Methane Generation from Anaerobic Co-digestion of Food Wastes and Cattle Dung

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Abstract: Organic wastes, such as cattle dung and food wastes have long been blamed as a major source of air and water pollution. However, organic wastes can become part of the solution instead of the problem by using appropriate technology to deal with such wastes. The most promising technology is probably anaerobic digestion which can convert organic wastes into biogas to produce energy while achieving environmental and economic benefits. Therefore the objective of this study was to investigation the feasibility of biogas and methane production from food wastes and cattle dung by co-digestion system under traditional condition in the batch bench-scale digester including three horizontal and three vertical shapes. Three mixtures of food wastes (F) and cattle dung (C) based on total solids (TS) percentage [F:C, (25%:75%), (50%:50%) and (75%:25%)] were digested with hydraulic retention time (HRT) 155 days. The results showed that, the maximum yield of biogas and methane were 0.34 L biogas/g VS and 0.21 L CH_4/g VS at 25% TS of food wastes in the mixture of horizontal digester. Meanwhile the minimum biogas and methane yield were 0.097 L biogas/g VS and 0.068 L CH_4/g VS at 25% TS of food wastes in the mixture of vertical digester. We concluded that, the biogas yield was influenced by the digester shape and TS based food wastes. The initial, final and average ambient temperature of co-digestion mixtures inside digester were 20.5, 33.3 and 29 °C respectively. The change of temperature has a negative effect on bacterial activity. The quantitative variety in biogas and methane production were related to digester shape, total solids of food wastes in the mixtures, pH value, C:N ratio and ambient temperature.

***Keywords*:** Anaerobic co-digestion; Food wastes; Cattle dung; Batch; Biogas; Methane content; digester shape.

INTRODUCTION

The disposal of biodegradable solid wastes such as food wastes and activated sludge alone, or with other solid wastes creates serious environmental and economic problems everywhere in the world (Lim *et al.*, 2008). Therefore there is a great need to develop of alternative methods for treating food wastes in Egypt. Anaerobic digestion of sorted organic fraction of municipal solid wastes, especially food wastes, is the considered as a perspective way for its disposal and the most cost-effective technology (Fehr *et al.*, 2002; Rao and Singh, 2004).

Food wastes can be digested rapidly, making it a good source of material for anaerobic digestion. High calorie food waste is easily degraded by fermentative bacteria, which produce large amounts of organic acids. Acid production lowers reactor pH inhibiting the methanogenic system and limiting the generation of significant amounts of methane (Bouallagui *et al.*, 2004). The activity of methanogenic bacteria begins to become inhibited at a pH 6.6 and pH values below 6 are clear indication that too much acid is being formed as a result of too few methanogenic bacteria (Kuria, 2008). The amount of one type of organic waste generated at a particular site at a certain time may not be sufficient to make anaerobic digestion cost-effective all year round. Co-digestion then becomes an interesting alternative as it is a well-established concept and it has many advantages (Mata-Alvarez *et al.*, 2000; Misi and Forster, 2001).

Optimization of methane generation from anaerobic systems has focused on digester design and operation, although it has been stated that the feedstock is as important as the digester technology (Lissens *et al.*, 2001). There are a number of technical constraints associated with anaerobically digesting food wastes that may be overcome using a range of techniques such as co-digestion and sequential batch operation. From a technical perspective, the practice of mixing food wastes with dairy manure in anaerobic digesters has shown that, increased biogas production and possibly a reduction of H_2S concentration in biogas, provides buffering capacity to prevent acidic conditions and continued microbial feeding when the food waste is not available (Fiesinger, 2006). Co-digestion of dairy manure and food waste is considered to be one of the effective options to improve the economics of dairy digesters, because food waste is a highly biodegradable substrate as compared with manure (Zhang *et al.*, 2007). Anaerobic batch digestion experiments are useful because they can be performed quickly with simple, inexpensive equipment, and are useful in assessing the rate at which a material can be digested (Stewart *et al.*, 1984 and Lissens *et al.*, 2001).

In developing countries, many of the digesters do not have mixing components, do not require continuous monitoring, and are adaptable to any tropical climate (Ong *et al.*, 2000). Temperature fluctuations could occur even when digesters are lagged resulting in low and uneconomic biogas yield. This is because the response of methane-forming anaerobes (methanogens) to temperature changes is almost immediate since this affects the rate of their enzymatic-catalyzed reactions and causes shock on them (Itodo *et al.*, 1997; Itodo and Philip, 2001). Also, changes in ambient temperature can have a negative effect on bacterial activity (GTZ, 2007). Methanogenic bacteria are also known to be very sensitive to temperature changes, the degree of sensitivity being dependent on the range of temperature change. Changes in temperature of less than ±2 °C /h, ±1 °C /h and ±0.5 °C /h in the cryophilic, mesophilic and thermophilic anaerobic temperature ranges, respectively, are considered to be un-inhibitive (Hohfeld and Sasse, 1985). In additions, a sudden change of more than 5 °C /day may cause a digester to stop working temporarily resulting in accumulation of volatile acids and eventual stalling of the digester. This phenomenon is less of a problem in large digesters where, the high heat capacity of the slurry ensures that the digester temperature changes slowly (Fulford, 1988). The acetogenic microorganisms have an optimum temperature of 30 °C, whereas the methanogenic ones have an optimum temperature of 35 °C (Gerardi, 2003). Conventional anaerobic digesters require feed material with total solids content below 10% (Forster-Carneiro *et al.*, 2008).

Optimum C:N ratio in anaerobic digesters are between 20 and 30:1 (Marchaim, 1992 and Kuria, 2008). Meanwhile the values most commonly recommended for C:N ratio for effective biodegradation are in the range of 25:1 to 30:1 (Mital, 1996). A high C:N ratio is an indication of a rapid consumption of nitrogen by the methanogens and results in a lower gas production. On the other hand, a lower C:N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. Optimum C:N ratio of the feedstock materials can be achieved by mixing waste of low and high C:N ratio, such as organic solid waste mixed with animal manure (Shefali, 2002). The C:N ratio of the dung for cattle and buffalo varied from 19.57 to 49.83 depending upon the feed material, a higher C:N ratio was observed with feeding of straw rather than with green fodder (NPCS Board of Consultants & Engineers, 2008). Hohfeld and Sasse (1985) reported that, the kitchen waste C:N ratio is 28.6. The pH of kitchen waste average, minimum and maximum value was 4.5, 3.8 and 5.3 respectively (Fuchigami *et al.*, 2001).

