Biogas Production from Different Agricultural Residues

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Abstract

The main aim of this work is to study the biogas production from different agricultural residues to overcome the energy scarcity and environmental pollution. To achieve that study the different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) on the total solids, volatile solids of slurry, biogas yield, methane yield, CO_2 and H_2S. The results show that the total solids (TS) and volatile solids (VS) of slurry decrease with increasing retention time for all treatments. The highest value of accumulated biogas yield (260.93 m^3 per ton TS) was found with the Poultry litter and rice straw (50:50). Meanwhile, the lowest value of accumulated biogas yield (229.96m^3 per ton TS) was found with Dairy manure, poultry litter and rice straw (25:25:50). The highest value of accumulated methane yield (196.10 m^3 per ton TS) was found with the Poultry litter and rice straw (50:50). Meanwhile, the lowest value of accumulated methane yield (156.30 m^3 per ton TS) was found with Dairy manure (100:0). CO_2 and H_2S increase with increasing retention time for all treatments.

Keywords: biogas yield, cattle manure, Total solids, Volatile solids, Methanne.

Introduction

Biogas is a product of anaerobic degradation of organic substrates, which is one of the oldest processes used for the treatment of industrial wastes and stabilization of sludges. Since it is carried out by a consortium of microorganisms and depends on various factors like pH, temperature, HRT, C/N ratio, etc., it is a relatively slow process. Lack of process stability, low loading rates, slow recovery after failure and specific requirements for waste composition are some of the other limitations associated with it **(Van der Berg and Kennedy, 1983)**.

Anaerobic digestion has been proven to be an efficient and green technology in disposing of sewage sludge, crop residues, food waste and animal manure **(Wan *et al.*, 2011 and Li *et al.*, 2009)**. Advantages are the production of renewable energy in the form of biogas and the possibility to recycle valuable nutrients, concentrated in the digestion residue **(Zhang *et al.*, 2012 and Angelidaki *et al.*, 2003)**.

Anaerobic digestion of organic waste and residues combines both sustainable treatment and renewable energy production. Some substrates, such as lignocellulosic materials, are resistant to anaerobic digestion and can be converted into biogas, although only to low extents. The low susceptibility of these materials to conversion into biogas is attributed to their composition and structure. Lignocellulose is the complex and rigid matrix of plant cells; it is resistant to enzymatic attack because of the tight association between lignin, cellulose, and hemicellulose. Cellulose and hemicellulose can be degraded in biogas processes. However, lignin cannot be degraded under anaerobic conditions **(Fernandes *et al.*, 2009)**.

Organic waste, being a source of pollution (water and soil pollution in storage sites, unpleasant odors, greenhouse gas emissions during decomposition, pathogenic bacteria, etc.), is not only an environmental issue but also an economic loss. Given the emphasis on the issue of depletion of fossil fuels, it is necessary to find solutions for the problems related to the availability of energy sources **(Lakatos *et al.*, 2016 and Meyer, 2017)**. Given these prospects, the conversion of organic waste into primary or secondary sources of raw materials used in energy technologies is the subject of many studies, which leads to the sustainable development of environment and society as well as the economy **(Hayashi *et al.*, 2016 and Hausknost *et al.*, 2017)**.

The rural biogas utilization of agricultural crops in china is regarded as typical waste treatment for energy utilization. In this field, many studies have been conducted on biomass waste. Not only for sole substrate but also co-digestions process have attracted much attention. **Callaghana *et al.* (2002)** studied the co-digestions of cattle slurry with fruit/vegetable waste and with chicken manure. Under mesophilic conditions, the retention time was kept at 21 days, and the organic loading rate (OLR) was maintained at 3.19 - 5.01 kgVS/m^3.day. The possible use of potato tuber and its industrial by-products (potato stillage and potato peels) on farm scale co-digestion with pig manure was evaluated in a laboratory experiment **(Kaparaju and Rintala, 2005)**.

Methane production from biomass waste has attracting more and more interest. While, the conventional digestion process directly accepting raw waste using continuous stirred tank reactor needs a long HRT and has a low VS removal rate. So, usually the digestion of biomass waste could not give satisfied results. Appels provide a detailed and comprehensive review of sludge anaerobic digestion. The researcher points out that hydrolysis is recognized as rate-limiting step in the complex anaerobic digestion process **(Appels *et al.*, 2008)**.

