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Bioenergy Production from Anaerobic Co-Digestion of Sewage Sludge and Abattoir Wastes

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Abstract

Energy is the pillar of human economic development. Several energy sources, renewable and non-renewable, have been exploited to assure and sustain the need for sustainable development. However, depletion of non-renewable energy sources forced researchers to search for alternative cost effective and environmental friendly energy sources. Thus, conversion of waste materials into energy has obtained considerable attention. In line with this, the aim of this study is to investigate the improvement of bio-energy production through anaerobic digestion of mixture of wastes from sewage sludge and abattoir sources. The abattoir waste is functioned as a co-substrate. Laboratory scale batch anaerobic co-digestion of the waste is carried out under mesophilic condition for 20 days. Sewage Sludge (SS) alone, and different mix ratios of SS to Abattoir Waste (AW) were analyzed for bioenergy production. Besides, the nutrient values and reduction in volume of the sewage after digestion were determined. The results show that methane productions of 33.8%, 48.3% and 56.9% were obtained for SS alone and for SS:AW mix ratios of 4:1 and 3:2, respectively. The nutrient values of the slurry increased as mix ratio decreased due to the increase in the amount of AW. The obtained results indicate that bio-energy production can be improved through co-digestion of SS using AW as a co-substrate; thus warranting further investigation for the practical application in the energy production.

Keywords

Bio-Energy, Anaerobic Co-Digestion, Abattoir Wastes, Sewage Sludge

1. Introduction

Treatment of municipal wastewater results in the generation of large amounts of sewage sludge. Major part of

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the dry matter (cake) content of this sludge consists of nontoxic organic compounds, which is a combination of primary sludge and secondary (microbiological) sludge. There are many sludge-management options in which resource recovery (energy and organic fertilizer) through anaerobic process is one of the key treatment steps [1].

Anaerobic digestion is a microbiological process that converts the chemically complex organic biomass into methane, carbon dioxide, and in offensive humus like material. The reactions occur in a closed tank or digester that is anaerobic—that is, devoid of oxygen. The conversion takes place through a series of reactions.

Anaerobic digestion of biomass under mesophilic condition has been a widely used technique in the efficient management of biomass wastes of all kinds and in the simultaneous recovery of useful resources, such as energy and soil conditioner [2]-[4]. In addition, utilizing methane produced at the treatment site plays a great role in minimizing the release of greenhouse gas to the atmosphere.

Anaerobic digestion has many environmental benefits including the production of a renewable energy carrier, the possibility of nutrient recycling and reduction of waste volumes [5]-[7]. Many kinds of organic waste have been digested anaerobically in a successful way, such as sewage sludge, industrial waste, slaughterhouse waste, fruit and vegetable waste, manure and agricultural biomass.

Much attention has been focused on the improvement of methane production in order to upgrade the role in stabilizing the sludge and to produce a feasible bioenergy power plant [8]. An interesting option for improving methane yields is co-digestion. This is a process where resource recovery can be optimized by improving the nutrient and organic content of substrates to be used in anaerobic digester.

Nowadays many successful efforts have been reported in co-digestion of sewage sludge with several other substrates, such as the source-sorted organic fraction of municipal solid waste [9]-[11], confectionery waste [12], sludges from the pulp and paper industry [13], coffee waste [14] and grease-trap sludge from meat processing plants [15] [16], have been reported. The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates [17].

Therefore, the aim of this study is to investigate, under laboratory set up, improvement of the recovery of resources (bioenergy and biofertilizer) through anaerobic co-digestion of sewage sludge (SS) and abattoir waste (AW) under mesophilic condition at 35˚C. Rate of production of biogas was also investigated under different SS:AW mix ratios.

2. Materials and Methods

2.1. Materials

Different analytical instruments were employed to measure different parameters. Glass bottle, filter papers (DP-70, 47 mm), N840.3FT.18 type vacuum filter, crucibles, folks, Jenway model 3510 digital pH meter, Beschickung-Loading model 100 - 800 type oven, dissector, armfield W8 Anaerobic Digester, magnetic stirrer, rubber hose, incubator, muffle furnace, measuring cylinder, sterile plastic Petri dish, hand lens, lids, GA-45 gas analyzer, Lovibond oxidirect TS 606/4-I type, HI 839800 COD Hanna Reactor, Tedlar gas sampling bag, model NOV AA 400 AAS and JD 210-4 mode3l No. weighing scale were are few to mention. Analytical grade reagents were used throughout the study. The feed for the reactor (SS, inoculums and AW) were obtained from Kaliti Waste Water Treatment Plant, nearby residential biogas plant and Addis Ababa Abattoirs Enterprise respectively. Characteristics of the feeds and their different mix ratio were analyzed before and after digestion and results were recorded (**Tables 1-4**).

