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Treatment of Solid Wastes by Anaerobic Digestion for Compost and Biogas Production

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ABSTRACT. Municipal solid wastes as food wastes, cattle dung and sewage sludge require a proper and environmentally accepted management before final disposal, they are considered a major source of air and water pollution. We can invest the energy generated as biogas and production of high quality compost in addition to free pathogen soil fertilizer while achieving environmental and economic benefits. The objective of this study was to investigate the feasibility of biogas and methane production from food wastes and cattle dung in the first experiment. The second one is the production of biogas and methane from sludge and cattle dung by co-digestion system under mesophilic conditions. The experiment done in the bench scale batch anaerobic digester (vertical type) with 8.5 liter capacity, 6 liter digestion volume, stirrer 80 rpm/min and 85 days hydraulic retention time (HRT) under 36 °C mesophilic conditions and the mixing ratio 50:50%, with total solid (8% TS) after dilution for both experiment. The results showed that, the biogas and methane yield were 0.122 L biogas/g VS and 0.078 L CH4/g VS at 50% TS of in the mixture of food wastes and cattle dung, but this ratio receded in case of sludge and cattle dung where the biogas and methane yield were 0.093 L biogas/g VS and 0.062 L CH4/g VS at 50% TS. On the other hand the produced biogas percentage was higher in case of sludge and cattle dung (66%) than food wastes and sludge which was (63.9%). The equilibrium between carbon dioxide and methane production was dependent on acetogenic, methanogenic bacteria, degradation percent and pH value. When the degradation ratio increased and pH value decreased; the percentages of CO_2 increased and CH_4% decreased. Also when the degradation% increased and pH value increased, the carbon dioxide decreased while methane content is increased. The methane percentage is influenced by the C:N ratio, which increased and in the same time the average CO_2% is decreased. Recent research demonstrates that using co-substrates in anaerobic digestion systems improves biogas yields.

Keywords**:** Anaerobic digestion, Solid wastes, Batch fermentation, Biogas, Methane content; Mesophilic.

1. Introduction

Chemical treatment of solid wastes and sludge is sometimes used and it encourages small particles and dissolved substances to form larger particles which facilitate separation. This is called chemical precipitation. Sludge is formed when these larger particles clump together during suitable separation methods [1].

Anaerobic digestion is the most applied technique for solid wastes and sewage sludge stabilization resulting in the reduction of sludge volatile solids and the production of biogas. The anaerobic stabilization is a slow process. Therefore, long residence times in the fermenters and large fermenter volumes are required [2].

The important processes in anaerobic digestion are hydrolysis, fermentation, acetogenesis, and methanogenesis. In the hydrolysis stage, complex organic materials are broken down into their constituent at parts such as amino acids, fatty acids, simple sugars and glucose [3]. In the Acidogenesis process, acidogenic bacteria turn the products of hydrolysis into simple organic compounds, mostly short chain (volatile) acids. The transition of the substrate from organic material to organic acids in the acid forming stages causes the pH of the system to drop. This is beneficial for the acidogenic and acetagenic bacteria that prefer a slightly acidic environment, with a pH of 4.5 - 5.5, and are less sensitive to changes in the incoming feed stream, but is problematic for the bacteria involved in the next stage of methanogenesis. Methanogens are very sensitive to changes and prefer a neutral to slightly alkaline environment [4]. If the pH is allowed to fall below 6, methanogenic bacteria cannot survive. A better indicator is therefore methane production [5]. The change in pH can be both an indicator and the cause of process imbalance [6].

Anaerobic digestion is used to stabilize solid wastes and convert part of the volatile compounds into biogas. The biogas can be applied as an energy resource either at the wastewater treatment plant itself or elsewhere. In comparison to mesophilic digestion, thermophilic treatment has some advantages, such as a somewhat higher biogas production, a higher destruction degree of pathogens, and a larger reduction in the amount of organic solids. Also, the retention time of solid wastes in the reactor can be reduced [7].

