients and organic matter and it had tendency to give higher crop yield and soil microbial activities.

Keywords: anaerobic digestion, biogas, temperature, stirring time, methane, renewable energy, buffalo dung, slurry.

INTRODUCTION

Biomass in Egypt is divided into many different sources such as organic fraction of municipal solid waste, agricultural residues (crop residues), agro-industrial by-products (e.g. rice husk, bagasse), animal dung and poultry litter and droppings, forest residues, exotic plants (water hyacinth, reeds, etc.) and sewage sludge (Appels *et al*., 2011).

Cattle and buffalo farms are the main source of manure in Egypt, in addition to the poultry wastes (droppings and litter). The amount of animal manure was estimated at 11 million tons/ year for cows and buffaloes and about 2.3 million tons/ year for the poultry sector. 20% of these wastes normally used as organic fertilizer and 60% of them used as fuel by direct combustion (combustion efficiency is lower than 10), and the rest is lost during dealing (El-Hinnawi, 2006).

Agricultural wastes according to Elfeki *et al*., (2017) is classified as one of the problems of the present era in Egypt, where the amount of these wastes is about 46.7 million tons/ year while, about 52% of the agricultural residues are unused. Solid wastes production reaches millions of tons annually from many different sources such as industrial, agricultural and municipal (Global Waste Management Market Assessment, 2007).

One of the environmental benefits of biogas technology is reduce the use of chemical fertilizers for the soil because the anaerobic digestion of the biomass produces organic fertilizer, which reduces the soil contamination with chemical fertilizers (Borjesson and Berglund, 2007). The biogas fertilizer contains all the nutrients necessary to increase the activity and growth of microorganisms in the soil, which leads to increased soil fertility (Regueiro *et al*., 2012).

Eltawil and Belal (2009) stated that anaerobic digestion was used to produce a feature gas that is combustible, clean, healthy and economical as an alternative source of direct combustion of agricultural waste due to its negative effects on the environment. Esfandiari *et al*., (2011) added that in the agricultural sector, there is a big problem, including how to eliminate many animal waste produced every year, where biogas plants are working to quickly convert waste into huge amounts of methane, which is a promising technology that can be used to obtain energy directly.

Kaltschmitt *et al*., (2001), Singh and Sooch (2004), Kumar and Sharma (2014) and Lewis *et al*., (2017) defined biogas as a gas produced from a completely closed unit that does not interspersed with oxygen and is called digester. The wet animal manure is digested inside it. It contains several gases in different proportions, methane by 50% - 70% and carbon dioxide by 30 % - 50% and nitrogen by 0% - 3% and a very small proportion of gases (hydrogen sulfide - hydrogen).

According to Khalid *et al*., (2011) the temperature between 35 and 40 degrees is the optimum temperature for the activity of the bacteria responsible for the production of biogas.

EL-Ashmawy, (2004) investigated the effect of both the temperature and the hydraulic retention time on the efficiency of anaerobic digestion of livestock wastes using five different levels of temperature, control (without heating), 35, 40, 45 and 50 ºC with three different hydraulic retention times 20, 24 and 28 days. The results showed that maximum quantity of biogas at 40 ± 2ºC digestion temperature.

Nayono (2010) stated that the appropriate range of pH that increases the activity of anaerobic bacteria producing biogas is 6.5-7.5 and its peak at 6.8-7.6. Biogas production is therefore reduced if pH is over 7.6 or below 6.5.

Khalid *et al*., (2011) mentioned that the optimum C:N ratio for organic residues during the anaerobic digestion process

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is 20-35: 1 and the optimum ratio for fruit and vegetable residues during the anaerobic digestion process is 22-25: 1.

James (2001) stated that the best ratio of carbon to nitrogen during the anaerobic digestion process 15-30: 1 and in particular the ratio of 20: 1 is also the range of fresh animal manure and to improve the process of anaerobic digestion inside the digester to get the optimum percentage of C:N ratio some crop residues such as plant residues and leaves are added as a carbon-rich source.

El-Hadidi *et al*., (2016) studied the effect of high total solid concentrations on biogas production from cattle dung at three concentrations (10 %, 15% and 20%) of total solids, three different retention times of (20, 25, and 30 days) and three different stirring speeds of (80, 100, and 120 rpm) at 15 minutes every 4 hours stirring time and 40 ± 2ºC digestion. The results showed that total solids of 15% and 120 rpm stirring speeds gave the maximum average biogas production rates at different retention times.

Deublein and Steinhauser, (2008) said that the waste content of organic matter affects the production of biogas. Therefore, the percentage of dry matter in raw materials should be kept around 10% -12%.

Ostrem *et al*., (2004) reported that anaerobic digestion technology is divided into two processes: The first process: at the beginning of the decomposition time is put the substrate in the digester and close for the duration of the digestion time is called the batch process where it occurs all stages of the reaction and the retention time ranges from 30 to 60 days, where the gas production takes the bell curve and uses about 1/3 of the volume of the tank for active digestion. For cost savings, retention time is reduced by reducing the size of the digester. The second process is the continuous process and is fed daily with certain amounts of waste. Short-times systems are designed to achieve complete digestion. Shorter retention time reduces total digestion even if a high production rate is given as it must be balanced by controlling many factors that affect the digestion process such as the use of low solids or continuous stirring.