2.2. Experimental Setup

Series of batch experiments were carried out in the experimental set-up consisted of a jacketed glass reactor with controlled temperature under mesophilic condition (35˚C) with a volume of 5 liters laboratory scale cylindrical anaerobic digester W8 issue 3 arm field model, sealed with a rubber stopper. A magnetic stirrer was used for mixing. Digestion period of 20 days was used in the laboratory for each set up. Biogas production was determined by water displacement, methane and carbon dioxide in biogas measured by GA-45, gas analyzer.

The temperature of reactor was controlled by an electric heating mat wrapped around the external wall. The gas off-take from the reactor was taken to a volumetrically calibrated collector vessel operating by water displacement. A constant head, liquid seal device ensures that the gas pressure in the reactor is maintained at a constant value throughout the experiment.

Liquid and gas sampling points are located at all strategic points around the reactors. Non-return valves and liquid seal syphon breaks were included in the process pipe work to ensure each reactor operates at a constant volume without the entrance of air or the danger of accidental symphonic action. The equipment was mounted on a vacuum formed plastic base with an integral drain channel to cope with spillages and wash down.

Amount of biogas produced from only sewage sludge, and co-digestion of 4:1 and 3:2 (the first value is for SS and the second one is for AW) were determined through water displacement and the gases were collected using Tedlar gas sampling bag and subsequently analyzed by GA-45 (Geotechnical Instrument).

Table 1. Composition of SS before digestion (mean ± SD).

Parameter	Unit	Values
pH		7.47 ± 0.35
TS	mg/l	39,831 ± 3987.6
VS	mg/l	27,043 ± 4956
COD	mg/l	32,872 ± 2600.5
BOD5	mg/l	12,600 ± 3567
TN	mg/l	49.6 ± 8.3
TP	mg/l	78.8 ± 9.4
TK	mg/l	231.7 ± 13.25
Cu	mg/l	0.172 ± 0.0741
Ni	mg/l	0.1417 ± 0.0572
Cr	mg/l	0.00519 ± 0.0032
Pb	mg/l	<0.0001
Cd	mg/l	Nil
Zn	mg/l	0.3241 ± 0.082
TC	MPN/100 ml	20×10^6
FC	MPN/100 ml	12×10^6
Ascaris	No./l	18,000 - 39,000
Hook worm	No./l	0 - 3800

MPN = Most Probable Number.

Table 2. Composition of AW before digestion (mean ± SD).

Parameters	Unit	Values
pH		6.62 ± 0.47
TS	mg/l	10,823± 5656.85
VS	mg/l	2529.32 ± 638
COD	mg/l	6950 ± 636.40
BOD5	mg/l	3975±775
TN	mg/l	171.5 ± 26.16
TP	mg/l	69.5 ± 21.72

Table 3. Characteristics of the feedstock before digestion (mean ± SD).

Parameters	Unit	SS alone	SS:AW ratio	
			4:1	3:2
pH		7.47 ± 0.35	7.62 ± 0.23	6.78 ± 0.102
TS	mg/l	39,831 ± 3987.6	35,397 ± 3145.7	31,148 ± 2517
VS	mg/l	27,043 ± 4956	23,199 ± 2053	19,327 ±1678.4
COD	mg/l	32,872 ± 2600.5	28,203 ± 1609.7	25,607 ± 2345
BOD5	mg/l	12,600 ± 3567	11,222.9 ± 735.6	9895 ± 1507.2
TN	mg/l	49.60 ± 8.30	84.5 ± 11.30	91.10 ± 3.3
TP	mg/l	78.80 ± 9.40	67.61 ± 4.10	83.02 ± 7.4
TK	mg/l	231.7 ± 13.25	107.13 ± 21.08	99.87 ± 15.16
Ascaris	No/l	18,000 - 39,000	14,000 - 32,000	10,000 - 26,000
Hook worm	No/l	0 - 3800	0 - 2400	Nil

Table 4. Characteristics of feedstock after digestion (mean ± SD).