Methane production depends on the type of food waste. Lay *et al.* (1997) found the methane potential depending on the type of food such as for meat, cabbage, carrot, rice, and potato as 0.424, 0.096, 0.269, 0.214, and 0.203 L CH_4 g^{-1} VS, respectively. Sarada and Nand (1989) achieved 0.430 L CH_4 g^{-1} VS for tomato processing waste. All of these materials were found to some degree in the food waste collected from student restaurant Suez Canal University, Ismailia, Egypt. El-Mashad *et al.* (2006) studied mesophilic batch co-digestion of dairy manure and food waste and determined biogas yields from manure, food waste, and two mixtures. The first mixture was composed of 32% food waste and 68% dairy manure. The second mixture was composed of 48% food waste and 52% dairy manure. The percentage was based on volatile solids (VS). Biogas yields after 30 days of digestion were determined to be 366, 657, 455, and 505 L kg^{-1} VS for manure and food waste, the first and second mixtures with average methane content of the biogas being 66%, 54%, 62%, and 59%, respectively.

The aim of this study was to characterize the anaerobic biodegradability potential of food wastes and its biogas production, as well as component methane through batch anaerobic fermentation using different digester shape (horizontal and vertical) under ambient temperature. Also, the proportions of food wastes and cattle dung in mixtures were studied in order to determine optimum mixtures for successful co-digestion.

MATERIALS AND METHODS

Substrates

Food wastes

Food wastes were collected from the student restaurant at (Suez Canal University, Ismailia, Egypt). Components of the food wastes included cooked food such as rice, meat, potatoes, vegetables and bread. There was a high proportion of oily and fatty material associated with the food wastes. Any non-organic contamination such as paper, bones and another material was separated and removed by hand before use, then mixed and shredded to a diameter of 5 mm using a meat shredder.

Due to the calculation of the total solids and volatile solids percentage of food wastes and the digester process can confirm the conversion performance of the digester (organic loading rate and the biogas production). Therefore, the total solids (TS) of food wastes ranged between 12.9 to 21.3% with average 17.1%, while the average of volatile solid (VS) was 15.2%. The food wastes were diluted by tap water to rich total solid 8.3%, with a volatile solid 7.7%, approximately. The characteristics of food wastes and cattle dung under consideration are shown in Table (1).

Cattle dung

Cattle dung was collected from animal shed at Animal production station, Faculty of Agriculture, Suez-Canal University.

Table (1): Characteristics of the food wastes and cattle dung used in the experiments.

Characteristic	Food wastes	Cattle dung
pH	3.83	6.94
Total solids, TS (g/L)	83.0	79.0
Volatile solids, VS (g/L)	77.0	59.0
VS (% of TS)	93.0	74.3
Organic carbon (% of TS)	54.0	43.1
Carbon : nitrogen ratio C:N	29:1	36:1

Bench-scale biogas digester:

A bench-scale of cylindrical biogas digester (horizontal and vertical shape) is shown in Figs. (1) and (2). Six units; three horizontal and three vertical were manufactured at the Agricultural Engineering Department, Faculty of Agriculture, Suez-Canal University. Each digester was fabricated from galvanized steel sheet of 1.5 mm thick, 450 mm long and 250 mm diameter with total capacity of 22 liters and digestion volume of 17 liters. Galvanized steel inlet and PVC outlet tubes diameter 50.8 mm were connected to feeding the digester and rejecting the digested materials. To follow up the digestion processes, the digester was provided by two orifices, one to release the produced gas and another for the pH-temperatures measurements.

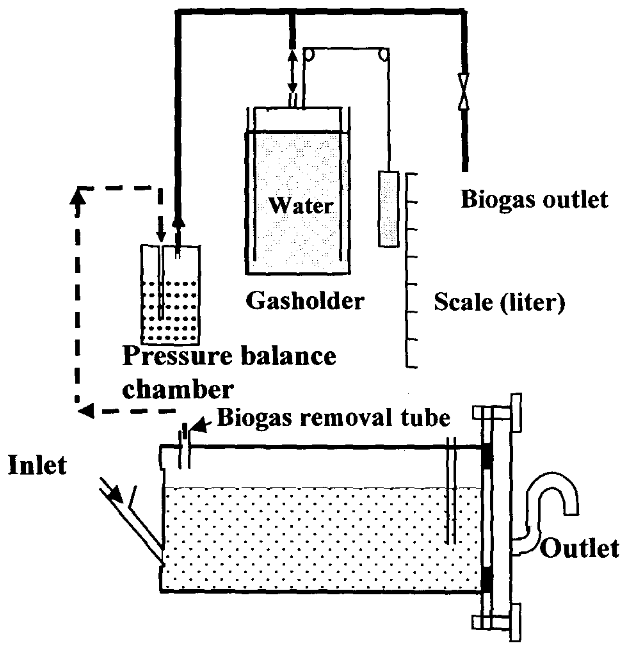

Fig. (1): Schematic diagram representing the horizontal bench-scale biogas digester.

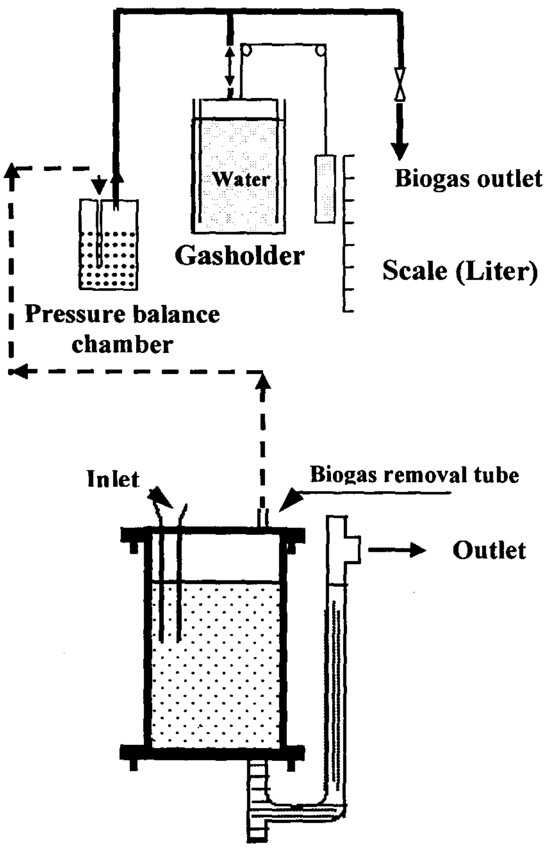

Fig. (2): Schematic diagram representing the vertical bench-scale biogas digester.

