Biogas and Bio solids Production from Tea Waste through Anaerobic Digestion

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Abstract

This study investigated the potential to harvest biogas from tea waste as a resource recovery and waste management initiative. The tea waste was shredded to a particle size of less than 2.5 mm and anaerobically digested over a period of 30 days in 10-L digesters. The composition of biogas obtained was 60% to 65% methane with a yield of 0.2 L/g of tea waste feedstock. A reduction in the tea waste chemical oxygen demand and volatile solids composition by more than 50% indicated that optimal tea waste digestion had occurred. The tea waste digestate was rich in nitrogen (4.5%), phosphorous (0.6%), and potassium (4.6%) and could potentially be adopted as a biofertilizer. Biogas and biosolids can be generated from tea waste as a waste to resource initiative.

Keywords: Anaerobic digestate, Biogas; Biosolids; NPK, Tea waste; Renewable energy; Waste management

1. Introduction

Agriculture and food bio wastes present an opportunity for conversion into biogas, a source of renewable energy, through anaerobic digestion (Sau et al., 2014; Jauke et al., 2015; Kader et al., 2015; Maile et al., 2017; Manyuchi et al., 2017; Wannapokin et al., 2017). Biogas is an odorless and colorless gas that has an ignition temperature of 650 °C to 750 °C, a calorific value of 20 MJ/m^3, and burns at approximately 60% efficiency (Ziauddin and Rajesh, 2015). Biogas presents an opportunity as an alternative fuel for heating and cooking purposes as well as combined power generation and has been increasingly been recommended for adoption as a renewable source of energy. Figure 1 shows the biogas production process as well as the potential energy generation and uses. Biogas production is mainly conducted under mesophilic conditions in dome shaped bio digesters and anaerobic digestate, also termed bio solids which can be further processed for fertilizer usage are obtained (Manyuchi et al., 2017). The biogas produced is rich in bio methane with compositions ranging from 55% to 70% and the other major composition is carbon dioxide with composition ranging from 25% to 35% (Ziauddin and Rajesh, 2015). The biogas calorific value can be enhanced by applying purifying techniques such as adsorption which separates the carbon dioxide to have bio methane content with more than 90% (Maile et al., 2017).

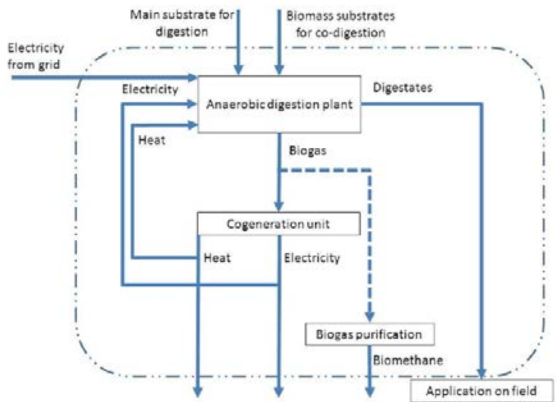

Figure. 1. Biogas generation for combined heat and power generation [8]

Another important by product from the anaerobic digestion of bio waste is the anaerobic digestate. This anaerobic digestate is also termed bio solids and contains nitrogen, phosphorous and potassium (NPK) as well as the other trace applications that make it applicable as a bio fertilizer (Makadi et al., 2012). Bio solids compositions of NPK ranging up to 4.27%N; 0.66%P and 4.71%K have been reported in literature (Makadi et al., 2012).

On the other hand, the Southern African region being agro based, tea plantations are a common feature in countries like Zimbabwe, of which the tea is further processed to tea bags and tea leaves. At least 470 tons of tea is generated on an annual basis in Southern Africa (Apostolides et al., 2006). Tea waste is a potential source of agro waste that can be a raw material for biogas generated. Tea is mainly cultivated in the high rainfall regions in Southern Africa. During its harvesting and processing, huge amounts are generated and are a potential environmental threat if not properly managed. Several processes whereby tea bio waste is generated include the withering, rolling, fermentation, drying, sorting and grading stages (Oirere, 2015). Figure 2 shows the tea processing stages and all the amount of bio-waste generated. Tea waste in combination with other sources of waste like food waste have been reported to be a good source of biogas production with enhanced yields as high as 30% being reported (Sau et al., 2014).