In the area of public health and pollution control, biogas technology can solve another major problem; that of the disposal of sanitation wastes. Digestion of these wastes can reduce the parasitic and pathogenic bacterial counts by over 90% [8,9]. There are several factors affecting biogas plants of which the major factors are summarized as follows: 1 .pH value, 2. Temperature, 3. Loading Rate, 4. Retention Time, 5. Alkalinity, 6. Toxicity and 7. C/N ratio .Microorganisms has a great role in this process, Anaerobic digestion is a complex microbial process wherein, a variety of bacteria are involved. These bacteria can be broadly classified as fermentative, acetogenic and methanogenic bacteria [10]. Hydrolytic bacteria bring about initial degradation of complex biopolymers such as cellulose, hemicellulose, proteins and lipids into dicarboxylic acids, volatile fatty acids (VFA), ammonia, carbondioxide, hydrogen, etc. Methanogenic bacteria which play a key role in the terminal step of anaerobic digestion use only a few compounds like acetate, methanol, methylamine, hydrogen and carbondioxide [11]. VFA and dicarboxylic acids are thus needed to be converted as much as possible to acetate, hydrogen and carbondioxide for maximum production of methane. This is brought about by hydrogen producing acetogenic bacteria which grow only in syntrophic association with hydrogen scavengers such as sulphate reducing or methanogenic bacteria [12]. Methanogenic bacteria or methanogens are the bacteria that act upon organic materials and produce methane and other gases in the process of completing their life-cycle in an anaerobic condition. As living organisms, they tend to prefer certain conditions and are sensitive to microclimate within the digester). To determine the organic content in the wastewater, the chemical oxygen demand, COD, is normally measured [13]. The COD test oxidizes both biologically degradable and non-biologically degradable organic material by adding an oxidizing agent, normally potassium dichromate ($K_2Cr_2O_7$). The COD test determines the energy released due to oxidation of the carbonaceous compounds. The COD test requires only 2 hours and is a more precise estimation of the organic content than the BOD test [14]. Biogas is generated when bacteria degrade biological material in the absence of Oxygen, in a process known as anaerobic digestion. Since biogas is a mixture of Methane (also known as marsh gas or natural gas, CH_4) and Carbon dioxide it is a renewable fuel produced from waste treatment [15]. Biogas is best used directly for cooking/heating, lighting or even absorption refrigeration rather than the complication and energy waste of trying to make electricity from biogas. It is also used to run pumps and equipment of a gas powered engine rather than using electricity. Biogas usually contains about 50 to 70 % CH_4, 30 to 40 % CO_2, and other types of gas, including Ammonia, Hydrogen Sulfide and other Noxious gas. It is also saturated with water vapor [16].

The objectives of this study were to characterize the anaerobic biodegradability potential for mixtures of (Sewage Sludge with cattle dung) and (food wastes with cattle dung) using batch experiments vertical digesters under mesophilic temperature and to determine the most suitable conditions for biogas and methane production.

2. Materials and Methods

2.1. Origin and preparation of organic material

2.1.1 Substrates

These substrates are mixture of Sewage sludge, cattle dung (Mix1) and food wastes with cattle dung (Mix2) from the following Sources.

2.1.2 Sewage sludge

The sewage sludge used for the experiment was collected from Mansoura wastewater treatment plant in Egypt. pH for sludge was 5.1.

2.1.3. Cattle dung

Cattle dung was collected from animal shed in rural village belonged to Mansoura city, prepared before entry to fermentor and pH was (7). Sewage sludge mixed with cattle dung 50:50 %, and total solid (TS) was 8 % and volatile solids (TS) was 6.14 %, as shown in the mixture sample which collected before entry of digester . The characteristics of Sewage sludge and cattle dung are shown in Table (1).

2.1.4. Food wastes

Food wastes were collected from the public restaurant at (Mansoura city, Egypt). There was cooked food wastes such as bread, potatoes, rice, meat, and vegetables, these wastes included to fatty and oily material associated with the food wastes. The non-organic material such as bones and papers were separated and removed by hand before using, after that, they mixed and shredded to a diameter of 0.5 Cm. pH for Food wastes was (4).

Table 1a. The characteristics of Sewage sludge and cattle dung mixture1.