El-Bakhshwan et al., (2015) conducted an experiment on two fixed dome digesters with a total volume of 20 m3 to study the effect of different speeds of mechanical stirring as well as stirring times on biogas productivity and energy balance in large-scale digesters. Three different speeds were used (30 rpm, 45 rpm and 60 rpm) and four stirring times were used (15 min/hr, 15 min/2hr, 15 min/3hr and 15 min/4hr). They found that the highest biogas production rate was 0.423 m3/m3/day and it was occurred at stirring speed of 60 rpm. The maximum biogas production was at the stirring time of 15 min/2hr at different speeds and the lowest energy consumption at 15 min/4hr at different speeds and the high net energy gained at stirring speeds of 60 rpm.

Kaparaju *et al*., (2008) conducted an experiment on three lab-scale continuously stirred tank reactors to study the effect of stirring on manure in anaerobic digestion at 55 °C, using continuous (control), minimal (stirring for 10 min.) and intermittent stirring (stirring for 2 hours). In intermittent stirring strategies, there was an increase in methane production of 1.3% and 12.5% in a minimal stirring strategy compared with continuous stirring.

This study was carried out at the biogas laboratory of the Agricultural Engineering Department, Faculty of Agriculture, Mansoura University to compare the performance of two digesters type (horizontal and vertical) under some engineering factors (digestion temperature and stirring times).

MATERIALS AND METHODS

Two pilot plants of biogas production (horizontal and vertical digesters) were designed, constructed and installed at the biogas laboratory of the Agricultural Engineering Department, Faculty of Agriculture Mansoura University in order to compare the performances of the two digesters.

Materials:

Fresh buffalo manure:

The buffalo dung was obtained from the animal farm of faculty of Agric., Mansoura University. The chemical analysis of buffalo dung is tabulated in table (1).

Table 1. Chemical analysis of the used buffalo manure

Constituent	Amount
Total solids, (Ts %)	17.07
Volatile solids, (%from Ts)	79.41
Total nitrogen, (%from Ts)	2.64
Organic carbon, %	39.08
Ash	20.6
Phosphorus, (P %)	0.51
Potassium, (K %)	1.12
C\N ratio	15.71
PH	6.95

The total volume of slurry fed to the two biogas digesters were 0.033 m^3 for each one, with final total solid (Ts) of 12 %. The required amount of water was calculated to adjust the required total solids in the biogas digester using the following equation (LO *et al*., 1981):

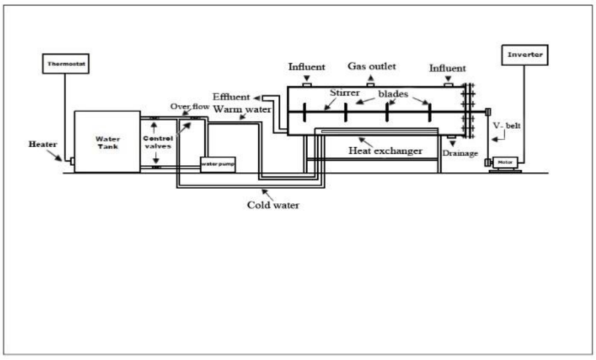
$$Y = \frac{X(Ts_{man} - Ts_{dig})}{Ts_{dig}} \quad \text{.................}(1)$$

Where:

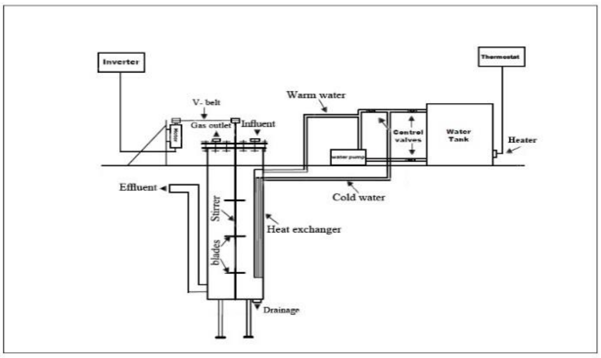
Y = The amount of water required for dilution, (kg).
X = The amount of manure added (raw material), (kg).
Ts_{man} = The total solids of manure (raw material), %.
Ts_{dig} = The total solids of influent (digestion material), %.

The digester specifications:

In this research work, each pilot plant consists of digester, mechanical stirring system, heat exchanger in addition to the biogas outlet tube as shown in Fig. (1a, b).



a. Horizontal digester.



b. Vertical digester.

Fig. 1. Biogas experimental units.

The experimental digesters were cylindrical in shape. It made from stainless steel sheet of 1.0 mm thick. It has gross dimensions of 800 mm long and 250 mm diameter with total volume of 0.039 m^3. The curved surface areas of two digesters were insulated by using a layer of glass wool insulation with a thickness of 10 mm to reduce the heat losses from them. The diameter of feed and discharge openings were 38.1 mm and they passed from the digester cover.