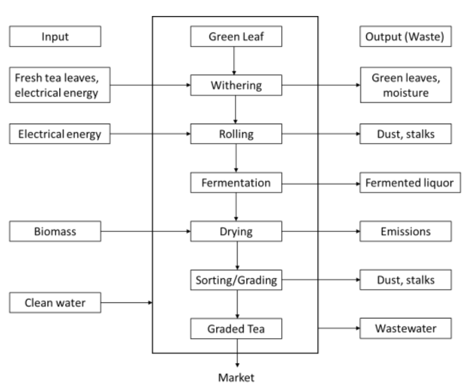

Figure. 2. Generation of tea bio-waste during tea processing [11]

In this study, the potential to harness biogas from tea waste, as a source of renewable and alternative energy was investigated. Furthermore, the potential of using the resulting digestate as a biofertilizer was explored.

2. Experimental

2.1Materials

Tea wastes were collected from a local tea plantation in Chipinge, Zimbabwe. A biogas 5000 analyzer was used for analyzing the composition of the gas. Gas collecting Tedlar bags were obtained from Sigma Aldrich, Johannesburg, South Africa. An A&D moisture analyzer (Shanghai, China) was used for moisture content and total solids analysis, and a bench scale muffle furnace (Savanti Instruments, Mumbai, India) with a temperature range of 100 °C to 1200 °C was used for the volatile solids determination. A Hach model DR 3900 spectrophotometer (Johannesburg, South Africa) was used for determining the nutrient composition of the tea waste digestate and the pH of the feedstock was determined using a HI98107 Hanna instrument (Johannesburg, South Africa).

2.2 Methods

The tea leaves' moisture content was determined by drying 5 g of the tea leaves at 105 °C and then calculating the difference between the mass of the crucible with the tea leaves against the mass of the empty crucible. The moisture content was calculated in accordance; to Equation 1:

$$Moisture\ content\ (\%) = \left(\frac{w2 - w3}{w2 - w1}\right) x\ 100 \ldots \ldots \ldots . . (1)$$

Where: w_1 is the weight of the crucible, w_2 is the total weight of the crucible and raw sample; w_3 is the total weight of the crucible and sample after heating.

The total solids (TS) were determined by subtracting the moisture content from 100%. The volatile solids (VS) were estimated by heating in a furnace at 600 °C for 2 h. Equation 1 was used to calculate the amount of volatile solids in the tea waste samples. The chemical oxygen demand (COD) was measured using the APHA manual (Apha, 2005).

Approximately 8 kg of the tea waste slurry was first ground to a particle size of less than 2.5 mm to speed up the digestion process; afterwards it was anaerobically digested in 10-L lab made digesters over a 30 day period. Mesophilic conditions of temperatures around 35 °C were considered for anaerobic digestion because they are ideal for biogas production from tea wastes (Sau et al., 2013). Biogas was collected in Tedlar bags and analyzed for its content of methane, carbon dioxide, and other gases using a Biogas 5000 (Geotech, Leamington Spa, UK) biogas analyzer. The cumulative biogas production over the 30 days was also monitored. The tea waste digestate was analyzed to determine the content of nitrogen, phosphorous, and potassium using spectrophotometric methods (Hach model DR 3900 spectrophotometer, Johannesburg, South Africa) (Seu, 2003).

3. Results and Discussion

3.1 Feedstock Characteristics

The tea waste was ground to a particle size of less than 2.5 mm before digestion to enhance the anaerobic digestion process for biogas production. The tea waste had 8.2% to 9.5% moisture content on a dry basis, volatile solids (VS) of 92% to 95%, and chemical oxygen demand (COD) of 68.9 g/L to 72.9 g/L. A summary of the physicochemical parameters is shown in Table 1. The high COD and total solids in the tea waste allowed for the anaerobic digestion of the tea waste to biogas. The reduction in the VS and COD during the anaerobic digestion process was a good indication that the tea waste slurry was highly converted to biogas (Chellipan et al., 2011; Ezekoye et al., 2011; Khalid et al., 2011). This potential for high anaerobic digestion of the tea waste can also be related to the high total solids contents in the feedstock that were on average 91%. The pH in the feedstock (6.6 to 7.1) was almost neutral and this provided ideal conditions for anaerobic digestion to take place because bio-waste anaerobic digestion favors neutral pH (Hamawand and Baillie, 2015).

Table 1. Tea waste physicochemical characteristics

Parameter	Value

Total solids	90.5% to 91.5%
Particle size	1.5 mm to 2.5 mm
Moisture	8.2% to 9.5%
pH	6.6 to 7.1
COD	68.9 g/L to 72.9 g/L
VS	92% to 95%

3.2 Biogas Production from Tea Waste

The amount of biogas produced from tea waste increased with increase in retention time of 30 days (Figure 3). The increase in the amount of biogas produced was attributed to all the tea waste being able to be digested over the retention period. An average conversion of 0.7 was noted and the remaining tea waste was converted to anaerobic digestate (bio solids). Ezekoye *et al*. (2011) and Chelliapan *et al.* (2011) reported the same trend when the biogas quantity produced increased with retention times of up to 82 days.