Experimental design

The various investigated mixtures of food wastes and cattle dung are presented in Table (2). They were prepared before entering the digesters to ensure a sufficient homogeneity. Six digesters (D1-D6) containing food wastes of 25, 50 and 75% of TS were performed. The first three digesters were horizontal shape while another three digesters were vertical shape. The corresponding food wastes to cattle dung ratio FCRs were 0.33, 1.0 and 3.0 respectively. The digestion mixtures had final TS concentrations, approximately 8%. The experiments were run for 155 days hydraulic retention time (HRT) from 4 April to 6 September 2008 at room temperature without mixing and terminated when no significant gas production was observed over a one week period. All other factors, such as physical parameters were kept constant.

The Compositions of co-digestion of food wastes and cattle dung are presented in Table (3).

Table (2): Amounts of food wastes and cattle dung, expressed as % of TS and the food wastes to cattle dung ratio (FCR) used in the various batch digestion experiments (D1–D6).

Exp. No.	D1	D2	D3	D4	D5	D6
Digester shape	Horizontal			Vertical		
Cattle dung (% of TS)	75	50	25	75	50	25
Food wastes (% of TS)	25	50	75	25	50	75
FCR	0.33	1	3	0.33	1	3

Table (3): Compositions of co-digestion of food wastes and cattle dung.

Exp. No.	D1	D2	D3	D4	D5	D6
Total solids, TS (g/L)	80	79	81	80	79	81
Volatile solids, VS (g/L)	67	66	72	67	66	72
VS (% of TS)	83.8	83.5	88.9	83.8	83.5	88.9
Organic carbon (% of TS)	48.58	48.48	51.56	48.58	48.48	51.56
Carbon : nitrogen ratio C:N	34:1	32:1	31:1	34:1	32:1	31:1
pH	5.73	4.79	4.58	5.73	4.79	4.58

Analytical methods:

Released biogas volume was collected in gasholder and evaluated by using the wetted displacement with a previously calibrated scale in liter as it is presented Figs. (1) and (2). The biogas composition was fractioned in a percentage *i.e.* methane and CO_2 percentage using the Potassium hydroxide 40% (Abdel-Hadi, 2008). The TS, VS and total Kjeldahl nitrogen (TKN) levels were determined according to standard methods (APHA-AWWA-WPCF, 1998). The temperature and pH value of the mixtures solution inside the bench-scale digesters were measured regularly every five day using Jenway pH hand held meter model 370pH/mv.

RESULTS AND DISCUSSION

The biogas and methane yield during anaerobic co-digestion of food wastes and cattle dung at different concentrations of TS are shown in Fig. (3). As shown in the Fig., the maximum of biogas and methane yield were 0.34 L biogas/g VS and 0.21 L CH_4/g VS at 25% TS of food wastes in mixture and FCR 0.33 for horizontal digester shape. Meanwhile the minimum biogas and methane yield recorded 0.097 L biogas/g VS and 0.068 L CH_4/g VS at 25% of TS food wastes and FCR of 0.33 for vertical digester shape. The biogas and methane yield showed decrease with increasing food wastes concentration from 25% to 75% in mixture at horizontal digester, meanwhile the biogas increased with increasing food wastes concentration from 25% to 75% in mixture at vertical digester. Methane yield increased with increasing FCR from 0.33 up to 1.0 and decreased with higher FCR up to 3.0. The obtained results indicted that, the mixtures in vertical digester have a higher height than horizontal digester, so the fermentative bacteria *i.e.* acetogenic and methanogenic bacteria may be more effective in different layers of mixtures. Also the degradation percent in vertical digester more than in horizontal digester (see Table 5 for details). Generally the obtained methane yield L /g VS was little due to the food wastes has high content of rice, and potato waste (Lay *et al.*, 1997).

The methane production (L / day / kg VS) during different HRT is illustrated in Fig. (4). It is clear that, there was slowly increase of the methane production in digester D1 and D2 up to day 65, and then decreased with increasing with HRT. Thus may be due to degradation of organic matter. Meanwhile the methane production (L / day / kg VS) in D4, D5 and D6 was little than D1 and D2 may be due to the pH value, which influenced by shape of digester. The methane quantity in the biogas mixture depends on the biogas yield, composition of food wastes and fermentation conditions.

The pH can be described as an indicator of the stability of the digestion medium as it is dependent upon the buffering capacity of the digester itself. It is an indicator of the state of equilibrium of the complex system, which is influenced by number of chemical balances. The relationship between biogas composition in terms of methane content and pH value during batch co-digestion is shown in Fig. (5).

In the all digesters the methanogenic bacteria was initially inhibited for about days 10-15. The D1, D2 and D3 followed by a slowly increase methane about 45.6, 70.1 and 50.3% at day 30 respectively, the average methane content for D1, D2 and D3 was 62.9, 69.1 and 49.4% respectively. Meanwhile the average methane content for D4, D5 and D6 was 70.5, 66.5 and 41.4% respectively. The decrease methane content was at D3 and D6 that refers to highest TS of food wastes in mixture and lower buffering from cattle dung. The relationship between biogas composition in terms of carbon dioxide content, degradation percent fed materials and pH value during batch co-digestion is shown in Fig. (6).