Characteristic	inoculum mixture (Sludge and cattle dung)
pH	6.4
Total solids, TS (g/L)	80.0 = 8 %
Volatile solids, VS (g/L)	61.4 = 6.14%
VS (% of TS)	76.75
Organic carbon (% of TS)	44.5
Carbon : nitrogen ratio C:N	12.8
Alkalinity (mg/l) as $CaCO_3$	5,500

In the First experiment for Sludge, pH was 5.4 at the beginning, (5.7 % TS) & (4.42 % OTS "VS"). In the Second experiment for Food Wastes, pH was 4.0 at the beginning, (7.92 % TS) & (7.1 % OTS "VS"). VS (% of TS) 89.5%. The beginning for Dung in both experiments was 7.1 pH, (6.8 % TS) & (5.1 % OTS "VS").

Table 1b. The characteristics of food wastes and cattle dung mixture2.

Characteristic	inoculum mixture (food wastes and cattle dung)
pH	5.8
Total solids, TS (g/L)	80.0 = 8.0 %
Volatile solids, VS (g/L)	58.0 = 5.8 %
VS (% of TS)	72.3
Organic carbon (% of TS)	42
Carbon : nitrogen ratio C:N	21.6
Alkalinity (mg/l) as $CaCO_3$	4,920

2.2. Bench-scale Biogas Digester

A bench-scale of cylindrical biogas digester (vertical type) as shown in Fig. 1. was constructed at the workshop in Mansoura city . The digester was fabricated from galvanized steel sheet of 270 mm long and 200 mm diameter with total capacity of 8.5 liters and actual digestion volume of 6 liters. To follow up the digestion processes, the digester was equipped by two orifices; one for releasing the produced gas and the other for the pH and temperatures measurements. Released gas volume was collected in gasholder and determined.

Fig. (1). Model of the Vertical bench-scale biogas digester.

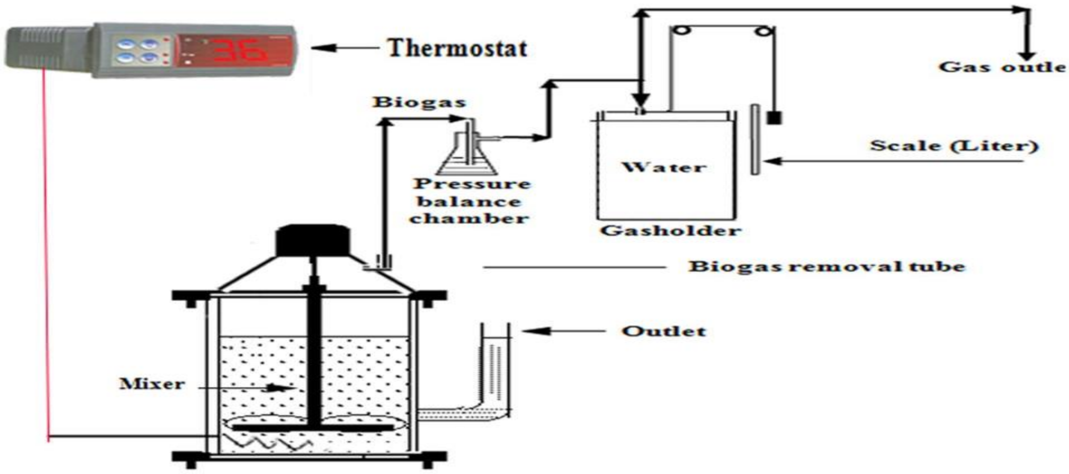

Fig. (2. Schematic diagram of vertical bench-scale biogas digester

The bench-scale digester was used to measure and detect the suitable operating conditions to obtain the maximum possible biogas production with high methane percentage at used mixture 8.0 % TS of sewage sludge, cattle dung and food wastes separately (50:50 %) for both experiment. Adigital thermostatic heating unit was connected to the digester in order to adjust the temperature of the digester. The temperature of the mixture inside digester was adjusted within the mesophilic process (36^{o}C). The retention time of mixture Was 85 days and mixer "stirer" adjusted automatically at 80 rpm/min for 5 minute/ hour. In the both experiments for sludge with cattle dung and Food wastes with cattle dung TS% under the same conditions was 8.0 %.

