Ethiopian Journal of Science and Sustainable Development (EJSSD)

p-ISSN 1998-0531 Volume 5 (2), 2018

# Study on the Biogas Energy Potential of Cactus (Opuntia Ficus-Indica (L.) Mill.)

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## Abstract

*Bioenergy is a renewable energy and it contribute to solve the present and future energy problems. Among the alternative bio energy sources, biogas production from different sources were currently applicable. Biogas production from energy crops, agriculture waste and various residential and industrial waste material are limited; thus, new renewable sources are sought after. This paper presents the experimental results of the anaerobic digestion of cactus (Opuntia ficus-indica) (L.) and methane content of each of the treatments. The sample of the plant (cactus) was cut, purified from spin and homogenized. The processes of anaerobic digestion for the generation of biogas was then conducted by varying the temperature and the maturity of cactus in eight treatments as, T1 and T2 (<1-year cactus at 27°C and 37°C), T3 and T4 (1-year cactus at 27°C and 37°C), T5 and T6 (2-year cactus at 27°C and 37°C), T7 and T8 (3-year cactus at 27°C and 37°C) were performed. From 500g of cactus, it was found that the amount of biogas production and quality was highest in T2 (3500 ml of biogas and 49% $CH_4$) and T7 produced the minimum biogas production and quality (2500ml of biogas and 33% $CH_4$). Thus, Cactus can be digested alone or it can be one of the feed stock for co-digestion process.*

**Keywords**: *Aanaerobic digestion, methane, biogas, cactus*

## 1. Introduction

A large-scale biofuel feed stock cultivation using agricultural land decreased food availability and boosted food price dynamics, especially in developing countries (Valentine et al., 2012). Due to these negative impacts, second generation feed stocks were the alternatives for biofuel production, and research for these new feed stocks is intense. Several issues must be analyzed in the search for the most appropriate substrate, including availability of agro-industrial residues, adaptation of second-generation energy crops to local soil and climate, transportation costs and environmental impacts (Calabrò et al., 2016; Chandra et al., 2012; Moraes et al., 2014). Among the alternative feed stock cactus (opuntia ficus-indica) is a promising feed stock for biogas production.

This paper focuses mainly on biogas production from cactus (opuntia ficus-indica). The advantage of the digestion of these biomass is: it does not compete with the land usage for feed or food production, which can tolerate surprising bouts of cold weather and it can be grown on veritable desert-like wastelands, where conventional crops would wither and die. Although the cactus is native to semi-arid regions with stifling hot temperatures, it can also survive and even thrive in mountainous areas that can have temperatures as low as minus 15 degrees Celsius. (wayland, 2010). The world has millions of hectares of land prone to drought and desertification, Opuntia helps create vegetative cover, which enhances soil regeneration and improves the infiltration of rainfall back in to the soil (Calabrò et al., 2017).

## 2. Material and Method

### 2.1. Description of cactus (opuntia ficus indica)

The cactus (Opuntia ficus indica) used in all experiments are obtain from Adigrat (Tigray, Ethiopia). It was collect with its age group that is <1, 1, 2, and 3 years old and the age was determined by asking the cactus farmer. The collected cactus was cut manually into small pieces and homogenize used for digestion as reported in Wayland (2010). Per Santos et al. (2016); Gabriel and Victor (2014); Malainine et al. (2015) and Yang et al. (2015), the composition of these residuals in dried form was 7-22% cellulose, 9-19% hemicellulose, 8-16% lignin, 64-71% carbohydrate (total polysaccharides) and 17-24% ash. As reported in Calabrò et al. (2017), the cactus had a total of 93.4% water, 6.6% solid content and 78.2% volatile solid content.