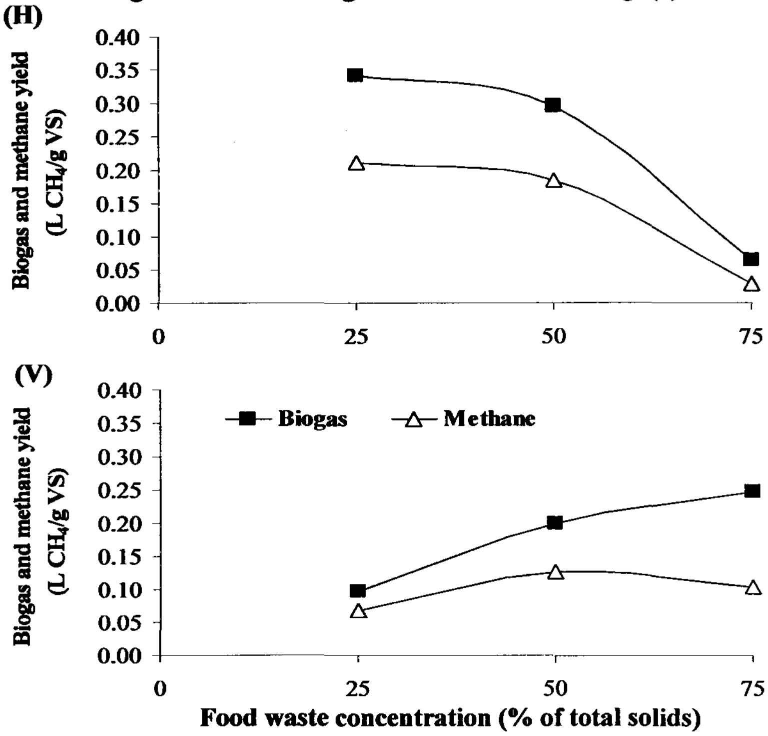

Fig. (3): Biogas and methane yield during batch anaerobic co-digestion of food wastes and cattle dung at different concentration of TS, (H) horizontal digester and (V) vertical digester.

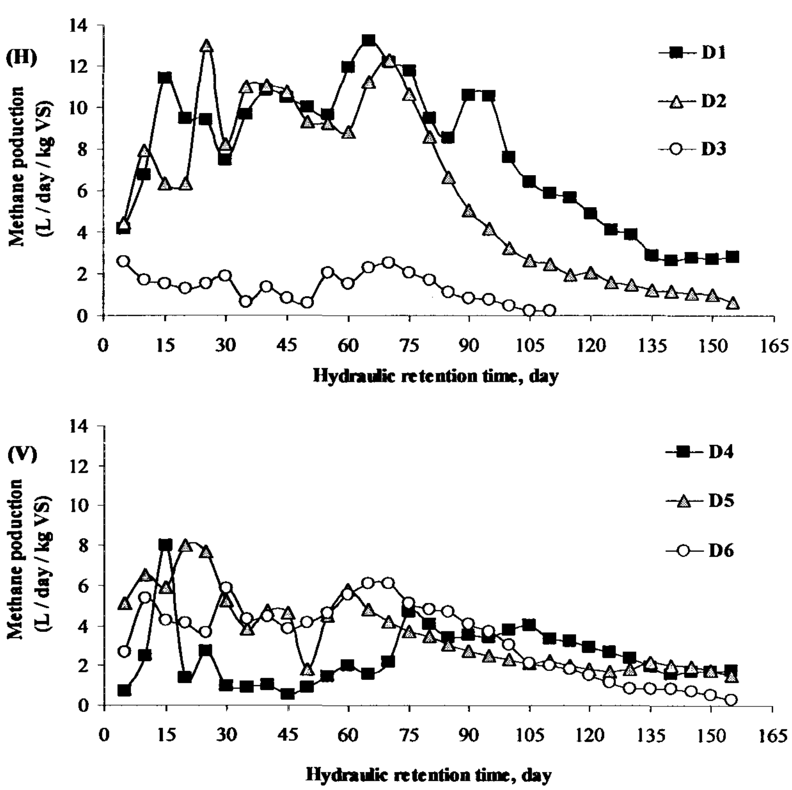

Fig. (4): Methane production (L / day / kg VS) during anaerobic co-digestion of food wastes and cattle dung, (H) horizontal digester and (V) vertical digester.

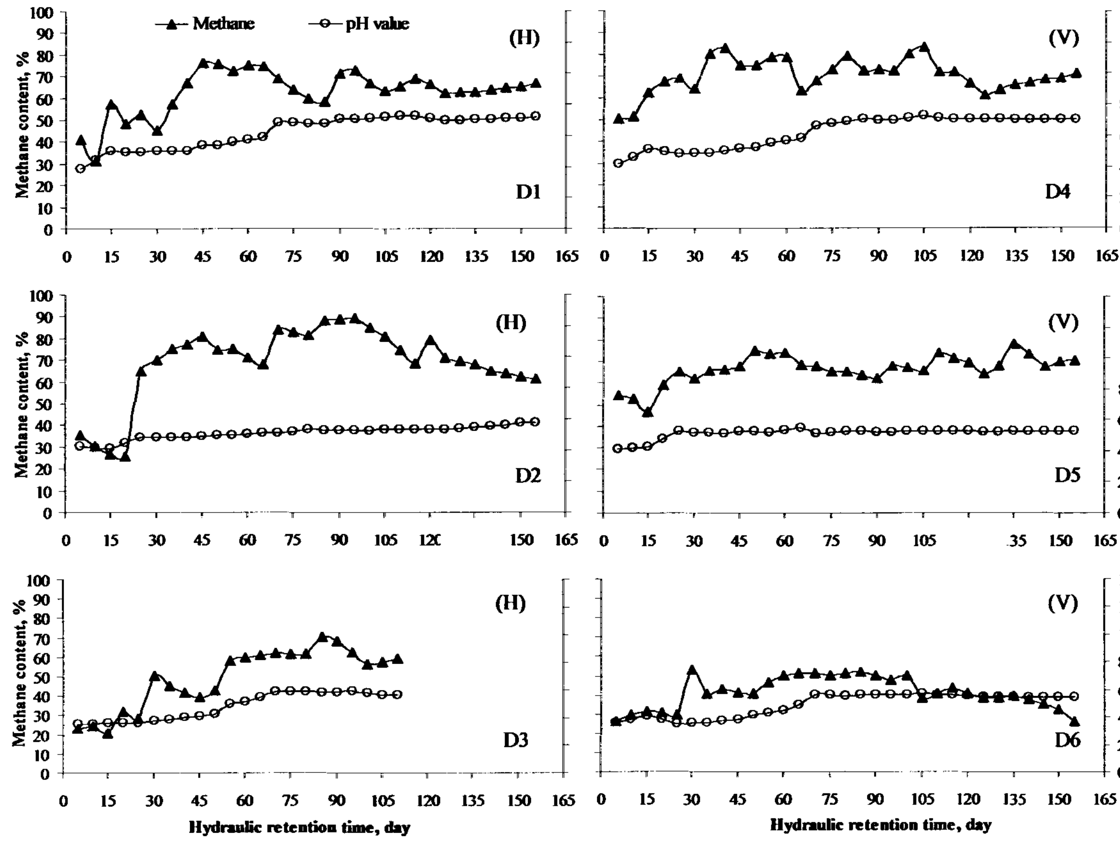

Fig. (5): Relationship between methane content and pH value during anaerobic co-digestion of food wastes and cattle dung, (H) horizontal digester and (V) vertical digester.