2.3. Analytical Methods and Instrumentation

Total alkalinity, **Chemical Oxygen demand** (COD), **Total Kjeldahl Nitrogen** are described in Standard methods [17].

Total solids (TS) and **organic total solids** (OTS) determination were calculated from the following DEV formula [18]:

$$TS\% = (MTS/MF) \times 100$$

$$OTS\% = ((Mash - M\,TS)/MF) \times 100$$

Where, *Mf* is the fresh mass, MTS is the mass of total solids and Mash is the ash mass

Meanwhile, the organic total solids (OTS) mass in kg was determined from the formula of Wittmaie [19].

$$OTS = MF \times OTS\%$$

Organic Total Carbon (OTC) can be calculated according to Black et al, using the following equation [20].

$$\text{Total Organic Carbon (\%)} = VS(\%)/1.724$$

Daily biogas production: during the batch fermentations the released gas volume in m.liter everyday was measured laboratory using the wetted displacement with a calibrated scale**.**

Methane percentage: The daily released biogas was fractioned in a percentage, i.e. methane and CO_2 percentage using the Potassium hydroxide 40% [6,21].

Temperature and pH

Temperature and pH value of the Mixture solution inside the bench-scale digesters were regularly daily measured using Symphony pH meter and confirmed by Jenway pH hand held meter. The temperature of mixtures inside digester was adjusted within the mesophilic region (36 ºC).

Degradation ratio:

The degradation ratio of organic matter was determined each 15 days along the hydraulic retention time (HRT) for each experiment and averaged. It was determined as the percentage of the difference between the OTS from the beginning of experiments and after definite days divided by the OTS at the beginning.

2.4. Statistical analysis

The SPSS statistical package, version 10.0 (SPSS Inc., Michigan, USA), was used for the statistical analysis. Bivariate correlations analysis was done to establish the significance of differences in both biogas and methane yield [21].

3. Results and Discussion

3.1. Biogas and methane production

Biogas, Methane yield and percentage were recorded in two experiments with mesophilic conditions. The results show that the biogas yield in the first experiment for mixture of sludge and cattle dung was 93 $L.kg^{-1}$ OTS, and methane yield was 62 $L.kg^{-1}$ OTS. Determination of methane quality and percentage by statistical analysis was 66%. The comparison of results between the sludge mixture experiment and food wastes mixture experiment was as shown in figure(3). The statistical calculation of biogas quantity in case of food wastes and cattle dung mixture was more than Mix.1(S+C), with long hydraulic retention time 122 $L.kg^{-1}$ OTS, and methane yield was 78 $L.kg^{-1}$ OTS with less methane quality percentage 63.9, as shown in figure(4), which illustrates the comparison between methane quantities and percentage of quality for methane shown in figure (5).

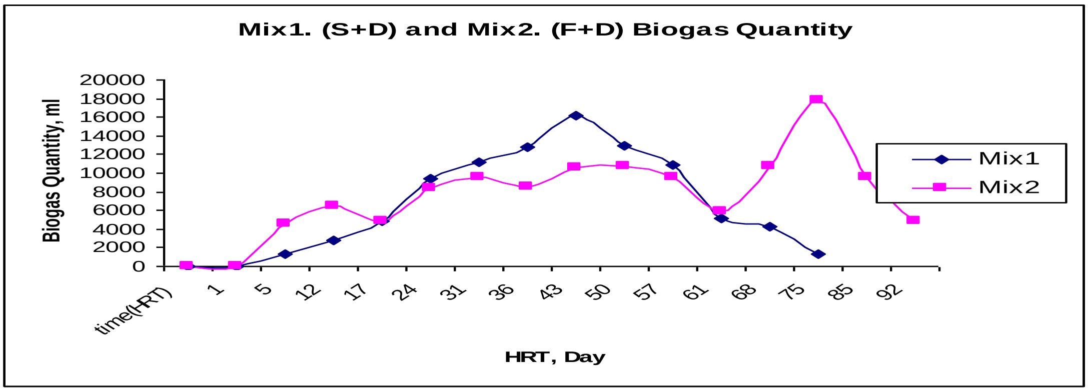

Fig. (3). The comparison of results between the Mix1 (Sludge+ Dung) and Mix2 (Food + Dung) Biogas quantities and HRT/ day