### 2.2. Determination of the Physico-Chemical properties of the Feed stocks

#### 2.2.1. Total Solid (TS), Volatile Solid (VS), Carbon to Nitrogen ration (C/N)

10 gm of freshly collected samples of each of cactus age were weighed using digital weight measuring device and placed inside an oven maintained at 105°C for 24 hours, then the sample ignited at 650°C in furnace for 3 hours as indicated in Jigar et al. (2011) in duplicate to determine the total and volatile solid content. The carbon content of the feed stock is measured by considering the volatile solids content that was expressed as a percentage and the total carbon content was obtained from volatile solids. The Kjeldahl method was employed to determine the total nitrogen content of the feedstocks.

### 2.3. Digester Composition

For the purpose of this study the amount of cactus in digesters was fixed to be 500 gm (taking the digesters volume in to consideration) and the wet cactus was added to 3 L of plastic bottle digesters. To prepare the cactus for anaerobic digestion first the cactus plant cut manualy by knife and reduce the size to 2 mm (Sun and Cheng, 2002) by blaender. It can be used to improve the digestibility of the lignocellulosic materials (Taherzadeh & Karimi, 2008). Per Sasse (1988) & Nijaguna (2002), a wet anaerobic digestion process has an optimal total solid (TS) content of 5 to 10%. When the TS values were above the optimal value, water was added to obtain the optimum concentration of 9% TS. For this study the water content were adjusted per the indicated optimal condition and to initiate or start up the digestion process 10% of inoculem was added for all treatments (Mazumdar, 1982; Nijaguna, 2002).

## 2.4. Controlling conditions

The digesters' internal working temperature was maintained at 27°C for the sample <1, 1, 2 and 3 years old cactus and 37°C for the other <1, 1, 2 and 3 years old cactus samples and PH was adjusted at 6.8 once for all treatments. This is in agreement with a pH range of 6.25 to 7.5 which is conducive for methanogenic bacteria to function properly as indicated by Rai (2004). The tempreture were constant througout the process time. This tempreture is controled by using the water bath (model:HWS-24, voltage 220 V, 50 Hz, power 1000 w).

## 2.5. Expermental setup

The experimental set up for the study on batch digestion consists of plastic bottle with a plastic stopper (Figure 1). All the eight anaerobic digesters were constructed in bench-scale experiments at which the degradation of the substrate was accomplished in sealed plastic bottles with a capacity of 3 liters in Addis Ababa institute of technology (AAiT) Environmental Engineering laboratory. Each bottle was sealed with a rubber stopper having one outlets. The outlet was attached to the branched connector one branch connect to plastic air bag and the other one is closed and it is used to measure the volume collected gas. Manual agitation was take place by shacking the digester by hand in each day. There were eight (8) treatments T1 (<1-year cactus at 27°C), T2 (<1-year cactus at 37°C), T3 (1-year cactus at 27°C), T4 (1-year cactus at 37°C), T5 (2-year cactus at 27°C), T6 (2-year cactus at 37°C), T7 (3-year cactus at 27°C) and T8 (3-year cactus at 37°C).

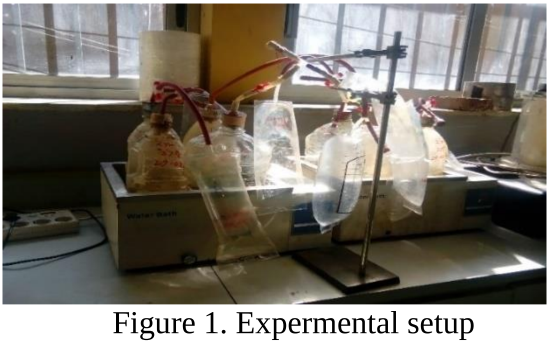

Figure 1. Expermental setup



 

## 3. Result and Discussion

### 3.1. Characterization of feed stocks

The Characteristics of feed stock (% moisture content, %TS, %VS, %C, %N and % C/N between the samples (values are mean and SE, n=4)) were determined. Each test were conducted two times and the average values are shown in Table 1.