Stirring system:

Stirring is very important for keeping the digester contents homogenous and to maintain uniform distribution of temperature as much as possible inside the digester. Both horizontal and vertical laboratory units are equipped with a mechanical stirrer which consists of a steel shaft with diameter of 12 mm and 1000 mm long. The shaft is connected to four blades each having a gross dimension of 20 mm thick, 40 mm wide and 150 mm long. Each stirrer was operated using V-belt and 550 W electrical motor.

Heating system:

The heating system was used to provide the optimal temperature of the digested slurry. The heating system consists of a heating water tank with gross dimensions of 400 mm long, 380 mm Wide and 300 mm high and it was insulated by using 10 mm thick glass wool insulation to reduce the heat losses. The water surface was covered by bio - balls to reduce water evaporation. The heating source was an electrical heater (1 KW) and controlled by an electrical digital thermostat (model EWPC 902/T/R/P and 220V / 100A) and connected with conductor and switch 40 Amp. to keep temperature at a certain degree. The digested slurry was heated by warm water to maintain the required temperature level using an immersed heat exchanger. The heat exchanger was made of stainless steel tube (2000 mm long and 12.5 mm diameter).

Methods and Measurements:

The constructed digesters were evaluated taking into consideration the following indicators:

Gas determination:

Gas yield and calorific value:

The daily biogas production is measured at atmospheric pressure and room temperature using Ritter gas meter. Then ambient room pressure, biogas pressure and temperature of wet gas are measured daily to recalculate the daily biogas production to standard conditions (STP) by using the following equation according to (Gosch *et al.*, 1983):

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

Where:

V_{tr} = Volume of dry gas under standard conditions, m^3.
V_f = Volume of wet gas at pressure P_2 and ambient temperature T, m^3.
P_1 = Air pressure at temperature T, millibar.
P_2 = Pressure of wet gas at gas temperature T, millibar.
P_3 = Saturation steam pressure of water at temperature T, millibar.
T = Temperature of wet gas, °C.

The calorific value and density of biogas at standard conditions were assumed as 50 MJ/kg (36 MJ/m^3) and 0.72 kg/m^3 respectively as reported by Mitzlaff, (1988), as follow:

$$Hu = 36\, C_G \times CH_4\% \quad \text{.....................} (3)$$

Where:

Hu = Calorific value of biogas at standard conditions, MJ.
C_G = Cumulative biogas production under standard conditions, m^3.
CH_4% = Methane proportion in biogas, Percent.

Chemical analysis:

Total solids:

Raw material (buffalo dung) influent and effluent were dried in oven at 105 °C for about 24 hr according to (APHA, 1989). Percentage of total solids was calculated as follows:

$$Ts = \frac{W_D}{W_W} \times 100 \quad ,\% \quad \text{.....................} (4)$$

Where:

W_D = The weight of sample after drying, g.
W_W = The weight of sample before drying, g.

Volatile solids (Vs):

Digital Muffle Furnace was used to ignite raw material at 600°C for two hours. The loss in weight was taken as the volatile solids percentage (APHA, 1989).

$$Vs = \frac{W_D - W_{ash}}{W_D} \times 100 \quad ,\% \quad \text{.....................} (5)$$

Where:

W_{ash} = The weight of ash, g.

Organic matter (O.M):

The percentage of ash was estimated, from which the organic matter percentage is calculated by using the following equations according to (Black *et al.*, 1965):

$$\text{Organic matter } (\%) = 100\ (\%) - \text{ash } (\%) \quad \text{.....................} (6)$$

Where:

Ash (%): is the solid remains after burning in a digital Muffle Furnace.

Total nitrogen and organic carbon (T.N. and O.C.):

Total nitrogen and organic carbon in the organic wastes (influent) and the anaerobically digested (effluent) were measured in the Faculty of Agriculture Laboratory Mansoura University by C/N analyzer Model Thermo Scientific Flash 2000 elemental analyzer.

Biochemical oxygen demand (BOD):

Biochemical oxygen demand (BOD) of different experiments (influent and effluent) was measured in Micro Analytical Unit Faculty of Science, Mansoura University. The following equation was used to determine the efficiency of digestion process according to (Abd El-Magid, 2003):

$$DPE\ (\%) = \frac{BOD_{In} - BOD_{Ef}}{BOD_{In}} \times 100 \quad \text{.....................} (7)$$

Where:

DPE = Digestion Process Efficiency, %.
BOD_{In} = BOD influent, mg/l.
BOD_{Ef} = BOD effluent, mg/l.

Temperature and pressure:

The ambient temperature inside the laboratory was measured and recorded every 5 minutes by using onset-hobo-data-logger and the water tank temperature was controlled using an electrical digital thermostat to keep digestion temperature at levels of 35, 40 and 45 ºC. In addition, the atmospheric pressure was measured.