The convential energy become very expensive and harm environment. Due to the gradual increasing on convential energy prices in addition to the pollution. Agricultural wastes cause pollution and diseases and pests spading, therefore, the main aim of this work is to study the biogas production from different agricultural residues to overcome the energy scarcity and environmental pollution.

Materials and methods:

The experiment was carried out at Agricultural and Bio-Systems Engineering Department, Faculty of Agriculture Moshtohor, Benha University, Egypt. During the period of July to September, 2019 season to study the effect of fermentation temperature and agitation speed on biogas quality and productivity.

1. Materials:

1.1. System description

Figure (1) illustrates the system description. It shows the system which consists of digester tanks, heating tank, heat exchanger, mold and gas bag.

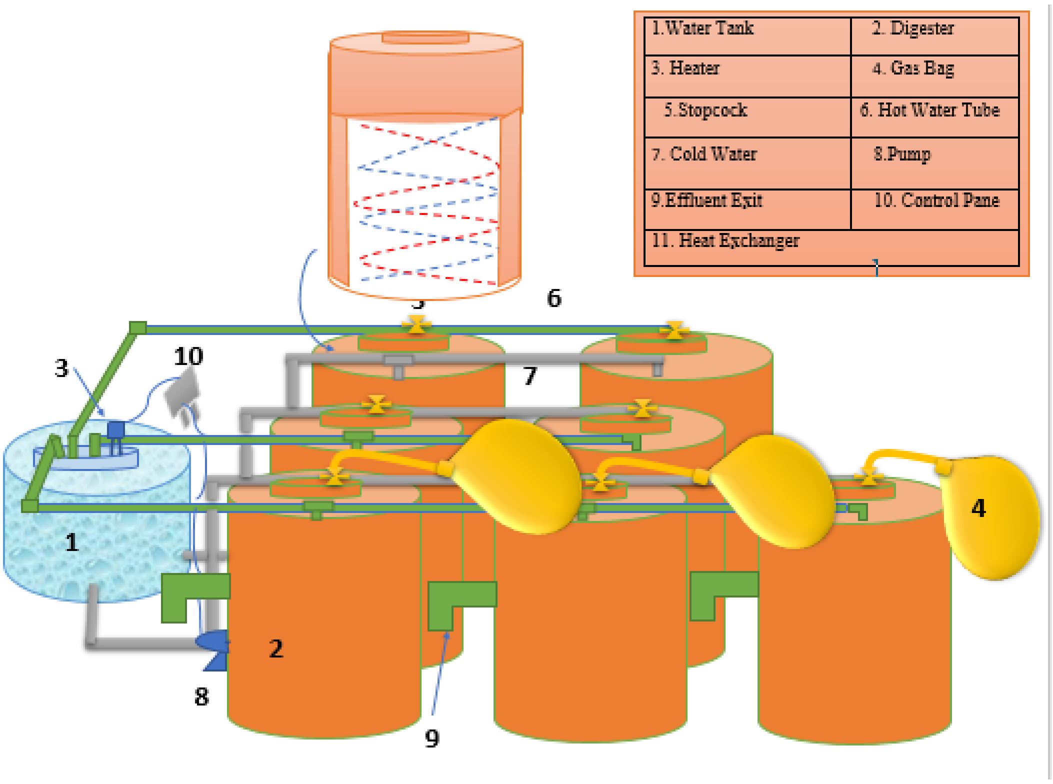

Figure (1): The experimental setup.

The system consists of seven digester tanks 1.0 m^3 capacity that used for biogas production. Dimensions of each tank are 1.0 m diameter and 1.3 m height. It is made of polyethylene and covered by glass rock sheet. A four inch PVC pipe diameter was used for feeding the raw materials, the length of feeding pipe was 0.88 m. Also, the digester tank was provided with drainage opening at high 1.0 m above the digester bottom. The diameter of drainage hole was three inches. The mixing system consisted of (a) a stainless steel mixing shaft (1 inch diameter and 1.0 m length) installed through the center of the tank, (b) six-vane flow disc impellers used to ensure adequate mixing in the vertical direction and (c) a heavy duty electric motor (0.5 hp) with a gear head reducer mounted on the tank and connected to a mixing speed controller. The digester was provided with heat exchanger for heating to maintain required temperature of materials. The gas was collected in the bag made of polyethylene (250 Micron thickness).