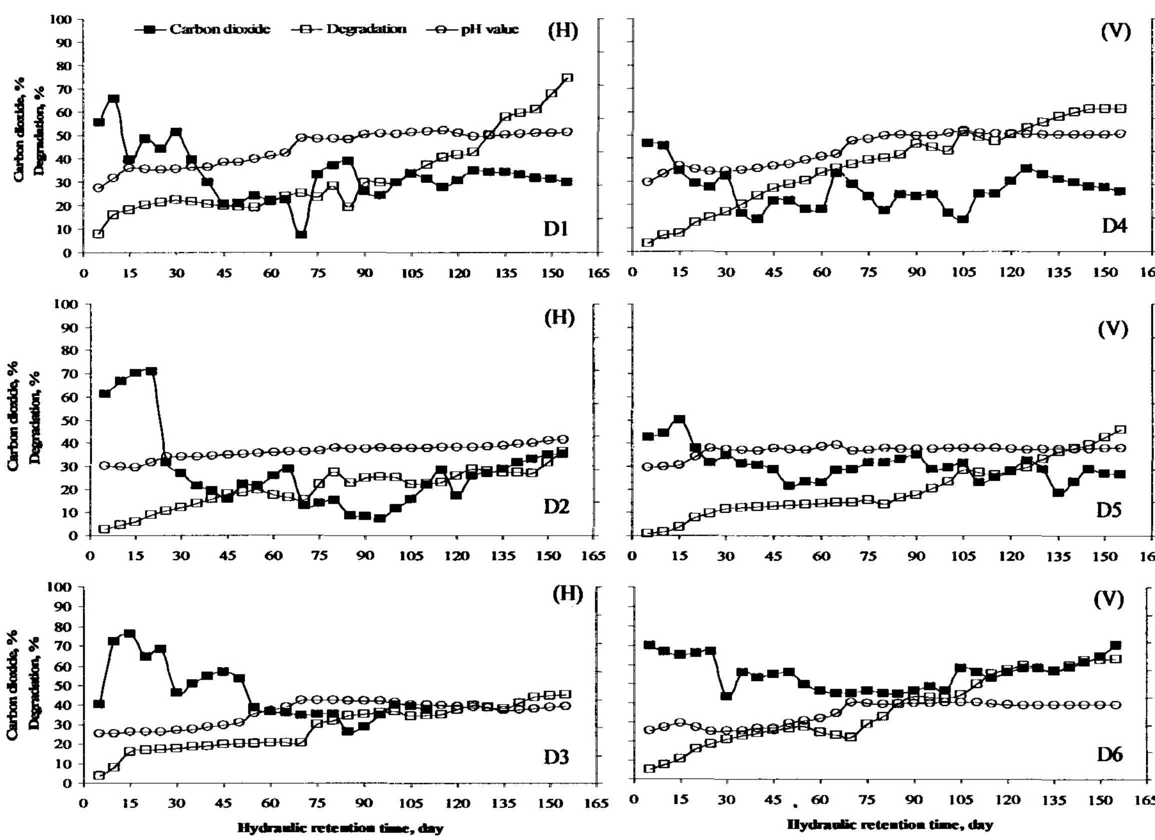

Fig. (6): The relationship between carbon dioxide percent, degradation percent and pH value during batch co-digestion of food wastes and cattle dung, (H) horizontal digester and (V) vertical digester.

In additions, the pH was largely dependent on carbon dioxide concentration in the medium but it also influenced by volatile fatty acid. According to Bouallagui *et al.* (2004) the degradation of food wastes is rapidly by fermentative bacteria, which lead to produce large amounts of organic acids. Acid production decreased the pH value, inhibiting the methanogenic bacteria and limiting the generation of significant amounts of methane.

Another factor also leads to organic acids production is the ambient temperature fermentative bacteria. The Characteristics of temperature of the co-digestion mixtures at the beginning and end experiments are given in Table (4). It can be seen that there was difference between the initial and final temperature co-digestion mixtures inside digester through hydraulic retention time of digestion; the range was around 12 °C. The minimum, maximum and average temperature was approximately 20.5, 33.3 and 29 °C respectively. This change of temperature can have a negative effect on bacterial activity (GTZ, 2007). The average temperature 29 °C co-digestion mixtures inside digester near the optimum temperature 30 °C for acetogenic microorganism, which lead to organic acids production and decreased pH value, whereas the methanogenic microorganism have an optimum temperature of 35 °C. This result is in agreement with the data published by Gerardi (2003).

Table (4): Characteristics in terms of temperature (°C) through the batch anaerobic co-digestion of food wastes and cattle dung from the beginning to the end experimental.

Exp. No.	Initial /Minimum	Maximum	Final	Range	Mean	Std. Deviation
D1	21.0	33.3	30.5	12.3	29.0	2.7693
D2	20.9	33.1	30.4	12.2	28.8	2.7888
D3	20.5	33.2	30.4	12.7	28.8	2.8235
D4	20.6	33.1	30.2	12.5	28.7	2.8623
D5	20.7	33.2	30.3	12.5	28.8	2.8781
D6	20.9	33.2	30.1	12.3	28.9	2.7884

During the digestion phase, the carbon is utilized to produce carbon dioxide and methane. The balance between carbon dioxide and methane production was dependent on acetogenic, methanogenic bacteria, degradation percent, pH value and C:N ratio. On another hand, when degradation percent increased and pH value decreased the carbon dioxide increased and methane production decreased. Also when, degradation percent increased and pH value increased the carbon dioxide decreased and methane production increased. Table (5) illustrated the average of degradation, carbon dioxide, methane percent, pH value and C:N ratio in all digesters.