Experimental treatments:

The treatments involved in this experimental work were:

A- Three different temperatures (T): 35, 40 and 45 ºC were used with stirring time of 15 minutes / 2 hr, total solid 12%, hydraulic retention time of 60 days and 120 rpm stirring speed to choose the optimal digestion temperature (O.D.T).

B- The optimal digestion temperature was applied with the same total solid, stirring speed and hydraulic retention time at different two stirring times:

1) 15 minutes / 3 hr daily.
2) 15 minutes / 4 hr daily.

C- The previous studying factors were applied with the two different types of digesters (horizontal and vertical).

Data analysis:

Excel spreadsheet was used to calculate the total solids contents, ash contents, the volatile solids and organic carbon. It was used also throughout the experimental work to calculate some measurements such as biogas production rates, influent dung and digested slurry (effluent) characteristics and biogas compositions at different treatments.

Statistical analysis:

A SPSS statistical analysis program was used to test the significant differences between the treatments.

RESULTS AND DISCUSSION

Effect of digestion temperature on biogas properties at stirring time of 15 min. / 2 hr:

For biogas production at 35ºC digestion temperature, the highest daily biogas production at standard conditions for horizontal and vertical digesters were 7.6 and 9.7 liters, respectively. These values were achieved at the twenty-one and eighteenth days, respectively and then started to decrease for the two digesters. Statistical analysis (T-test) at this digestion temperature revealed that there are statistically significant differences at the 1% level of significance between the two digesters type.

Data in Fig. (2) also showed that the cumulative biogas production obtained from horizontal and vertical digesters were 281.8 and 361.0 liters, respectively. This means that biogas produced from the vertical digester was 28.1% higher than this produced from the horizontal digester.

Methane content (%) of biogas was measured by Biogas Analyzer Model (GAS 5000). The results show that the maximum methane content of the produced biogas was 56.4 and 65.5 percent for horizontal and vertical digesters, respectively. These values were achieved at the twenty-eight and twenty day with the same digesters, respectively and then started to decrease for the two digesters.

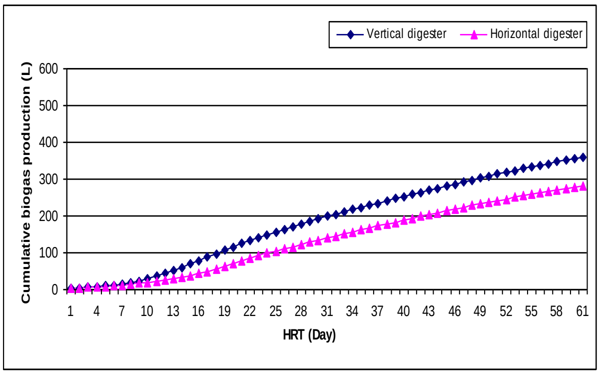


Fig. 2. The cumulative biogas production from the two biogas digesters at 35 ºC digestion temperature and stirring time of 15 min. / 2 hr.

For biogas production at 40 ºC, the highest daily biogas production at standard conditions for horizontal and vertical digesters were 11.1 and 12.7 liters, respectively. These values were achieved at fourteenth day for the two digesters, respectively and then started to decrease at the following time. Statistical analysis (T-test) at this digestion temperature revealed that there are statistically significant differences at 1% level of significance between the two digesters type.

Data in Fig. (3) also showed that the cumulative biogas production obtained from horizontal and vertical digesters were 383.0 and 503.3 liters, respectively. This means that biogas produced from the vertical digester was 31.4% higher than this produced from the horizontal digester. The results also show that, the maximum methane content of the produced biogas was 62.3 and 58.0 percent for the horizontal and the vertical digesters, respectively.

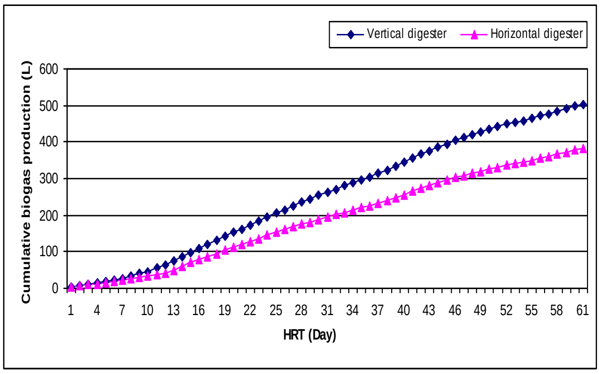


Fig. 3. The cumulative biogas production from the two biogas digesters at 40 ºC digestion temperature and stirring time of 15 min. / 2 hr.

On the other hands, biogas production at 45 ºC shows that, the highest daily biogas values at standard conditions for horizontal and vertical digesters were 14.5 and 18.3 liters, respectively. These values were achieved at the fourteenth and tenth day, respectively and then started to decrease for the two digesters. Statistical analysis (T-test) at this digestion temperature revealed that there are statistically significant differences at the 1% level of significance between the two digesters type.