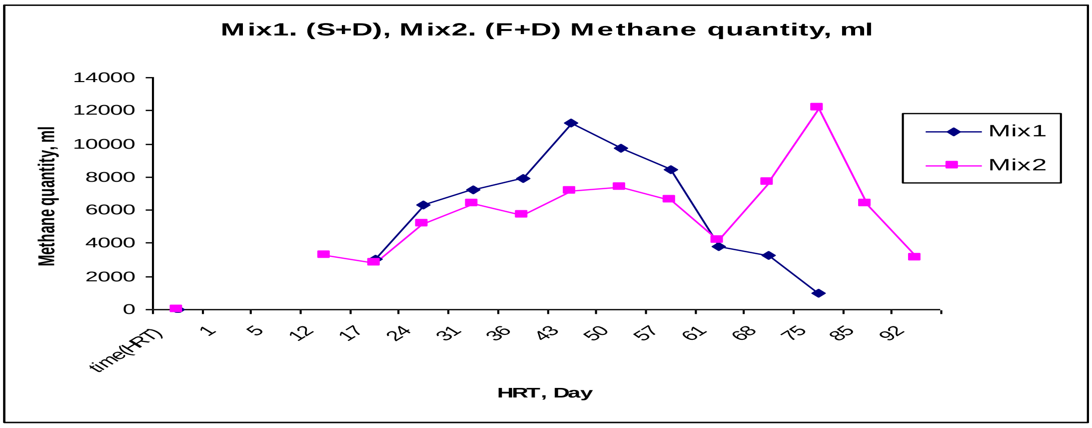

Fig. (4).The comparison of results between the Mix1 (Sludge+ Dung) and Mix2 (Food + Dung) Methane quantities and HRT/ day