Parameters	Unit	SS alone	SS:AW ratio	
			4:1	3:2
pH		7.93 ± 0.106	7.67 ± 0.230	7.4 ± 0.004
TS	mg/l	25,965 ± 1025	21,592.2 ± 451.7	18,880.6 ± 123.5
VS	mg/l	18,389.2 ± 1614.27	14,594.6 ± 1307	11,460.9 ± 605.32
COD	mg/l	10,891.6 ± 674.16	8172.9 ± 827.13	7228.1 ± 214.6
BOD5	mg/l	2898 ± 234.34	2581.26 ± 267	2275.8 ± 513.26
TN	mg/l	46.6 ± 6.82	62.6 ± 0.062	65.87 ± 0.023
TP	mg/l	68.6 ± 4.65	63.8 ± 0.042	76.349 ± 0.082
TK	mg/l	111.4 ± 8.67	69.2 ± 0.026	68.1 ± 0.034
Ascaris	No/l	18,000 - 39,000	14,000 - 32,000	10,000 - 26,000
Hook worm	No/l	0 - 3800	0 - 2400	Nil
Cu	mg/l	0.1602 ± 0.068	<0.0001	<0.0001
Ni	mg/l	0.0786 ± 0.084	0.0920 ± 0.018	0.1863 ± 0.048
Cr	mg/l	0.0139 ± 0.023	<0.0001	<0.0001
Pb	mg/l	0.0892 ± 0.056	0.0356 ± 0.023	<0.0001
Cd	mg/l	<0.0001	<0.0001	<0.0001
Zn	mg/l	0.748 ± 0.067	0.6627 ± 0.030	0.5777 ± 0.031
TC	MPN/100 ml	32×10^4	12×10^4	6×10^4
FC	MPN/100 ml	14×10^4	7×10^4	2×10^4

Physicochemical and biological characteristics (pH, TS, VS, BOD5, COD, heavy metals (Cd, Cr, Cu, Pb, Ni, and Zn), TKN, total phosphorus, potassium, and pathogens) of SS and different mixtures of SS and abattoirs wastes were analyzed before and after digestion.

Total solid was estimated from weight loss up on evaporation at 105˚C for 24 hours (Standard Method Procedure 2540 B). Total volatile solid content was estimated from weight loss upon ignition at 550˚C for 2hours in muffle furnace (Standard Method Procedure 2540 E) and pH was measured by Jenway model 3510 digital pH meter.

3. Results

The physiochemical and bacteriological characteristics of the SS and AW and their different mix ratios used were determined and the experimental results are given in **Tables 1-4**.

4. Discussion

4.1. Rate of Biogass Production

The amount of biogas production was increased as the mix ratio increased. The cumulative biogas produced during the experimental period for the digestion of the feed stocks is given in **Figure 1**. The results show that 0.51, 0.85 and 0.93 $m^3/d/m^3$ biogas with 33.8%, 48.3% and 56.9% methane were produced from SS alone, 4:1 and 3:2 mix ratios of SS to AW, respectively. The relative composition of the gases found in the biogas produced from SS alone and different mix ratios were also analyzed and the results are presented in **Figure 2**.

4.2. Characteristics of Feedstock after Digestion

Reductions in physicochemical properties analyzed in the study were observed. Accordingly, percentage reduction of TS 38%, 39% and 39.4%; VS 32%, 37.1% and 40.7%; and COD 70%, 71%, and 71.8%, were obtained from the digestion of SS alone, 4:1 and 3:2 mix ratio respectively (**Figure 3**). This shows that there is a slight increase in the removal efficiency of parameters understudy as the mix ratio of SS and abattoir waste increases. Besides, the digestion significantly reduce the coliform bacteria: 98.6% for fecal coliform and 98.4% for total coliform; but not the helminthes eggs, indicate that the digested sludge cannot be directly used for agricultural application without further treatment like sun drying which is less expensive than pasteurization to completely inactivate the remaining bacteria and helminthes eggs. It was observed complete removal of helminthes eggs after drying the digested sludge on direct sun light exposure for one month. WHO reports the same situation of complete removal of parasite when the fermented slurry is dried in the sun [18].