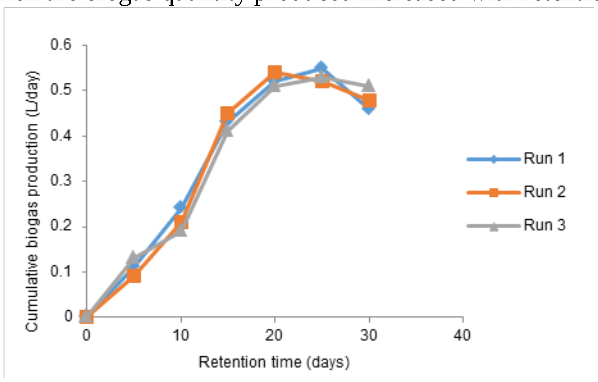

Figure 3. Biogas generation from tea waste

3.4 Biogas Composition and Yield

The produced biogas had a methane content that ranged from 60% to 65% (Table 2) and the biogas yield obtained was 0.19 L/g to 0.20 L/g of the tea waste used. The high methane content indicated the success of the bioconversion of the tea waste to biogas through anaerobic digestion. This high yield was also attributed to the mesophilic conditions that were employed during the biogas production process as well as the high quality tea waste feedstock used. The high biogas yield and methane composition was similar to the results obtained by Rouf *et al*. (2015) when they produced biogas from dried fallen leaves under anaerobic conditions for 10 days, as well as Khalid *et al.* (2011) when they digested solid waste. The results obtained were a good indication that tea waste is a potential raw material for biogas conversion. The tea waste biogas also contained carbon dioxide as the other major composition (30% to 35%) (Table 2). The carbon dioxide can be further separated from the biogas using technologies like membrane separation and adsorption to increase the calorific value of the methane and allow it to be used for electricity generation. However, contaminants in the biogas like hydrogen sulphide and ammonia can be separated by scrubbing to enhance the purity and calorific value of the methane.

Table 2. Tea waste biogas composition

Gas	Composition by Volume (%)
Methane	60 to 65
Carbon dioxide	30 to 35
Water	3 to 6
Hydrogen sulphide	1.5 to 2.0
Ammonia	0.02 to 0.04
Nitrogen	0.06 to 1.0
Oxygen	0.05 to 1.0
Hydrogen	0.01 o 0.05

3.5 Methane Variation during Anaerobic Digestion

As the tea waste was digested over the 30 days retention period, the amount of methane generated from the tea waste also increase to an average value of 65%, then reached a maxima (Figure 4). This trend was attributed to the increase in the digestion of the tea waste and also can be due to the enhanced performance by the methanogenic bacteria available in the tea waste. The same trend in methane concentration was reported by Kader *et al.* (2015) when the methane concentration increased to 69% upon anaerobic digestion of food waste for a retention time of three works. The increase in the methane produced was also attributed to the increased performance of the methanogenic bacteria as the digestion process time increased.

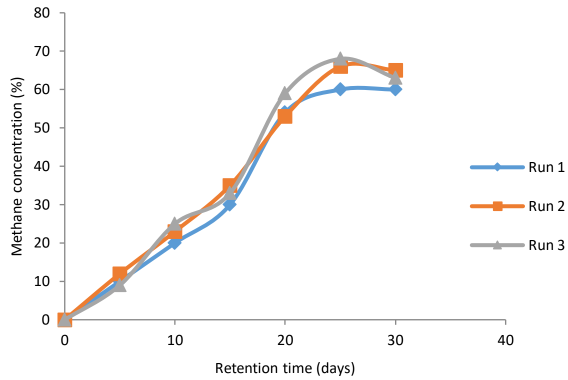

Figure. 4. Methane concentration composition during tea waste digestion

3.6 Effect of Retention Time on Digestate (Bio solids) Quality

3.6.1 Effect on N

As the anaerobic digestion process increased to a period of 30 days, the amount of nitrogen in the digestate also increased by 56.6% (Figure 5). Previous studies by Moller and Muller (2012) indicated that there is potential to increase the nitrogen composition in highly biodegradable matter due to the anaerobic processes. This therefore, can be the case for the tea waste which is highly biodegradable and promotes a good environment for digestion bacteria especially under mesophilic conditions. Risberg *et al.* (2017) also reported that anaerobic digestate have high ammonium contents when they were compared to animal manure that had not gone through anaerobic digestion.