The heating system consists of heating tank 1.0 m^3 capacity that used for heating water. Dimensions of heating tank are 1.0 m diameter and 1.3 m high. It is made of polyethylene and covered by glass rock sheet. Electric heater (2 kW) was used to heating water. The hot water was circulated by a pump (Model First QB60 – Flow Rate 30 L min^{-1} – Head 25 m – Power 0.5 hp, China) from the heating tank to the heat exchanger. The hot water was pumped to the heat exchanger by pump through iron pipes of 1.0 inch in diameter. Figure (2) shows the heating system.

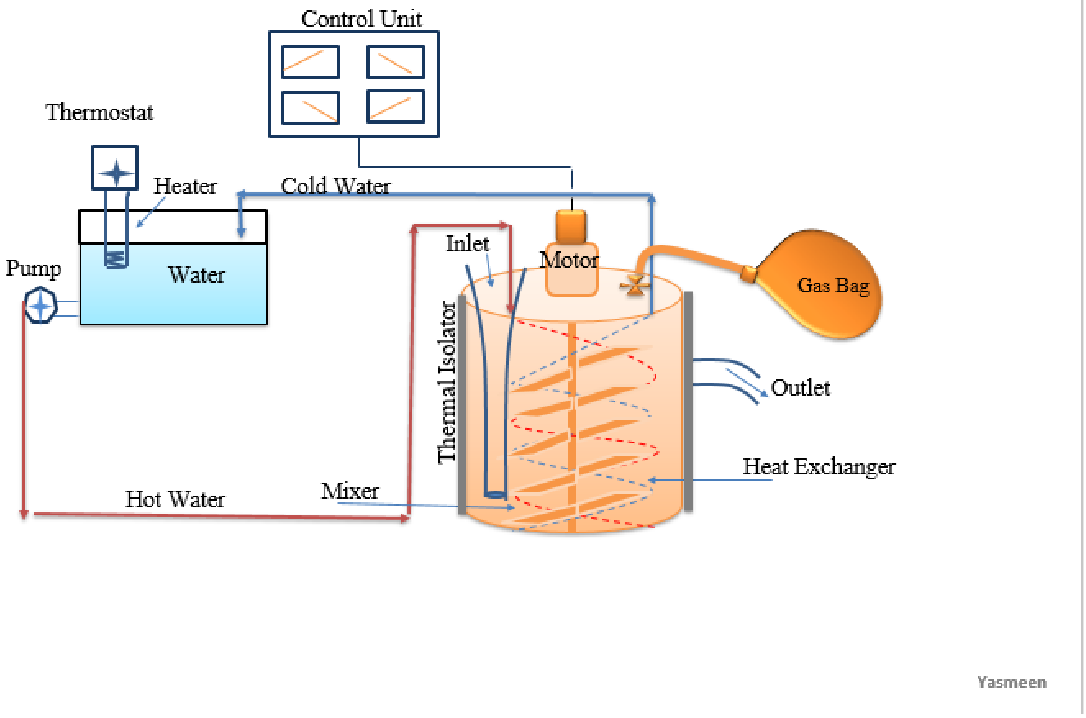

Figure (2): The heating system.

1.2. Raw materials:

The agricultural wastes used for biogas production are cattle manure, poultry litter and rice straw. The agricultural wastes used was produced from farmers at Experimental Research Station at the Faculty of agriculture, Moshtohor, Benha University. The properties that used in the manufacturing the biogas are listed in table (1).

Table (1): Properties of the raw materials used in biogas making.

Properties	Cattle Manure	Poultry Litter	Rice Straw
PH	7.03	8.2	6.93
Moisture content (%)	83	67.5	10.9
Total solid (%)	17	32.5	89.1
Volatile solid (%)	80	75	78
C/N Ratio	24.8	7.7	74.7
Total Nitrogen (%)	0.29	1.84	0.54
Total Carbon (%)	7.2	14.14	40.31

2. Methods:

2.1. Treatments:

Seven different types of mixing were obtained by mixing dairy manure with poultry litter and rice straw at different ratios to form:

1- C_1: Dairy manure (100:0)
2- C_2: Poultry litter (100:0)
3- C_3: Dairy manure, poultry litter and rice straw (25:25:50)
4- C_4: Dairy manure and rice straw (20:80)
5- C_5: Dairy manure and rice straw (80:20)
6- C_6: Dairy manure, poultry litter and rice straw (40:40:20)
7- C_7: Poultry litter and rice straw (50:50)