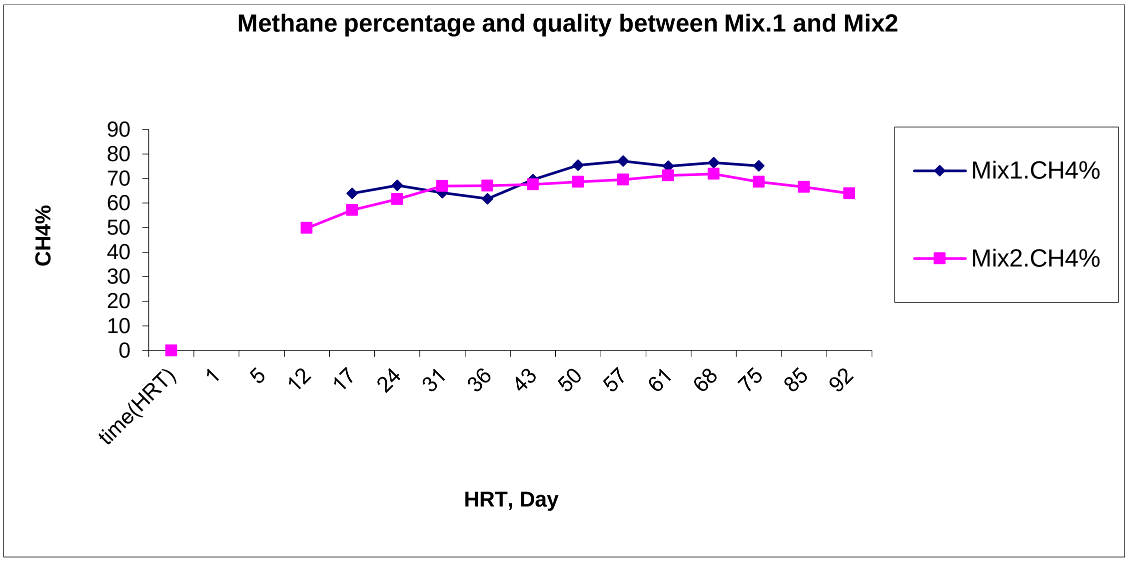

Fig. (5). CH_4 percentage and its quality for Mix1 and Mix2 with HRT/day

3.2. Effect of pH change at different intervals for two experiments

The best pH measured for biogas production, was (7.1) for two Mixtures. The measured pH values for anaerobic digestion for first and second mixture at experimental intervals are shown in the fig. 6, The pH were ranged from 6.7 to 7.0, and from 5.2 to 7.5 in the first and second Mixture, respectively.

The pH is known to influence enzymatic activity, because each enzyme has a maximum activity within a specific and a narrow pH range. The pH of the digestion liquid material and its stability as well comprises an extremely important parameter, since methanogenesis only proceeds at high rate when pH is maintained in the neutral range (6).

Most methanogenic bacteria function optimally at pH 7 to 7.2, and the rate of methane production declines at pH values below 6.3 or exceeding 7.8 [22,23]. Hydraulic retention time in two experiments by (Day) as shown in fig. 6. the change in pH values for two experiments at different intervals.

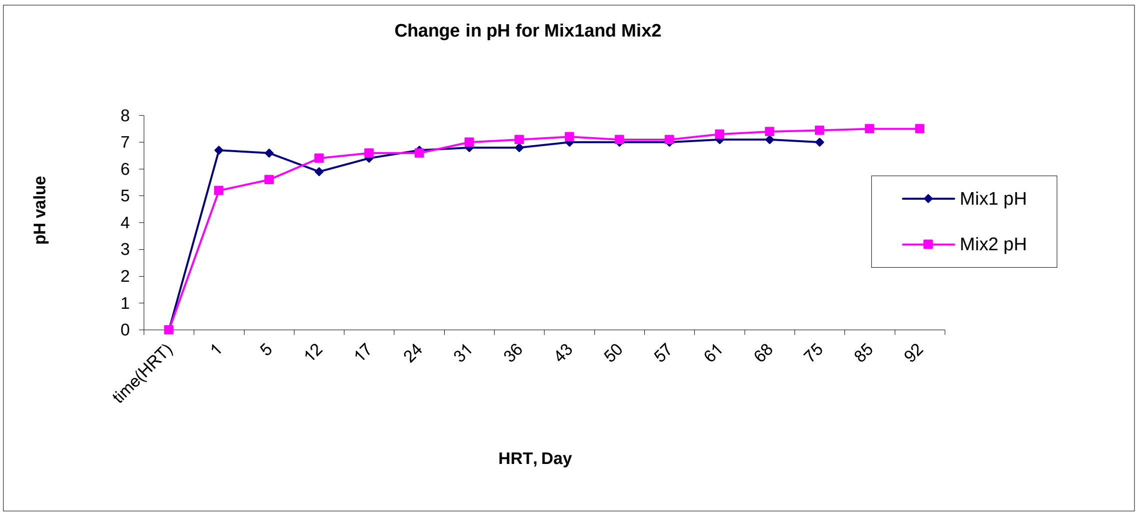

Fig. (6). Change in pH values for Mix1 and Mix2 with HRT /day

3.3. Degradation of organic carbon

The decomposition of sludge and cattle dung under anaerobic digestion was highly response to another parameters present as concentration of organic total solids and degradation rate according to the primary value as the percentage of the difference between the OTS from the beginning of the experiments and after definite number of days divided by the OTS at the beginning as in fig. 7.