Table 1. Characteristics of feed stock (% moisture content, %TS, %VS, %C, %N and % C/N between the samples (values are mean and SE, n=4))

| Parametres | S1 (%) | S2 (%) | S3(%) | S4(%) | Mean | SE |
|---|---|---|---|---|---|---|
| Moisture content | 95.3 | 93 | 90.5 | 87 | 91.45 | 1.78 |
| TS | 4.7 | 7.0 | 9.5 | 13 | 8.55 | 1.78 |
| VS as percentage of TS | 80.8 | 74.3 | 73.7 | 69.2 | 74.5 | 2.39 |
| Ash as percentage of TS | 19.1 | 25.7 | 26.3 | 30.8 | 25.47 | 2.41 |
| C | 44.9 | 41.3 | 40.9 | 38.4 | 41.37 | 1.34 |
| N | 1.3 | 0.92 | 0.83 | 0.72 | 0.94 | 0.12 |
| C/N | 34.5 | 44.9 | 49.3 | 53.3 | 45.5 | 4.0 |

The mean moisture shows that the moisture content of cactus less than one year old cactus was higher than other cactus samples, as a result increasing the degree of digestion as bacteria can easily access liquid substrate for relevant reactions to take place easily. Determining TS and VS, it is important to understand that high content of volatile fatty acids (VFAs) in the substrates. The maximum TS (sample 4) was measured in 3 years old cactus, where as the minimum TS were measured from < 1 year old cactus (Table 1). This may show that 3 years old cactus contain more total solids compared to other samples, but the biodegradiabilty of the sample were determined by analyzing the volatile content of substrates. The total solid content of all sample before AD was between 4.7 to 13.0%. Per Sasse (1988) and Nijaguna (2002) biogas digesters generally follow a wet anaerobic condition process with an optimal total solid (TS) content of 5 to 10%. Except the last sample (TS=13%) all sampleas were allmost under optimal condition. And Out of the total solid the volatile solid (VS) were 69.2 - 80.8% this indicated that large fraction of cactus is biodegradable and thus it can serve as an important feedstock for biogas production. The carbon to nitrogen ratio of the feed stocks is another factor that affects the anaerobic digestion process. The percent degradation of organic carbon for < 1 year old cactus (44.9) was higher than all (from 38.4 to 41.37) (Table 1). The results also revealed that there are differences in percentage of organic carbon between samples. Comparison of %C showed that %C significantly decreased when the age of cactus increases. The C/N of all samples does not agree with the sugessted value 20:1 to 30:1 as reported by Dahlman and Forst



 

(2001) as cited in Yitayal Addis (2011). This indicates that cactus needs additional substrate to minimize its C/N ratio to the optimum level.

### 3.2. Characteristics of digesters (Tempreture and PH)

Temperature and PH are the main factors that affect bio-digestion. Consequently, the temperature were adjusted at 27°C for the treatments T1, T3, T5,T7 and 37°C for the treatments T2, T4, T6, T8. From the expermental result treatments those treated in 37°C (T2 (49% CH4), T4 (45% CH4), T6(40% CH4) and T8 (40% CH4)) produced higher amount methane when compered to other corrosponding treatments T1, T3,T5 and T7 those treated in 27°C. Producing biogas in a tempreture of 37°C was much better than producing in 27°C. The PH of each digester were also adjusted 6.8 at the beginning of the digestion process. The PH of all the treatments came down at the end of the digestion period. This may be due to the formation of acids by acidogenic bacteria, the PH of the treatments were adjusted once before starting the digestion at 6.8 (Ria, 2004) and after digestion the PH of the treatment were T1=5.1, T2=5.5, T3=4.7, T4=5.4, T5=4.2, T6=4.6, T7=4.5, T8=4.8. The relative higest value of the out put PH was the indication of the digestion of volatile acid and nitrogen compounds, and more methane was produced.