2.2. Measurements:

Total solids content (TS) were determined according to the following equation:

$$TS = \frac{MDS}{MFS} \times 100$$

Where:
TS is the total solids, %
MDS is the mass of dry sample, g
MFS is the mass of fresh sample, g

The volatile solids content (VS) were determined according to the following equation:

$$VS = MSD - \frac{MASH}{MSD} \times 100$$

Where:
VS is the volatile solids, %
MASH is the mass after ignition, g

The biogas yield was measured daily by using the following equation:

$$V = \left(W_1 - W_2\right) \times \rho \qquad (3)$$

Where:

V is the biogas, m^3

W_1 is the bag weight with gas, g

W_2 is the bag weight empty, g

ρ is the biogas density, 0.717 kg m^{-3}

The composition of biogas was measured by gas chromatography analysis.

The daily gas production was measured by collecting the produced gas in bag used to collect the gas. This was connected to the fitting to regulate the flow of gas in / out of the bag and weight it.

Results and Discussion:

1. Total solids of slurry (TS):

Figure (3) shows the total solids of slurry (TS) of different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) during the retention period. The results indicate that the TS of slurry decreases with increasing retention time. It could be seen the TS of slurry decreased from 8.50 to 0.10, 8.12 to 0.02, 15.90 to 0.33, 17.76 to 0.10, 16.13 to 0.20, 13.50 to 0.32 and 12.66 to 0.18 %, when the retention time increased from 1 to 45, 1 to 45, 1 to 55, 1 to 65, 1 to 55, 1 to 50 and 1 to 65 day, respectively, for Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50), respectively.

The results indicate that the highest rate of the decrease total solids of slurry (99.75%) was happened with the Poultry litter (100:0). Meanwhile, the lowest rate of the decrease total solids of slurry (97.76%) was found with Dairy manure, poultry litter and rice straw (40:40:20).

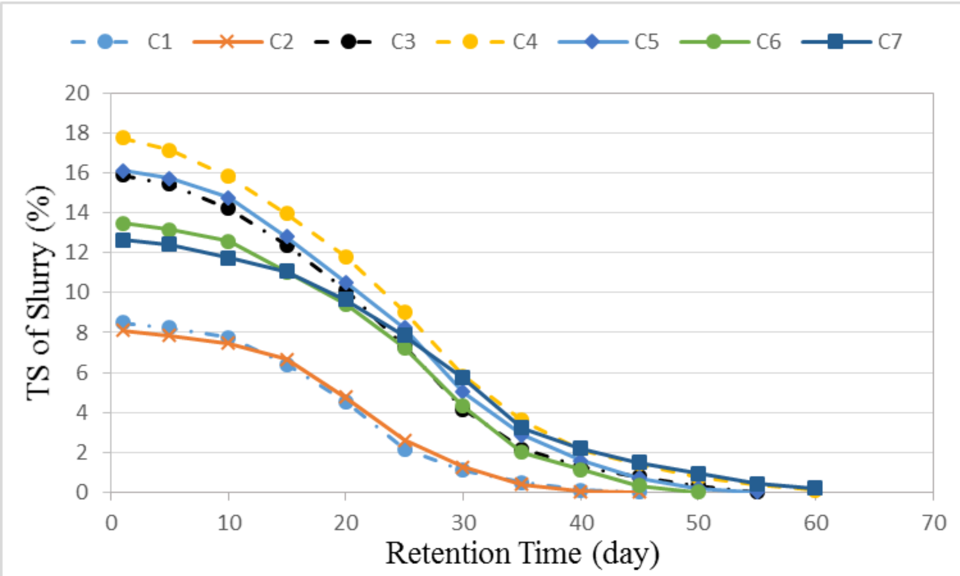

Figure (3): The total solids of slurry (TS) of different types of mixing during the retention period.

2. Volatile solids of slurry (VS):

Figure (4) shows the volatile solids of slurry (VS) of different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) during the retention period. The results indicate that the VS of slurry decreases with increasing retention time. It could be seen the VS of slurry decreased from 6.80 to 0.08, 6.09 to 0.01, 12.36 to 0.25, 13.92 to 0.08, 12.84 to 0.16, 10.48 to 0.25 and 9.69 to 0.13 %, when the retention time increased from 1 to 45, 1 to 45, 1 to 55, 1 to 65, 1 to 55, 1 to 50 and 1 to 65 day, respectively, for Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50), respectively.