Data in Fig. (4) also showed that the cumulative biogas production obtained from horizontal and vertical digester were 428.5 and 505.9 liters, respectively. This means that biogas produced from the vertical digester was 18.1% higher than this produced from the horizontal digester. While, the maximum methane content of the produced biogas was 57.8 and 56.6 percent for the horizontal and the vertical digesters, respectively.

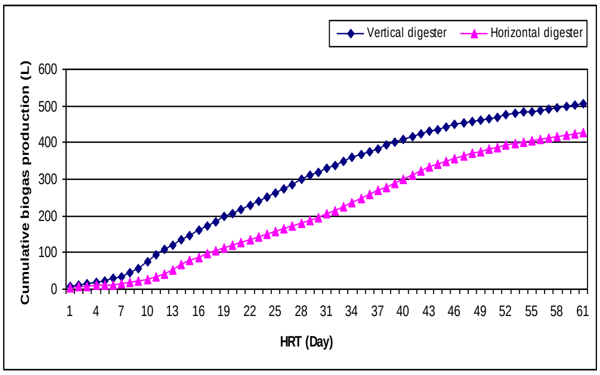


Fig. 4. The cumulative biogas production from the two biogas digesters at 45 ºC digestion temperature and stirring time of 15 min. / 2 hr.

Statistical analysis (ANOVA) showed that there were statistically significant differences for both the horizontal and the vertical digesters in biogas production at 35 °C and 40 °C with stirring time of 15 minutes every 2 hours while there were no significant differences for both digesters in the production of biogas at 40 °C and 45 °C the same time.

Effect of stirring time on biogas properties at digestion temperature of 40 °C:

The effect of stirring time of 15 minutes every 3 hours stirring time was studied to evaluate the biogas properties at

40 °C. Data revealed that the highest daily biogas production at standard conditions for the horizontal and the vertical digesters were 22.3 and 21.3 liters, respectively. These values were achieved at the thirty-two and sixteen day, respectively and then started to decrease for the two digesters until reached the end of retention time.

Data in Fig. (5) also showed that the cumulative biogas production obtained from horizontal and vertical digesters were 541.4 and 578.1 liters, respectively. This means that biogas produced from the vertical digester was 6.8% higher than this produced from the horizontal digester. Moreover the maximum methane content of the produced biogas was 65.3 and 59.2 percent for the horizontal and the vertical digester, respectively.

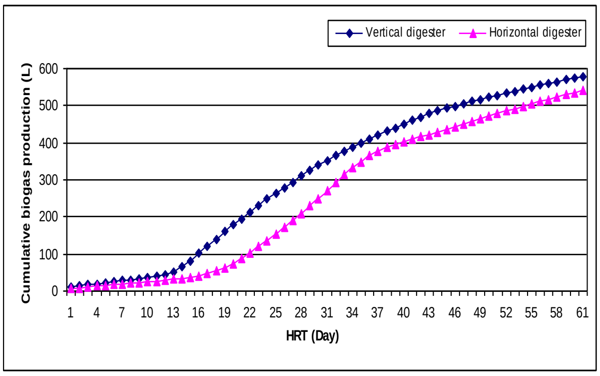


Fig. 5. The cumulative biogas production from the two biogas digesters at 40 ºC digestion temperature and stirring time of 15 min. / 3 hr.

The effect of stirring time of 15 minutes every 4 hours stirring time was also studied to evaluate the biogas properties at 40 °C. Data revealed that the highest daily biogas production at standard conditions for horizontal and vertical digesters were 13.0 and 21.8 liters, respectively. These values were achieved at twenty third day for the two digesters and then started to decrease for the two digesters type.

Data in Fig. (6) also showed that the cumulative biogas production obtained from horizontal and vertical digesters were 339.7 and 434.4 liters, respectively. This means that biogas produced from the vertical digester was 27.9% higher than this produced from the horizontal digester. While, methane content of produced biogas reached the maximum was 57.8 and 51.3 percent for the horizontal and the vertical digesters, respectively.

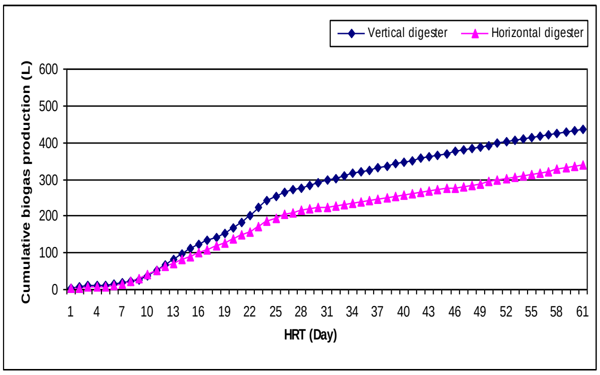


Fig. 6. The cumulative biogas production from the two biogas digesters at 40 ºC digestion temperature and stirring time of 15 min. / 4 hr.

Statistical analysis (ANOVA) revealed that for horizontal digester at 40 °C, there were statistically significant differences in biogas production with 15 minutes every 2 hours and 15 minutes every 3 hours stirring times. Also, there were statistically significant differences for the same digester and the same digestion temperature with 15 minutes every 3 hours and 15 minutes every 4 hours stirring times. While, there were no statistically significant differences in biogas production with 15 minutes every 2 hours and 15 minutes every 4 hours stirring times.