### 3.3. Amount and Quality of biogas production

Biogas production and its methane content were measured for about 45 days of digestion period until gas production was stopped. It was found that treatment T4 produced the highest (900 ml) of gas in the first 20 days of digestion, the methane% is zero for all treatments for the first 15 days, but the other gases were produced in the first five days those are $CO_2$, $O_2$, $H_2S$ (<10ppm) and the balance were atmospheric nitrogen. This indicates that feed stock (cactus) were not satble for biogas production until day 20.

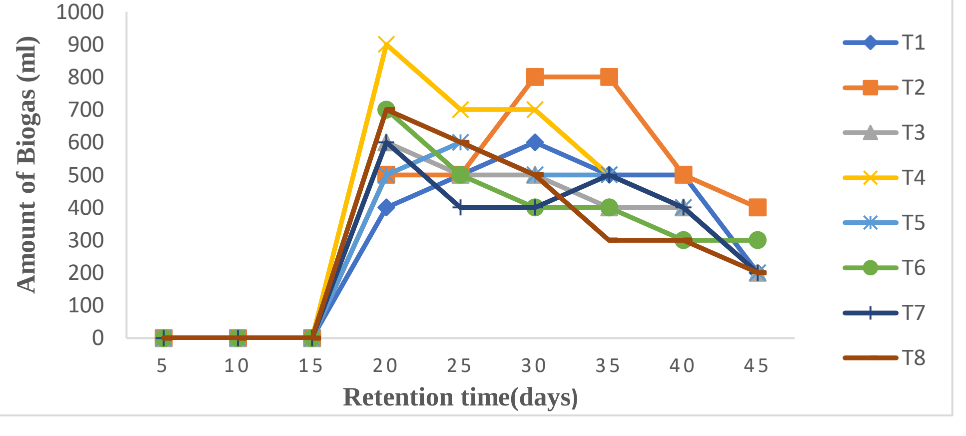


Figure 2. Biogas production comparisim between treatments



 

Figure 2. shows the amount of biogas (ml) produced in the whole digestion period. 2700 ml, 3500 ml, 2600 ml, 3400 ml, 2700 ml, 2600 ml, 2500 ml and 2600 ml of the total biogas produced in T1, T2, T3, T4, T5, T6, T7, and T8, respectively in the whole fermentation period. The standard diviation were 137.84, 172.24, 136.62, 250.33, 137.84, 150.55, 132.91, 196.63 for T1, T2, T3, T4, T5, T6, T7 and T8, respectivly. From the result the highest standrd diviation scored in T4 (250.33 Std. Diviation) which means there were the highest volume variation between measured days in test four. The amount of biogas within six treatment (T1, T3, T5, T6 , T7 and T8) were 2500 ml to 2700 ml, these indecated that the volume of biogas of the treatments were not highely affected by the controled parameters (age and temperature), but the two treatments T2 and T4 gives the higher amounts of bio gas (3500 ml and 3400 ml) than other treatments. And also T2 (<1 year cactus at 37°C) produced the maximum of average methane percentage 49% and T4 (1 year cactus at 37°C) was 45%. The maximum methane percentage were measured at day 30 for treatmets T1 up to T4 and day 35 for the remainnig four treatments. This indicated that < 1 and 1years old cactus were stable early. The lag phase was observed at the beginning of the experiment, because the cactus need time for stablization.

## 3.4. Comparison of treatments

Figure 3. indicate that the total gas production and the percentage of methane of treatments (T2 and T4) were greater than those of the corresponding treatments. For the first 15 days of fermentation period all treatments produced gas that have no methane and it containes $CO_2$, $O_2$, <10ppm $H_2S$ and the balance atmospheric nitrogen, after 15 days of lage phase the digester starts producing methane. T2 produced more than other treatments in day 20. The average methane quality was high in T2 (49%) and T4 (45%). The other treatments it is between 33 to 41%. These significant variations in the amount, quality and rate of biogas production may be due to the feedstock difference (different concentration and amount of volatile solid) and difference in tempreture.