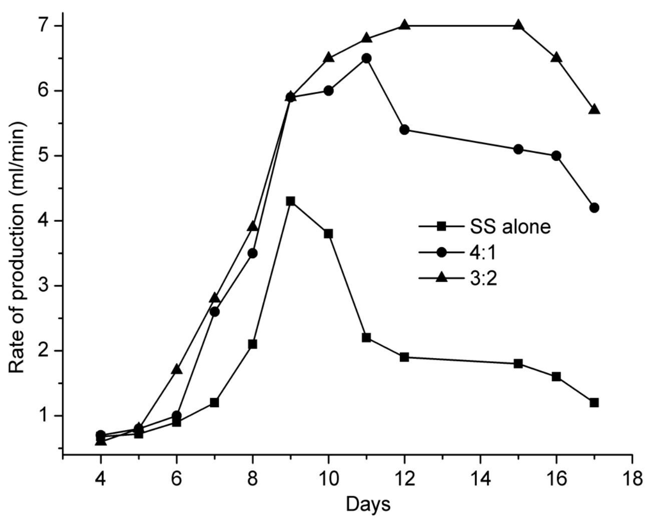

Figure 1. Rate of production of biogas from SS alone and different mix ratios.

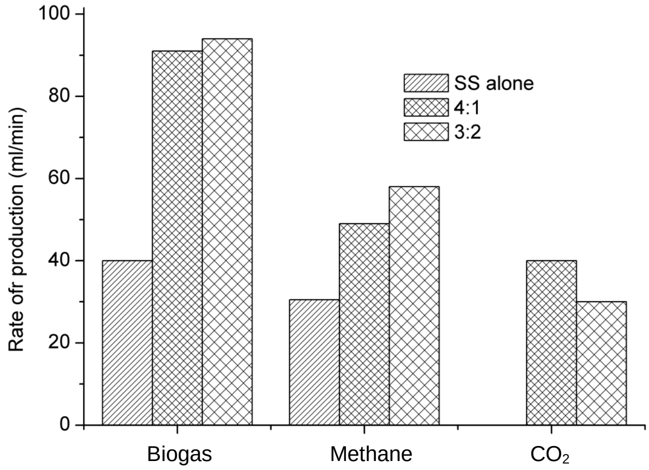

Figure 2. Composition of the biogas at different mix ratio.

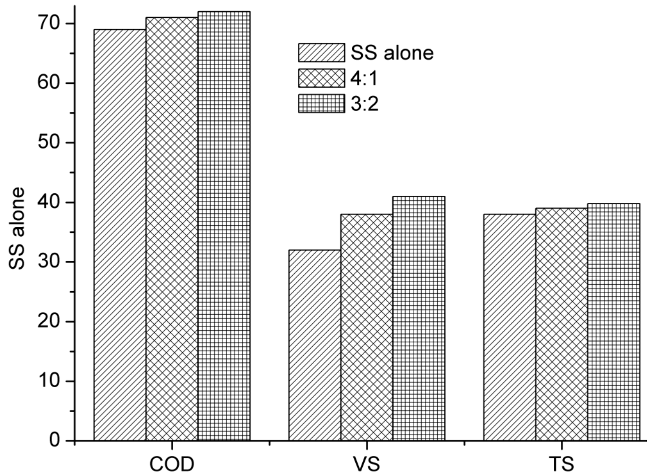

Figure 3. Reductions in physicochemical parameters.

5. Conclusion

SS wastes are loaded by organic portion, which contains the most valuable elements, carbon, for the formation of methane; whereas abattoir effluents contain excess valuable nutrients for anaerobes, which lead the co-digestion of the two wastes to high degree of methanization process. The mix ratio 3:2 was observed to produce the maximum quantity of biogas with the maximum percentage of methane. This shows that co-digestion of SS and AW enhances the quality and quantity of methane yield. The average percentage removal of TS, VS and COD increases with the mix ratio of the SS and its co-substrate (AW). The experimental results show that using anaerobic digestion of SS considerable amount of methane (annually 52,320 m^3 methane can be produced from the treatment site) can be captured from being emitted into atmosphere to prevent greenhouse effect. As observed in this study, biogas generation rate was increased with the mix ratio of AW with SS. This can be due to increase in dilution of the mixture, which can facilitate sympathetic environment for anaerobes or because of the addition of nutrients to the SS. Therefore, AW can be used as a co-substrate in the anaerobic digestion of sludge waste to increase the recovery of resources from waste.

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