Statistical analysis (ANOVA) for the three parameters of the vertical digester at 40 °C was done to study the effect of stirring time on biogas properties. Slight differences were found between the stirring times of 15 minutes every 2 hours and 15 minutes every 3 hours while there were statistically significant differences between 15 minutes every 3 hours and 15 minutes every 4 hours stirring time. Statistical analysis also showed that the digestion temperature of 40 °C and 15 minutes every 3 hours was the best operation conditions of biogas properties.

This variation in biogas production between the horizontal and the vertical digesters for all experiments was attributed to the regular temperature distribution and varied by different stirring time. The methane content of produced biogas in the first week was low for all experiments as a result of the reduction of carbon dioxide rather than of acetate cleavage with reduction of methyl group. This pattern indicated that only CO_2 was produced during the first week of digestion. On the second week after the O_2 in the digester was consumed anaerobic conditions prevailed and methane gas generation started. These results are in agreement with that obtained by Sayed-Ahmed and Huzayyin (1986) and El-Hadidi (1999).

Calorific value of biogas production:

The results illustrated in Figs. (7 and 8) show calorific value of biogas production for the vertical and the horizontal digesters at all experiments. The calorific value of biogas production was calculated according to the average methane content. The calorific value of biogas production for the vertical digester was 7.20, 9.60 and 9.49 MJ at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 10.73 and 7.23 MJ at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The calorific value of biogas production for the horizontal digester was 5.20, 7.80 and 7.90 MJ at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 9.50 and 6.61 MJ at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The results revealed that calorific value of biogas production for the vertical digester are always higher than calorific value of biogas production for the horizontal digester at all experimental conditions.

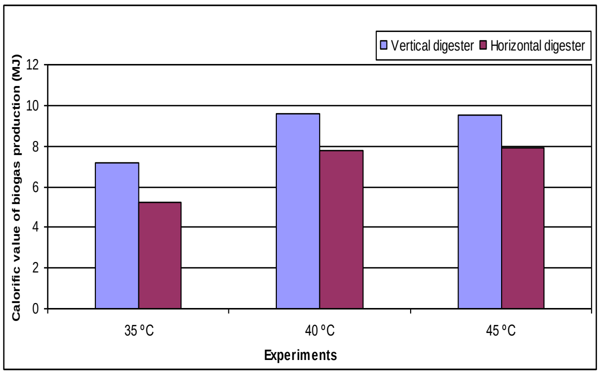


Fig. 7. Calorific value of biogas production at (35 ºC, 40 ºC and 45 ºC) digestion temperatures and stirring time of 15 min. / 2 hr.

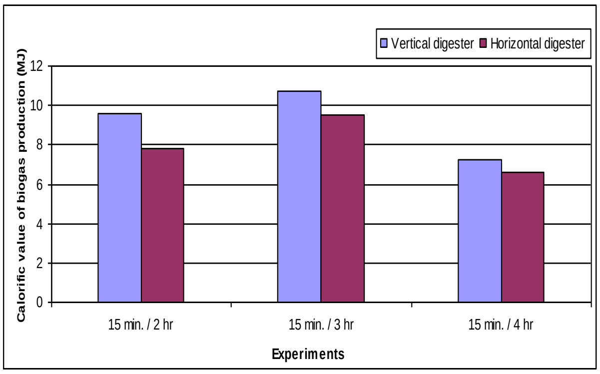


Fig. 8. Calorific value of biogas production at 40 ºC digestion temperatures with stirring time of (15 min. / 2 hr, 15 min. / 3 hr and 15 min. / 4 hr).

Chemical analysis of influent and effluent slurry:

Table (2) shows the obtained data of chemical analysis. It is evidenced that the effluent slurry of different experiments could be used as a good organic fertilizer.

This results are in line with that obtained by (Diaz *et al*., 2011 and Abubaker *et al*., 2012) who stated that the effluent slurry (Bio-fertilizer) obtained from bio-digestion process contains high concentration of plant nutrients (N, P, K concentration) and organic matter and it had tendency to gives higher crop yield and soil microbial activities. El-shimi and Badawi, (1993) also stated that, biogas fertilizer application at the rate equivalent to traditional chemical fertilizer increased the yield of maize 35.7%, wheat 12.5%, rice 5.9%, broad beans 6.6%, cotton 27.5%, carrots 14.4% and spinach 20.6%.

Table 2. Chemical analysis of influent and effluent slurry through anaerobic digestion.