Table (5): The average of the degradation, carbon dioxide, methane percent, pH value and C:N ratio at all digester.

Exp. No.	D1	D2	D3	D4	D5	D6
Digester shape		**Horizontal**			**Vertical**	
Degradation, %	33.6	21.0	29.5	38.9	20.9	38.1
Carbon dioxide, %	34.5	28.8	46.1	27.4	31.4	57.5
Methane, %	62.9	69.1	49.4	70.5	66.5	41.4
pH value	6.5	5.3	5.2	6.4	5.3	5.1
C:N ratio	26:1	27:1	25:1	30:1	27:1	23:1

The percentage of methane and carbon dioxide were direct proportion with the C:N ratio. The average of methane as % increased from 41.4 to 70.5% and in the same time the average percent of carbon dioxide was decreased from 57.5 to 27.4% by increased C:N ratio from 23:1 to 27:1 respectively. From the previous obtained date the methane productivity influenced by C:N ratio, which essential for cell synthesis and metabolism of anaerobic digestion. This result is in agreement with Shefali (2002) and Mital (1996). During the digestion process, the carbon is utilized to produce CO_2 and CH_4, leading to the reduction in carbon content and the C:N ratio decreased. The C:N ratio of the mixtures during batch anaerobic co-digestion is illustrated in Fig. (7).

Based on the previous results the quantitative variations in biogas and methane production were related with digester shape, total solids of food wastes in mixtures, pH value, C:N ratio and ambient temperature.

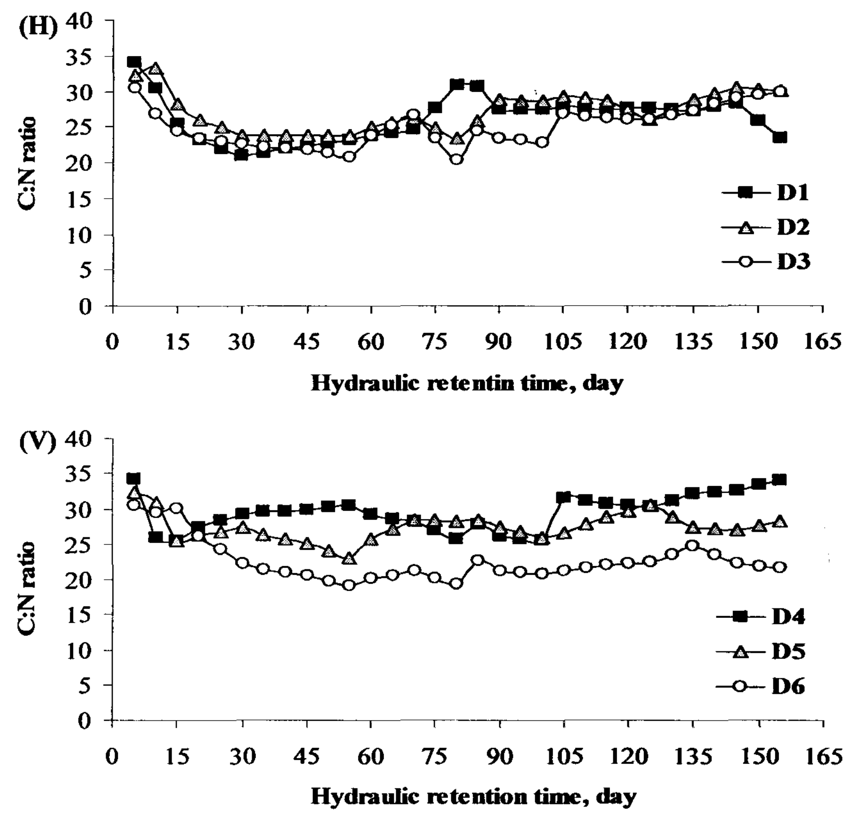

Fig. (7): Periodical changes in C:N ratio during batch anaerobic co-digestion of food wastes and cattle dung, (H) horizontal digester and (V) vertical digester.

CONCLUSIONS

From this study the following conclusion can be drawn:

- The preparation of food wastes before anaerobic fermentation must be done by removing paper, bones and another material from food wastes, and then mixed and shredded to a diameter of less than 5 mm. Then dilute the total solid content of food wastes with water around 8.0% TS.
- The maximum biogas and methane yield, 0.34 L biogas/g VS and 0.21 L CH_4/g VS, was obtained at 25% TS of food wastes in mixture at horizontal digester. Meanwhile the minimum biogas and methane yield, 0.097 L biogas/g VS and 0.068 L CH_4/g VS, was obtained at 25% TS food wastes at vertical digester.
- The biogas yield is influenced by the digester shape and TS based food waste, it decreased from 0.342 to 0.065 L biogas/g VS with increasing food wastes concentration from 25% to 75% in mixture at horizontal digester, meanwhile, it increased from 0.097 to 0.247 L biogas/g VS with increasing food wastes concentration from 25% to 75% in mixture at vertical digester.
- The balance between carbon dioxide and methane production was dependent on acetogenic, methanogenic bacteria, degradation percent and pH value. When the average degradation as % increased and pH value decreased; the percentages of CO_2 increased and CH_4 % decreased. Also when, the degradation percentage increased and pH value increased; the carbon dioxide decreased while methane content is increased.
- There was a difference between the initial and final co-digestion mixtures temperature inside digester; the range was around 12 °C. The minimum, maximum and average temperatures were 20.5, 33.3 and 29 °C approximately, respectively. This change of temperature has a negative effect on bacterial activity.
- The methane percentage is influenced by the C:N ratio, which increased of 41.4 to 70.5% and in the same time the average carbon dioxide % is decreased from 57.5% to 27.4% by increased C:N ratio from 23:1 to 27:1 respectively.
- The maximum biogas and methane generation from co-digestion food wastes and cattle dung were depended on digester shape (horizontal or vertical) and mixing components in digester; operation system such as the digestion temperature, which must be constant in region mesophilic; characteristics of components such as C:N ratio; proportions of food wastes and cattle dung based to TS%.