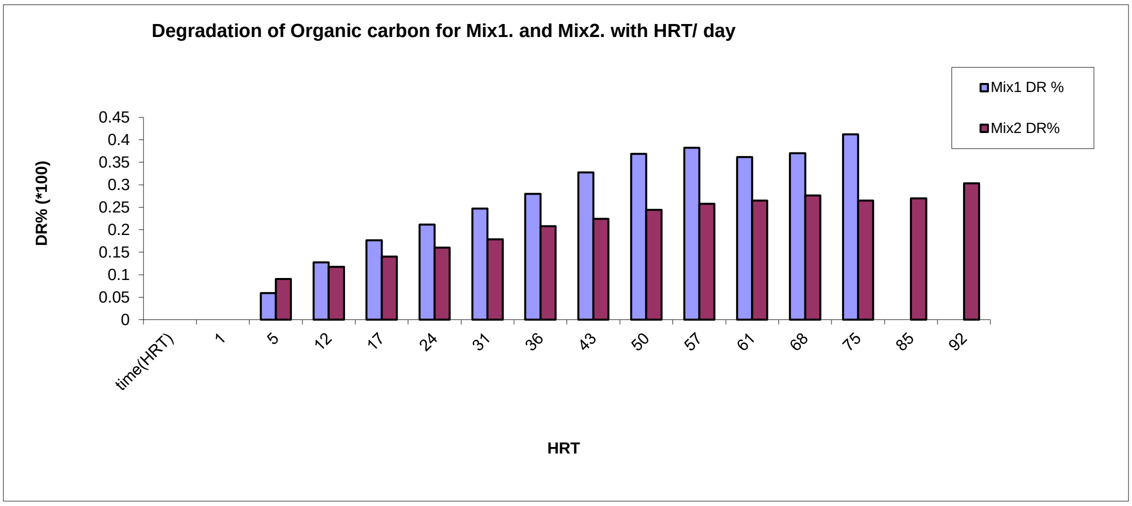

Fig. (7). Degradation of Organic carbon for Mix1 and Mix2 with HRT/ day

3.4. The change of Carbon/ Nitrogen Ratios

The C/N ratio is used as an index of the decomposition rate, Fig. 8. shows the C/N ratio for the different treatments during the hydraulic retention time. The results revealed that there are differences in the change of C/N ratios. Total nitrogen ranged from 1.8 to 2.18% and from 5.2 to 2.51% for first and second mixture, respectively. The methane productivity influenced by C:N ratio, which essential for cell synthesis and metabolism of anaerobic digestion. 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 as in second Mix. experiment, but in the first Mix., total nitrogen decrease due to bacterial activity. The C:N ratio of the mixtures during batch anaerobic co-digestion increased as illustrated in Fig. 8, produced the best C/N ratio for the yield of the mixture.

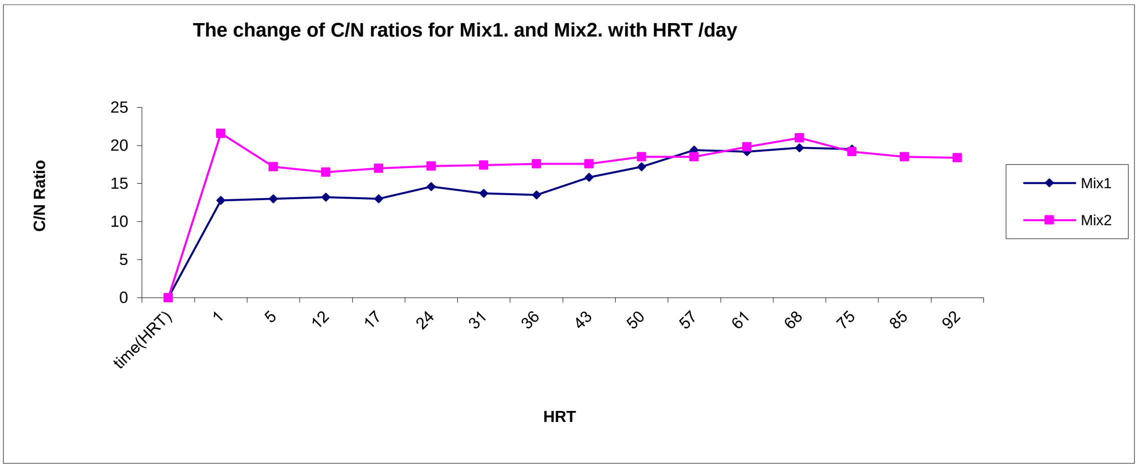

Fig. (8). The change of C/N ratios for Mix1 and Mix2 with HRT /day

4. Conclusions

The study conducted to the following:

- The biogas production was positively correlated with Methane yield, and negatively correlated with carbon dioxide yield in the same treatment from the two experiments.
- The highest biogas yield was observed in Mix2. (food wastes and cattle dung) which was 122 L kg^{-1} OTS, this ratio higher than Mix1 (sludge and cattle dung) which was 93 L kg^{-1} OTS but with lower concentration of methane (63.9%). On the other hand, Mix2. has higher hydrolic retention time than Mix1, and Mix1 has higher concentration of methane (66%).
- The biogas production and methane was positively correlated with pH.
- The biogas production and methane was positively correlated with TS quantity but with low concentration.
- The C/N ratio was positively correlated with methane yield in Mix2 experiment more than mix1 which lead to production of high quantity of biogas.
- Degradation rate was higher in Mix1. experiment than Mix2., which explain the higher concentration and quality of methane produced from Mix1.
- There are reduction in carbon content during the intervals of two experiments.
- Adjusting pH at 7.1 has a great effect on methanogenic bacteria activity, and methane production.
- The results indicated that, the relationship between the pH and organic total solids was found to be directly proportional to methane percentage.

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معالجة النفايات الصلبة بالتخمر اللاهوائي لانتاج سماد الكمبوست والغاز الحيوي (البيوجاس)

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ملخص البحث. تعتبر معالجة النفايات الصلبة بالتخمر اللاهوائي هي أفضل الطرق للتخلص من البكتيريا الممرضة والكائنات المتطفلة، والحد من انتشار الأمراض المعدية، بالإضافة لإنتاج سماد يستخدم بصورة آمنة، وليس هذا فحسب ولكن أيضا إنتاج الغاز الحيوي (البيوجاس) . إجراء هذه التقنية في الدول العربية محدود ولهذا كان الهدف من هذه الدراسة هو تحري الظروف المناسبة والمعايير التي تؤثر علي إنتاج البيوجاس وغاز الميثان ومدى جودة هذا المنتج. ولقد أجريت دراسة معملية لتجربتين الأولى علي خليط من حمأة الصرف الصحي وروث الأبقار والثانية فضلات الطعام وروث الأبقار في مخمر رأسي وبنسب خلط 50 : 50 والمخمر مصنع من الحديد المجلفن بقطر 0.2 متر و الارتفاع 0.27 متر بحجم كلي 8.5 لتر وحجم تخمر 6 لتر، والمخمر به قلاب يعمل بمعدل 5 دقائق لكل ساعة وبسرعة 80 لفة/دقيقة ، وتم اجراء التجارب عند درجة حرارة 36°م بالنظام الميزوفيلي ومزودة بمنظم حراري رقمي وتمت متابعة درجة الحرارة طوال أيام التجربة باستخدام أجهزة قياس الحرارة. وكانت المادة الجافة الكلية للخليط في كلا من التجربتين 8%، وكانت كمية البيوجاس في التجربة الثانية لمخلفات الطعام والروث أكبر من كميته في التجربة الاولي المتمثلة في خليط الحمأة روث الأبقار، ولكنها –تجربة2- استغرقت وقتا أطول للتخمر، وكانت كفاءة الإنتاج في الحماة أعلي من مخلفات الطعام بالرغم من قلة الكمية المنتجة وزمن الاستبقاء الاقل. تم تقدير النسبة المئوية للمادة الجافة العضوية OTS معملياً في المادة المتخمرة للخليط في كلا من التجربتين لحساب نسبة تحلل المادة العضوية خلال وقت الاستبقاء. كما تم تقدير نسبة الكربون/النيتروجين C/N وقياس رقم الأس الهيدروجيني pH ودرجة الحرارة في المعاملات تحت الدراسة. تم قياس كمية الغاز الحيوي ونسبة الميثان اليومية المتحصل عليها للمعاملات المختلفة وتم حساب كمية الغاز الحيوي و الميثان باللتر المتحصل عليها من كل واحد كيلو جرام مادة عضوية جافة.