Stirring time	Temperature	Dung	D.M, %	N, %	P, %	K, %	O.C, %	O.M, %	C:N ratio	pH
15min./2hr	35ºC	Influent	10.53	2.33	0.41	1.14	37.48	64.62	16.09	7.06
		Vertical effluent	9.30	2.51	0.57	1.45	34.64	59.72	13.8	7.2
		Horizontal effluent	9.61	2.47	0.47	1.35	30.25	52.16	12.25	7.24
	40ºC	Influent	10.64	2.35	0.49	1.09	40.67	70.12	17.31	7.25
		Vertical effluent	9.61	2.57	0.83	1.53	39.95	68.88	15.54	7.43
		Horizontal effluent	9.86	2.55	0.71	1.25	39.35	67.84	15.43	7.48
	45ºC	Influent	10.84	2.62	0.62	1.35	38.51	66.4	14.7	7.13
		Vertical effluent	8.44	2.7	0.69	1.67	37.21	64.16	13.78	7.37
		Horizontal effluent	8.78	2.67	0.64	1.50	36.64	63.17	13.72	7.41
15min./3hr	40ºC	Influent	10.24	3.26	0.46	1.11	52.97	91.33	16.25	6.65
		Vertical effluent	9.12	3.43	0.77	1.61	49.24	84.9	14.36	7.46
		Horizontal effluent	9.50	3.32	0.70	1.42	45.21	77.95	13.62	7.5
15min./4hr	40ºC	Influent	10.03	2.65	0.58	0.92	37.57	64.78	14.18	6.66
		Vertical effluent	9.12	2.7	0.67	1.05	36.83	63.5	13.64	7.45
		Horizontal effluent	9.50	2.67	0.63	1.04	35.64	61.45	13.35	7.51

The BOD status for the influent and effluent at all experiments:

The results illustrated in Figs. (9 and 10) show the BOD status for the influent and effluent of the different experiments. The BOD values for the vertical digester effluent are always lower than the BOD values for the horizontal digester effluent at all experiments. The BOD values for the influent were 400, 500 and 355 mg/l at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 315 and 215 mg/l at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The BOD values for the vertical digester effluent were 45, 40 and 20 (mg/l) at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 15 and 22.5 mg/l at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The BOD values for the horizontal digester effluent were 80, 75 and 30 mg/l at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 20 and 33.5 mg/l at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The results revealed that the variation in the BOD values between the horizontal and the vertical digesters with all experiments was attributed to the regular temperature distribution. The BOD values of the effluent slurry decreased by increasing the digestion temperature and varied by different stirring time.

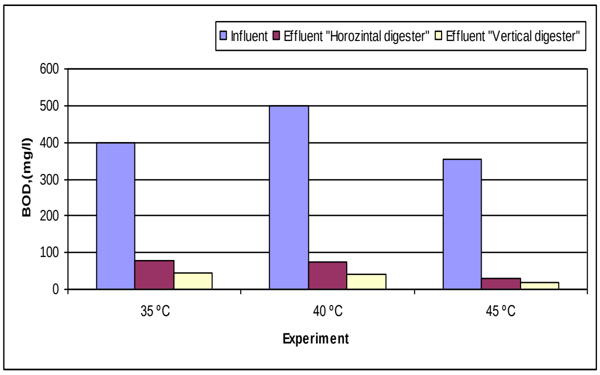


Fig. 9. BOD values at (35 ºC, 40 ºC and 45 ºC) digestion temperatures and stirring time of 15 min. / 2 hr.

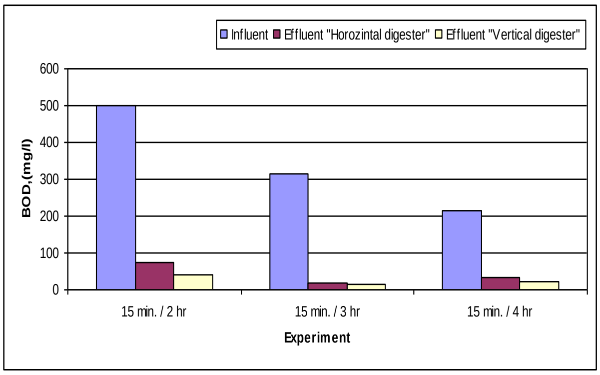


Fig. 10. BOD values at 40 ºC digestion temperatures with stirring time of (15 min. / 2 hr, 15 min. / 3 hr and 15 min. / 4 hr).

Digestion process efficiency at all experiments:

The results illustrated in Figs. (11 and 12) show the efficiency of the digestion process was increased by increasing the digestion temperature and varied by different stirring time. The efficiency of the digestion process for the vertical digester was 88.75, 92.0 and 94.37 % at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 95.24 and 89.54 % at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The efficiency of the digestion process for the horizontal digester effluent was 80.0, 85.0 and 91.54 % at digestion temperatures of 35 ºC, 40 ºC and 45 ºC, respectively, at stirring time of 15 minutes every 2 hours, while it was 93.65 and 84.51 % at digestion temperature of 40 ºC with stirring time 15 minutes every 3 hours and 15 minutes every 4 hours, respectively. The results revealed that the efficiency of the digestion process for the vertical digester are always higher than the efficiency of the horizontal digester at all experimental conditions.