The results indicate that the highest rate of the decrease volatile solids of slurry (99.84%) was happened with the Poultry litter (100:0). Meanwhile, the lowest rate of the decrease total solids of slurry (97.61%) was found with Dairy manure, poultry litter and rice straw (40:40:20).

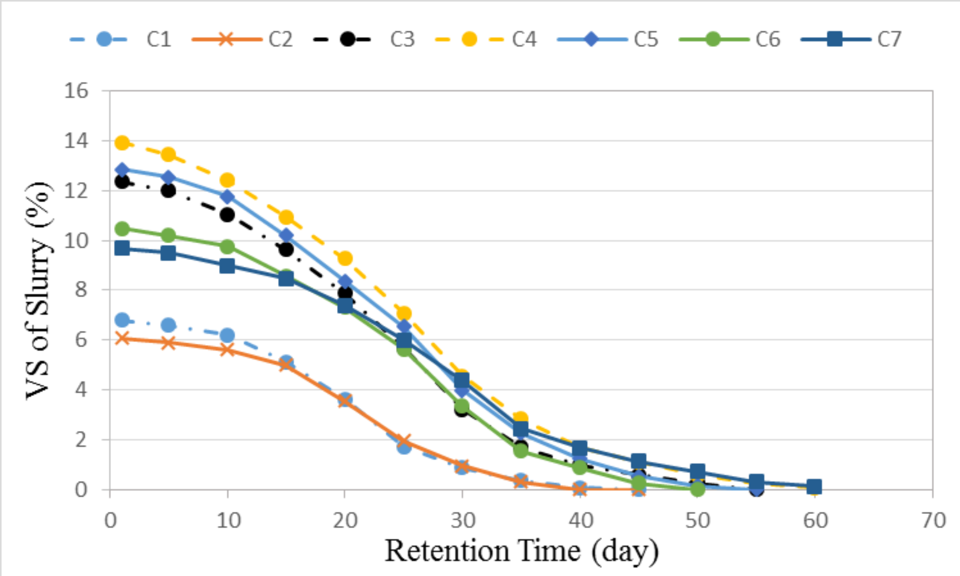

Figure (4): The volatile solids of slurry (VS) of different types of mixing during the retention period.

3. Biogas yield:

Figure (5) shows the accumulated biogas yield of different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) during the retention period. The results indicate that the accumulated biogas yield increases with increasing retention time. It could be seen the accumulated biogas yield increased from 7.35 to 250, 8.46 to 259.2, 6.52 to 229.96, 8.24 to 239.98, 5.65 to 229.97, 6.48to 249.98 and 4.64 to 260.93 m^3 per ton TS, when the retention time increased from 5 to 45, 5 to 45, 5 to 55, 5 to 65, 5 to 55, 5 to 50 and 5 to 65 day, respectively, for Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50), respectively. These results agreed with those obtained by **Qiao *et al.* (2011)**.

The results indicate that the highest value of accumulated biogas yield (260.93 m^3 per ton TS) was found with the Poultry litter and rice straw (50:50). Meanwhile, the lowest value of accumulated biogas yield (229.96m^3 per ton TS) was found with Dairy manure, poultry litter and rice straw (25:25:50).

The results indicate that the accumulated biogas yield increases with increasing total solids of slurry, it could be seen that the biogas yield increased from 16.24 to 35.52 m^3 per ton TS when the total solids increased from 8.12 to 17.76 %.