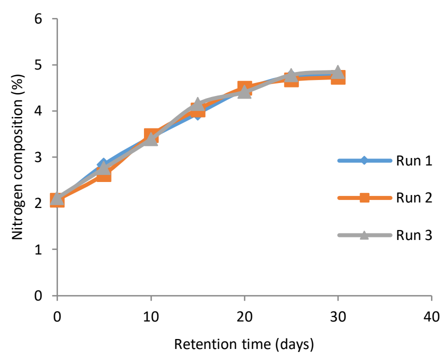

Figure. 5. Effect of anaerobic digestion on nitrogen content

3.6.2 Effect on P

As the anaerobic digestion period increased to 30 days, the amount of phosphorous composition in the anaerobic digestate increased by about 43.8% (Figure 6). The positive changes in the phosphorous content are attributed to the possible release of phosphorous in organic forms from the tea waste.

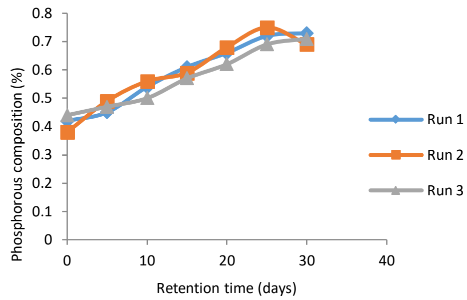

Figure. 6. Effect of anaerobic digestion on phosphorous content

3.6.3 Effect on K

As the tea waste digestion period increased to 30 days, the potassium content increased by about 24.2% (Figure 7). As the wet digestion period increases, there is potential for extraction of the water soluble and exchangeable potassium to the digestate hence the increase in the potassium composition.

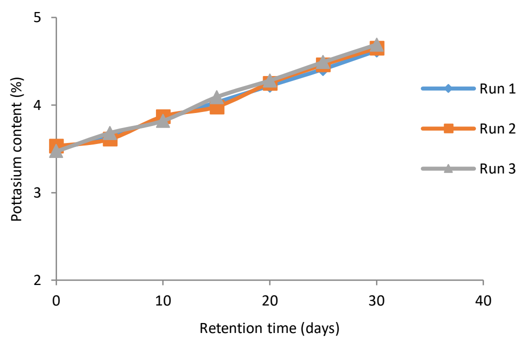

Figure. 7. Effect of anaerobic digestion on potassium content

3.7 Tea Waste Digestate (Bio solids) Composition

The final digestate (bio solids) from the tea waste was rich in nitrogen (4.12% to 4.79%), phosphorous (0.56% to 0.73%), and potassium (3.65% to 4.62%) content with potential to be used as a bio fertilizer. Nearly similar results were reported by Davis *et al.* (2012) when they quantified the potential of harnessing bio solids from sewage sludge digestate. The NPK results for the digestate were also in line with results reported by Makadi *et al.* (2012) who reported that the NPK composition for anaerobic digestate was 4.27%, 0.66% and 4.71% respectively.

The COD and VS in the tea waste was reduced 53% and 57%, respectively, which indicated that the efficient digestion of the tea waste to biogas and biosolids occurred. The physicochemical characteristics of the final digestate are given in Table 3. Biosolids from anaerobic digestion have also been reported to be a potential fertilizer by several authors (Sau et al., 2014; Jauke et al, 2015).

Table 3. Tea waste bio solids composition

Nutrient	Composition
Nitrogen	4.12% to 4.79%
Phosphorous	0.56% to 0.73%
Potassium	3.65% to 4.62%
COD	32.4% to 36.6%
VS	39.4% to 42.8%

Tea waste conversion into biogas does not only present an opportunity for renewable energy, but also potential to boost the agricultural sector as a potential source of biofertilizers, as well as proper tea waste management.

4. Conclusion

Tea waste was converted to a biogas with a methane content of more than 60%. The methane concentration in the biogas increased with increase in the anaerobic digestion retention time. The amount of biogas produced increased with increase in retention time of 30 days. The NPK composition of the tea waste digestate increase with increase indigestion time. The digestate rich in nitrogen, phosphorous, and potassium produced during the process was suitable for utilization as a bio fertilizer in organic farming. Anaerobic digestion of tea waste into bio gas is an effective waste to energy strategy of managing tea processing waste.

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