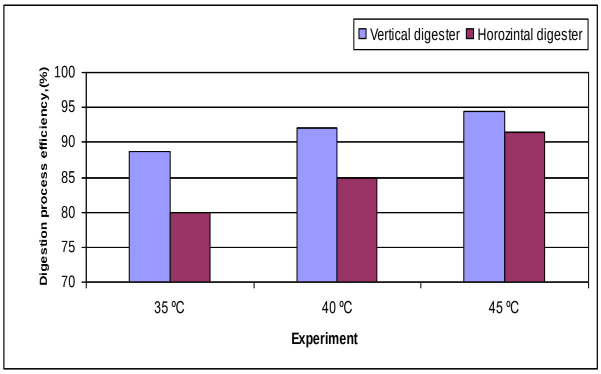


Fig. 11. Digestion process efficiency at (35 ºC, 40 ºC and 45 ºC) digestion temperatures and stirring time of 15 min. / 2 hr.

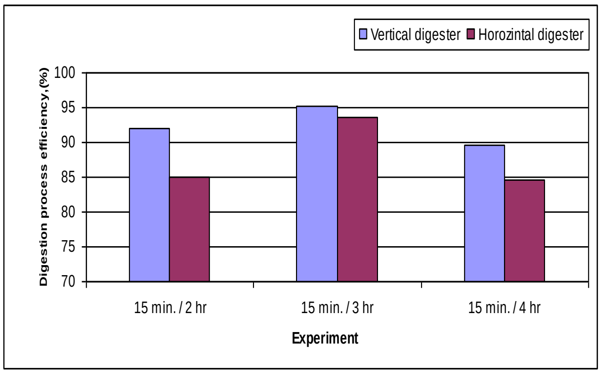


Fig. 12. Digestion process efficiency at 40 ºC digestion temperatures with stirring time of (15 min. / 2 hr, 15 min. / 3 hr and 15 min. / 4 hr).

CONCLUSION

1. The vertical digester showed more biogas production than that from horizontal one at all experimental conditions.
2. It is recommended to use temperature of 40 ºC with stirring time of 15 minutes every 3 hours and total solid 12% at stirring speed of 120 rpm in order to get the highest biogas production with high methane content and calorific value.
3. According to chemical analysis, the effluent slurry of different experiments could be used as a good organic fertilizer which contains high concentration of plant nutrients (N, P, K concentration).

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تأثير درجة حرارة الهضم وزمن التقليب على خصائص الغاز الحيوي بإستخدام وحدات رأسية وأفقية

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تم تنفيذ هذا العمل بهدف المقارنة بين أداء المخمر الأفقي و المخمر الرأسي لإنتاج الغاز الحيوي من المخلفات الحيوانية كمصدر للطاقة الجديدة والمتجددة في معمل الغاز الحيوي بقسم الهندسة الزراعية بكلية الزراعة - جامعة المنصورة. تم تغذية مخمرين من النوع الأفقي و النوع الرأسي بمحلول يحتوى على مخلف حيوانى (روث جاموس) و تشغيل المخمرين على ثلاث درجات حرارة (35 °م ، 40 °م ، 45 °م) مع تثبيت فترة التقليب عند 15 دقيقة كل ساعتين وعند تركيز 12٪ مادة صلبة وذلك لاختيار أفضل درجة حرارة للتخمر. تم استخدام أفضل درجة حرارة للتخمر مع فترتي تقليب مختلفتين (15 دقيقة كل 3 ساعات ، 15 دقيقة كل 4 ساعات) كما تم ضبط سرعة التقليب لجميع التجارب على 120 لفة في الدقيقة. عند زمن مكوث 60 يومًا. تم ايضاً إجراء التحليل الكيميائي والطلب على الأكسجين البيوكيميائي لكلاً من الروث قبل التخمر والحمأة الناتجة بعد التخمر. وتم تسجيل إنتاج الغاز الحيوي اليومي ومحتواه من الميثان وثاني أكسيد الكربون وتسجيل الضغط ودرجة الحرارة ثم حساب كلاً من معدل إنتاج الغاز الحيوي اليومى والتراكمي ، والإنتاجية ، ومحتوى الغاز من الميثان ، والقيمة الحرارية للغاز الناتج عند جميع المعاملات. وأوضحت أهم النتائج المتحصل عليها من الدراسة الآتي:1- إن المخمر الرأسي أفضل من المخمر الأفقي لإنتاج الغاز الحيوي من المخلفات الحيوانية كمصدر للطاقة الجديدة والمتجددة.2- يوصى باستخدام درجة حرارة 40 درجة مئوية مع فترة تقليب 15 دقيقة كل 3 ساعات ونسبة المادة الصلبة 12٪ عندما تكون سرعة التقليب 120 لفة في الدقيقة للحصول على أعلى قيمة من معدل إنتاج الغاز الحيوي ومحتواه من الميثان بالإضافة الى أعلى قيمة حرارية.3- وفقاً للتحليل الكيميائي ، يوصي بإستخدام الحمأة الناتجة من التجارب المختلفة كسماد عضوي جيد ومناسب حيث يحتوى على تركيز عالي من النيتروجين والفسفور والبوتاسيوم.