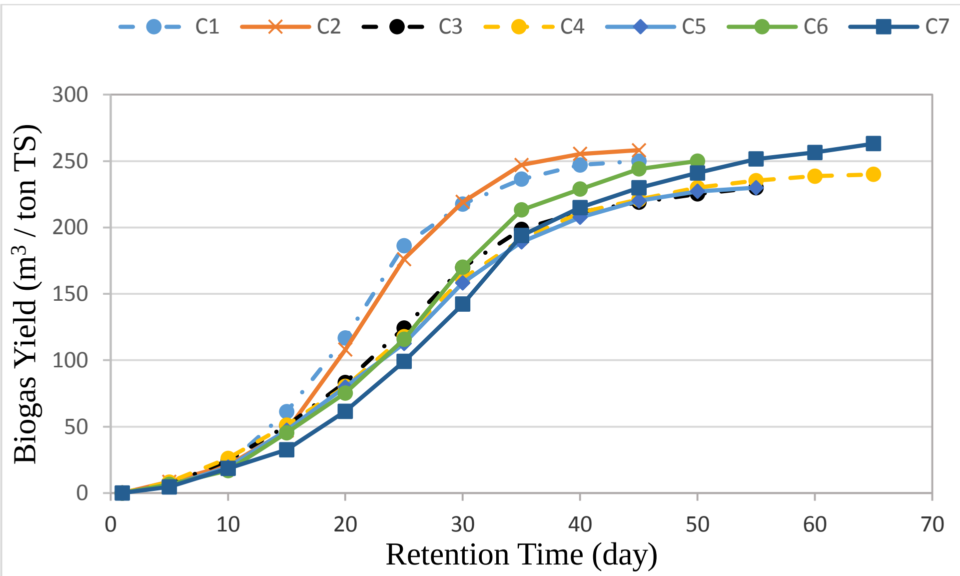

Figure (5): The accumulated biogas yield of different types of mixing during the retention period.

4. Methane yield:

Figure (6) shows the accumulated methane yield of different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) during the retention period. The results indicate that the accumulated methane yield increases with increasing retention time. It could be seen the accumulated methane yield increased from 4.60 to 156.30, 5.18 to 159.12, 4.85 to 171.11, 5.55 to 161.85, 4.11 to 167.03, 4.12 to 159.11 and 3.50 to 196.10 m^3 per ton TS, when the retention time increased from 5 to 45, 5 to 45, 5 to 55, 5 to 65, 5 to 55, 5 to 50 and 5 to 65 day, respectively, for Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50), respectively.

The results indicate that the highest value of accumulated methane yield (196.10 m^3 per ton TS) was found with the Poultry litter and rice straw (50:50). Meanwhile, the lowest value of accumulated methane yield (156.30 m^3 per ton TS) was found with Dairy manure (100:0).

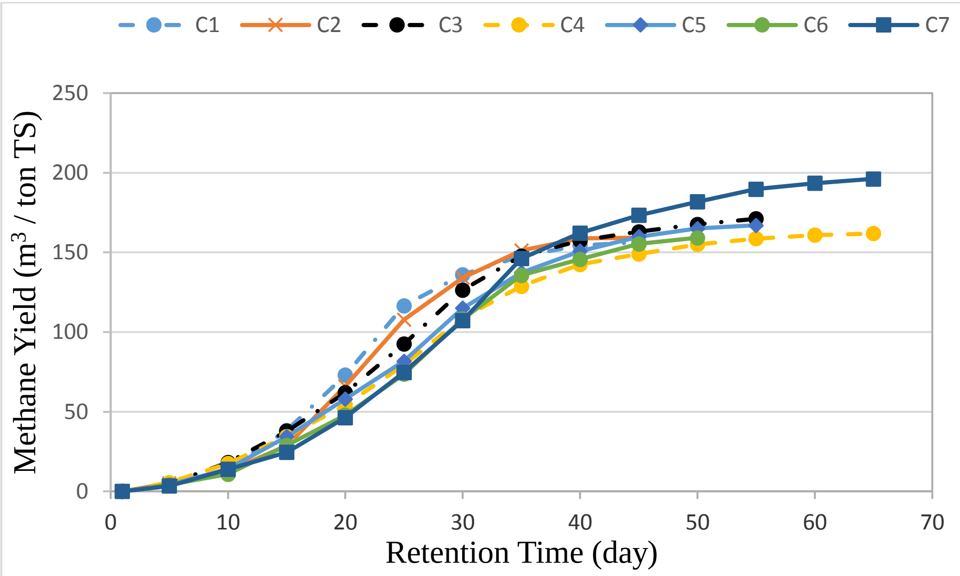

Figure (6): The accumulated methane yield of different types of mixing during the retention period.

5. CO_2 yield:

Figure (7) shows the accumulated CO_2 yield of different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) during the retention period. The results indicate that the accumulated CO_2 yield increases with increasing retention time. It could be seen the accumulated CO_2 yield increased from 2.55 to 86.85, 3.16 to 97.24, 1.61 to 56.82, 2.55 to 74.42, 1.49 to 60.41, 2.26 to 87.02 and 1.04 to 58.10 m^3 per ton TS, when the retention time increased from 5 to 45, 5 to 45, 5 to 55, 5 to 65, 5 to 55, 5 to 50 and 5 to 65 day, respectively, for Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50), respectively.