REFERENCES

Abdel-Hadi, M. A. (2008). A simple apparatus for biogas quality determination. Misr J. Ag. Eng., 25 (3): 1055–1066.

APHA-AWWA-WPCF (1998). Standards methods for the examination of water and wastewater. 20th edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington DC.

Bouallagui, H., M. Torrijos, J. J. Godon, R. Moletta, R. Ben Cheikh, Y. Touhami, J. P. Delgenes and M. Hamdi (2004). Two-phase anaerobic digestion of fruit an vegetable wastes: bioreactors performance. Biochemical Engineering Journal 21, 193–197.

El-Mashad, H. M., J. A. McGarvey and R. Zhang (2006). Bioenergy production from codigestion of food waste and dairy manure. In The Proceedings of The International Conference on The Future of Agriculture: Science, Stewardship, and Sustainability. 7-9 August 2006, Sacramento, California. Page 186-198.

Fehr, M., M. D. Calcado and D. C. Romao (2002). The basis of a policy for minimizing and recycling food waste, Environ. Sci., Policy 5, 247–253.

Fiesinger, T. (2006). A web-based spatial decision support system for utilizing organic wastes as renewable energy resources in New York State. Final Report, Prepared for The New York State Energy Research and Development Authority. 55 pp.

Forster-Carneiro, T., M. Pérez and L. I. Romero (2008). Influence of total solid and inoculum contents on performance of anaerobic reactors treating food waste. Bioresource Technology 99, 6994–7002.

Fuchigami, K., K. Mizuno, T. Minegishi, H. Atsuura and S. Ishimoto (2001). Methane Fermentation of Night Soil Sludge and Kitchen Waste Mixture. NKK technical review No.85. pp. 44-50, Japan.

Fulford, D. (1988). Running a Biogas Programme. A handbook, ITDG Publishing, ISBN 0946688494, London, UK.187 pages

Gerardi, M. H. (2003). The Microbiology of Anaerobic Digesters, John Wiley and Sons, New York. ISBN 0-471-20693-8. USA.

GTZ (2007). Biogas digest, Volume 1, biogas basics. http://www.gtz.de/de/dokumente/enbiogas-volume1.pdf (accessed November, 2007)

Hohfeld, J. and L. Sasse (1985). Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries. Schriftenreihe der gtz, No. 97. Grmany.

Itodo, I. N. and T. K. Philip (2001). Determination of suitable materials for anaerobic biogas digesters. Proceedings of the Annual Conference of the Nigerian Institution of Agricultural Engineers. 23:437-441

Itodo, I. N., E. B. Lucas and E. I. Kucha (1997). The effect of using solar energy in the thermophilic digestion of poultry waste. Journal of Engineering for International Development 3 (1): 15-21.

Kuria, J. (2008). Developing simple procedures for selecting, sizing, scheduling of materials and costing of small bio – gas units. International Journal for Service Learning in Engineering 3 (1), 9 - 40, ISSN 1555-9033.

Lay, J. J., Y. Y. Li, T. Noike, J. Endo and S. Ishimoto (1997). Analysis of environmental factors affecting methane production from high-solids organic waste. Water, Science and Technology 36 (6–7), 493–500.

Lim, S. J., B. J. Kim, C. M. Jeong, J. d. r. Choi, Y. H. Ahn and H. N. Chang (2008). Anaerobic organic acid production of food waste in once-a-day feeding and drawing-off bioreactor. Bioresource Technology, 99: 7866–7874.

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

Marchaim, U. (1992). Biogas processes for sustainable development. FAO Agricultural services Bulletin 95

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

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

Mital, K. M. (1996). Biogas Systems: Principles and Applications, New Age International (P) Limited Publishers, New Delhi, p. 412.

NPCS Board of Consultants & Engineers (2008). The Complete Book on Organic Farming and Production of Organic Compost. Handbook, Publisher: Asia Pacific Business Press Inc., ISBN: 9788178330433, Pp. 448.

Ong, H. K., P. F. Greenfield and P. C. Pullammanappallil (2000). An operational strategy for improved biomethanation of cattle-manure slurry in an unmixed, single-stage, digester. Bioresource Technology 73, 87–89.

Rao, M. S. and S. P. Singh (2004). Bio energy conversion studies of organic fraction of MSW: kinetic studies and gas yield-organic loading relationships for process optimization. Biores. Technol. 95, 173-185.

Sarada, R. and K. Nand (1989). Start-up of anaerobic digestion of tomato-processing wastes for methane generation. Biological Wastes. 30 (3), 231-237.

Shefali, V. (2002). Anaerobic digestion of biodegradable organics in municipal solid wastes, Master's thesis, Department of Earth & Environmental Engineering Fu Foundation School of Engineering & Applied Science, Columbia University, New York, USA.

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

Zhang, R., H. M. El-Mashad, K. Hartman, F. Wang, G. Liu, C. Choate and P. Gamble (2007). Characterization of food waste as feedstock for anaerobic digestion. Bioresource Technology, vol. 98, No. 4, pp. 929-935.

إنتاج الميثان بالتخمر اللاهوائي من خليط مخلفات الأغذية وروث الماشية

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يعتبر التخلص الآمن من المخلفات البلدية الصلبة القابلة للتحلل مثل مخلفات الأغذية التي تعد أحد مصادر تلوث البيئة (الهواء والماء والتربة) وانتشار الروائح الكريهة مشكلة اقتصادية. ويشكل ايجاد وتطوير طرق بديلة للتخلص من هذه المخلفات بدلاً من الطرق التقليدية (الحرق والكمر) أهمية قصوي في مصر. ويمثل التخمر اللاهوائي أحد الطرق البديلة الأقتصادية الآمنة لمعالجة المخلفات العضوية لإنتاج الغاز الحيوي (البيوجاز).