## 3.5. Characterization of Digestate (slurry )

One advantage of anaerobic digestion is the use of the digestate (slurry). To characterize the digestate tests were done two times and the mean values were indicated, total solid (TS) were 2.3%, 2.1%, 3.6%, 3.2%, 5.1%, 4.3%, 5.4 and 6.8% and volatile solid (VS) were 6.1%, 5.2%,12.5%, 11.3%, 13.2%, 12.4%, 15.1% and 14.7% for treatment T1, T2, T3, T4, T5, T6, T7 and T8. According to Joenssen et al. (2004) anaerobic digestion only removes organics and the main mineral material and almost all nutrients remain in the bottom sludge, the result indicated that organics are decomposed. After digestion , the PH of the slurry were 5.5, 5.1, 5.4, 4.7, 4.2, 4.6, 4.5, 4.3. for T1, T2, T3, T4, T5, T6, T7 and T8 respectively. The PH of the slurry of T1-T4 were higher than other treatments that revealed the four treatments (T1-T4) were better in methanoginesis procees (had high in conversion of acetic acid to methane). The solid digestate can be used for forage by mixing with flour of earth warms.

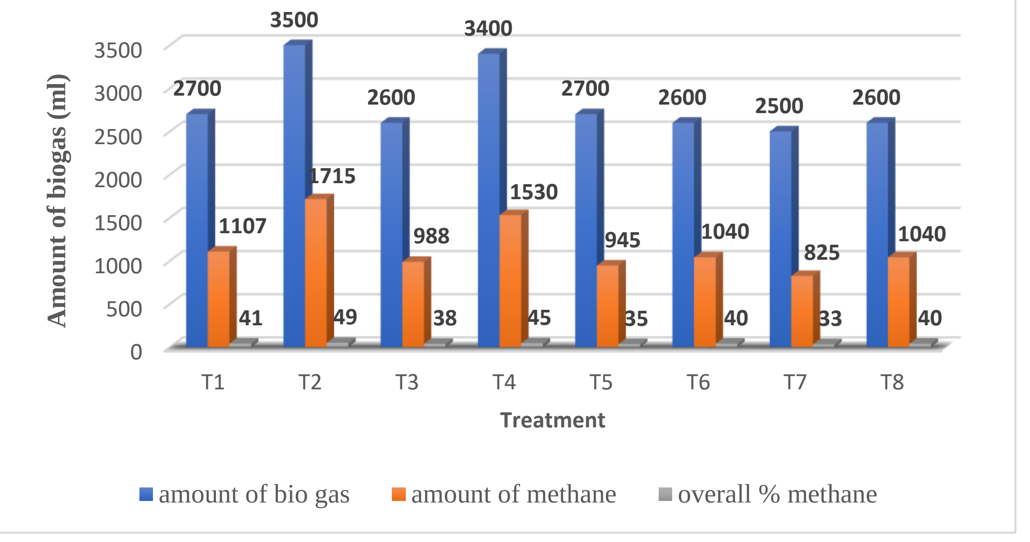


Figure 3. The total biogas, methane and its overall percentage of treatments

## 4. Conclusion

Out of the total solid, the volatile solid (VS) were 69.2 - 80.8% indicating that large fraction of cactus is biodegradable and thus it can serve as an important feedstock for biogas production. Less than one year old cactus and one year old cactus treated at 37°C (T2 and T4) give the highest quality biogas (49% and 45% $CH_4$) the the other treatments. Further research will be needed to confirm the high energy density of cactus for biogas production. The cactus biomass is highly organic that have less nitrogen, therefore it might need feed stocks which are rich in nitrogen, if used as substrate for biogas production. Further investigation will be needed to confirm which nitrogen reach substrate is sutable for co-digestuion with cactus for optimum biogas production.


## Acknowledgment

The authers acknowledge Center of Energy Technology and School of Chemical and Bio Engineering AAiT/AAU for laboratory facilities and Wolkite University for financial support.


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