The results indicate that the highest value of accumulated CO_2 yield (97.24 m^3 per ton TS) was found with the Poultry litter (100:0). Meanwhile, the lowest value of accumulated CO_2 yield (56.82 m^3 per ton TS) was found with Dairy manure, poultry litter and rice straw (25:25:50).

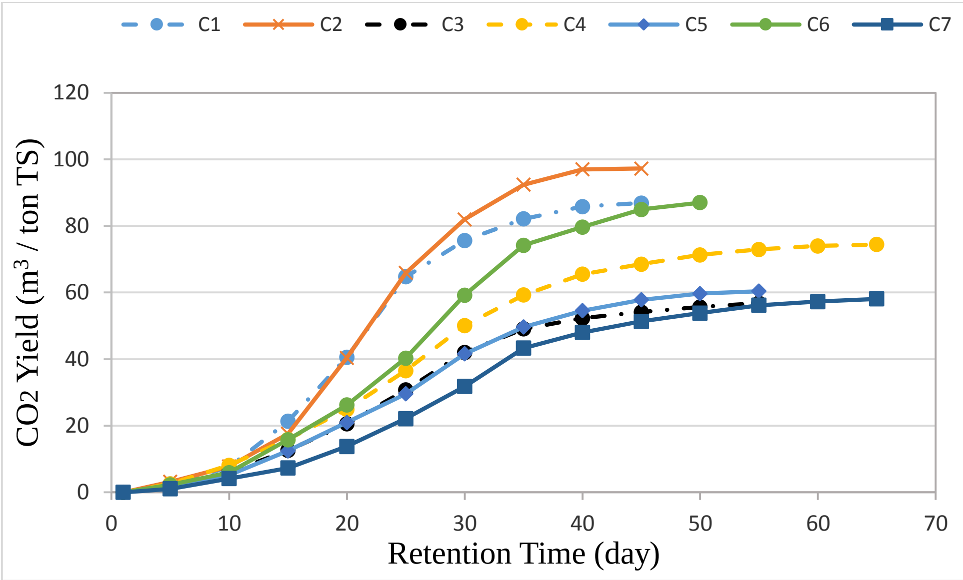

Figure (7): The accumulated CO_2 yield of different types of mixing during the retention period.

6. H_2S yield:

Figure (8) shows the accumulated H_2S yield of different types of mixing (Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50)) during the retention period. The results indicate that the accumulated H_2S yield increases with increasing retention time. It could be seen the accumulated H_2S yield increased from 0.14 to 4.75, 0.07 to 2.08, 0.05 to 1.58, 0.07 to 2.10, 0.03 to 1.38, 0.06 to 2.25 and 0.07 to 4.16 m^3 per ton TS, when the retention time increased from 5 to 45, 5 to 45, 5 to 55, 5 to 65, 5 to 55, 5 to 50 and 5 to 65 day, respectively, for Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50), respectively.

The results indicate that the highest value of accumulated H_2S yield (4.75 m^3 per ton TS) was found with the Dairy manure (100:0). Meanwhile, the lowest value of accumulated H_2S yield (1.38 m^3 per ton TS) was found with Dairy manure and rice straw (80:20).