وقد أجريت دراسة معملية لإنتاج الغاز الحيوي بالتخمر اللاهوائي من مخلفات أغذية مطعم المدينة الجامعية بجامعة قناة السويس بالإسماعيلية. حيث تم تجهيز المخلفات بالفرم الي قطر ٥ مم بعد فصل الورق والعظم والمواد الأخري الغير عضوية منها. تم تخفيف المخلفات الناتجة بالماء الي نسبة مادة جافة كلية ٨% TS ثم خلطت مخلفات الأغذية وروث الماشية بنسبة خلط ٧٥:٢٥ ، ٥٠:٥٠ و ٢٥:٧٥% مادة جافة من مخلفات أغذية : روث ماشية علي التوالي وبنسبة مادة جافة كلية ٨% TSفي الخليط بالوحدة التجريبية للغاز الحيوي بقسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس. وقد استخدمت ستة مخمرات (ثلاثة مخمرات أفقية وأخري رأسية) مصنعة من الحديد المجلفن بسمك ١,٥مم و متساوية القطر ٢٥٠ مم و الارتفاع ٤٥٠ مم بحجم كلي ٢٢ لتر وحجم تخمر ١٧ لتر.

تم تغذية كل نسبة خلط في مخمر افقي وآخر رأسي نظام تغذية مرة واحدة تحت ظروف تشغيل تقليدية من درجة حرارة الغرفة وبدون تقليب. وتم تقدير النسبة المئوية للمادة الجافة العضوية VS معملياً في المادة المتخمرة لخليط المخلفات لحساب نسبة تحلل المادة العضوية خلال وقت الاستبقاء ١٥٥ يوم كما تم تقدير نسبة الكربون:النيتروجين C:N وقياس رقم الأس الهيدروجيني pH ودرجة الحرارة في المعاملات تحت الدراسة.

تم قياس كمية الغاز الحيوي باللتر ونسبة محتواه من غاز الميثان كل خمسة ايام علي أمتداد التجربة للمعاملات المختلفة وتم حساب كمية الغاز الحيوي و الميثان باللتر المتحصل عليها من كل واحد كيلو جرام مادة عضوية جافة.

<u>وقد توصلت الدراسة إلي النتائج التالية:</u>

- لتجهيز مخلفات الأغذية (بقايا الأطعمة) قبل الأستخدام في التخمر اللاهوائي لأنتاج الغاز الحيوي يجب فصل وأزالة الورق والعظم والمواد الأخري ثم تقطيع وطحن هذه المخلفات الي طول أقل من ٥ مم ثم تخفيف محتواها من المادة العضوية الجافة الي نسبة ٨% تقريباً بأضافة الماء اليها.
- أعلي كمية غاز حيوي وميثان منتجة كانت ٠,٣٤ و ٠,٢١ لتر/ جرام مادة عضوية جافة علي التوالي تم الحصول عليها من المعاملة ٢٥% مادة عضوية جافة من مخلفات الأغذية في الخليط في المخمر الأفقي. بينما كانت أقل كمية ٠,٠٩٧ و ٠,٠٦٨ لتر/ جرام مادة عضوية جافة علي التوالي لنفس الخليط ولكن في المخمر الرأسي.
- كمية البيوجاز المنتجة تتأثر بنوع المخمر ونسبة المواد الجافة العضوية في الخليط فكانت تقل من ٠,٣٤٢ الي ٠,٠٦٥ لتر/ جرام مادة عضوية جافة مع زيادة نسبة المواد الجافة العضوية في الخليط من ٢٥ الي ٧٥% في الخمر الأفقي. بينما كانت تزداد من ٠,٠٩٧ الي ٠,٢٤٧ لتر/ جرام مادة عضوية جافة مع زيادة نسبة المواد الجافة العضوية في الخليط من ٢٥ الي ٧٥% في الخمر الرأسي.
- التوازن بين مكونات الغاز الحيوي من غاز ثاني أوكسيد الكربون والميثان يعتمد علي بكتريا إنتاج الأحماض العضوية والميثان التي تتأثر بنسبة التحلل ودرجة الأس الهيدروجيني في المحلول. فعندما تزداد نسبة التحلل وتقل درجة الأس الهيدروجيني يزداد إنتاج ثاني أوكسيد الكربون ويقل إنتاج الميثان. أيضاً عندما تزداد نسبة التحلل وتزداد درجة الأس الهيدروجيني يقل أنتاج ثاني أوكسيد الكربون ويزداد أنتاج الميثان.
- التغير في درجة حرارة الغرفة ادي الي تأثير سلبي في نشاط بكتريا انتاج الميثان فكانت أقل وأعلي درجة حرارة تخمر داخل المخمرات ٢٠,٥ و ٣٣,٣ م° علي التوالي وبمدي تغير ١٢ م° بينما كان متوسط درجة حرارة التخمر ٢٩ م°
- نسبة الميثان وثاني أوكسيد الكربون تتأثر بنسبة الكربون:النيتروجين فيزداد متوسط نسبة الميثان من ٤١,٤ الي٧٠,٥% في المعاملات وفي نفس الوقت يقل متوسط نسبة ثاني أوكسيد الكربون من ٥٧,٥ الي ٢٧,٤% مع زيادة نسبة الكربون:النيتروجين من ٢٣:١ الي ٢٧:١ علي التوالي.
- لأنتاج أعلي كمية غاز حيوي وميثان من مخلفات الأغذية فإن ذلك يعتمد علي نوع المخمر (افقي - رأسي) ونظام التشغيل مثل درجة الحرارة التي يجب أن تكون ثابتة في مدي الميزوفلك وتقليب المكونات اثناء التخمر ونسب مكونات نوعية مخلفات الأغذية. كذلك نسب خلط مخلفات الأغذية مع مخلفات المواشي كمادة موازنة للتخمر.

يتضح مما سبق أنه لنجاح التخمر اللاهوائي لمخلفات الأغذية لإنتاج الغاز الحيوي تحت الظروف التقليدية في المخمرات (افقية – رأسية) يحتاج الي تجهيز المخلفات من تقطيع وطحن ثم تخفيف بالماء ثم الخلط مع مخلفات المواشي بنسب ثابتة. كذلك عزل وتدفئة المخمر في درجة حرارة ثابتة في مدي الميزوفلك ثم التقليب لتوزيع درجة الحرارة وتجانس درجة الأس الهيدروجيني في مخلوط التخمر. فضلاً عن العوامل الأخري مثل نسبة التحلل ونسبة الكربون:النيتروجين C:N ورقم الأس الهيدروجيني pH في المادة المتخمرة.