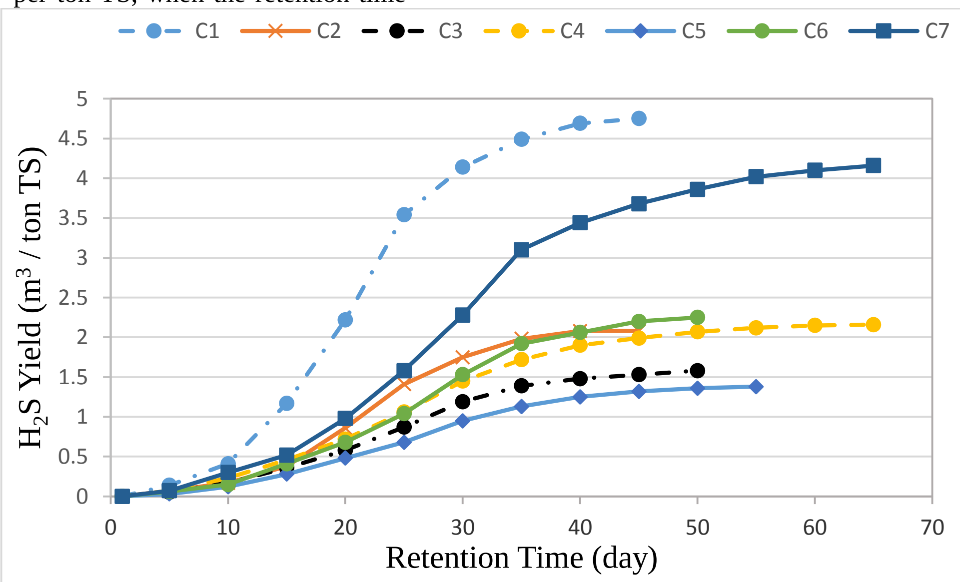

Figure (8): The accumulated H_2S yield of different types of mixing during the retention period.

Conclusion

The experiment was carried out to study the biogas production from different agricultural residues to overcome the energy scarcity and environmental pollution. The treatments under study are: Dairy manure (100:0), Poultry litter (100:0), Dairy manure, poultry litter and rice straw (25:25:50), Dairy manure and rice straw (20:80), Dairy manure and rice straw (80:20), Dairy manure, poultry litter and rice straw (40:40:20) and Poultry litter and rice straw (50:50). The obtained results can be summarized as follows:

The total solids (TS) and volatile solids (VS) of slurry decrease with increasing retention time for all treatments. The highest value of accumulated biogas yield (260.93 m^3 per ton TS) was found with the Poultry litter and rice straw (50:50). Meanwhile, the lowest value of accumulated biogas yield (229.96m^3 per ton TS) was found with Dairy manure, poultry litter and rice straw (25:25:50). The highest value of accumulated methane yield (196.10 m^3 per ton TS) was found with the Poultry litter and rice straw (50:50). Meanwhile, the lowest value of accumulated methane yield (156.30 m^3 per ton TS) was found with Dairy manure (100:0). CO_2 and H_2S increase with increasing retention time for all treatments.

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انتاج الغاز الحيوى من مخلفات زراعية مختلفة

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الهدف الرئيسي من هذه الدراسة هو دراسة إنتاج الغاز الحيوي من المخلفات الزراعية المختلفة للتغلب على ندرة الطاقة والتلوث البيئي. ولتحقيق ذلك ، تم دراسه أنواع مختلفة من الخلطات (سماد الألبان (100: 0) ، فضلات الدواجن (100: 0) ، سماد الألبان ، فضلات الدواجن وقش الأرز (25:25:50) ، سماد الألبان وقش الأرز (20: 80) ، روث الألبان وقش الأرز (80:20) ، روث الألبان ، فضلات الدواجن وقش الأرز (40:40:20) وفضلات الدواجن وقش الأرز (50:50)) على المواد الصلبة الكلية ، والمواد الصلبة المتطايرة من الملاط ، عائد الغاز الحيوي ، عائد الميثان ، CO2 و H2S. أظهرت النتائج أن مجموع المواد الصلبة (TS)والمواد الصلبة المتطايرة (VS)من الملاط ينخفض مع زيادة وقت الاستبقاء لجميع المعاملات . تم العثور على أعلى قيمة لعائد الغاز الحيوي المتراكم (260.93 متر مكعب لكل طن مادة صلبة) مع فضلات الدواجن وقش الأرز (50:50)). وفي الوقت نفسه ، تم العثور على أدنى قيمة لمحصول الغاز الحيوي المتراكم (229.96 متر مكعب لكل طن مادة صلبة) مع سماد الألبان ، فضلات الدواجن وقش الأرز (25:25:50). تم العثور على أعلى قيمة لمحصول الميثان المتراكم (196.10 متر مكعب لكل طن مادة صلبة) مع فضلات الدواجن وقش الأرز (50:50). وفي الوقت نفسه ، تم العثور على أدنى قيمة لمحصول الميثان المتراكم (156.30 متر مكعب لكل طن مادة صلبة) مع سماد الألبان (100: 0). يزداد ثاني أكسيد الكربون و H2S مع زيادة وقت الاستبقاء لجميع المعاملات.