Assessing the Potential of Electrical Energy Generation through Anaerobic Wastewater Treatment Processes at Pestalozzi Education center (PEC)

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Abstract

Small scale electricity generation for self-sustainability using biogas was investigated in this study. Biogas is a renewable energy produced by wastewater treatment processes. The case study was Pestalozzi Education Center (PEC), an institute which treats its wastewater using a Decentralized Wastewater Treatment System (DEWATS). The main objective of the study was to determine feasibility of small scale electricity generation, produced from anaerobic wastewater treatment.

Comparisons were made between actual biogas produced and the theoretically expected amount of biogas. It was observed that the actual biogas produced was much lower than expected and an increase in feedstock decreased the amount of biogas produced rather than increase as theoretically expected. Wastewater samples taken at every stage of treatment were analyzed for COD and results showed that the DEWATS was operating normally but not efficiently.

PEC is currently unable to generate electricity. Operating at optimum efficiency, agricultural waste addition would not reduce the biogas as currently is the case, but increase the biogas enough to generate electricity. This would still be more expensive than buying electricity from a utility company, thus, it is uneconomical for PEC to generate electricity.

Keywords: wastewater treatment processes; anaerobic treatment of wastewater; electricity generation; renewable energy; DEWATS; HOMER software

Introduction

For many years, biogas was considered a waste product of anaerobic sludge digestion systems and some plants converted to aerobic digestion systems to eliminate injury to personnel caused by the biogas and other problems associated with anaerobic sludge disposal systems [1]. Most Decentralized Wastewater Treatment Systems (DEWATS) have however, adopted the concept of Anaerobic Digestion (AD) for the treatment of wastewater. AD is defined as the decomposition of organic matter, in the absence of oxygen, with the aid of micro-organisms, producing biogas and digestate as end products [2].

DEWATS thus have the advantage of treating wastes as potential resources (biogas and digestate) and also, the wastes in such systems are usually treated close to the place of generation therefore reducing on expenses on appurtenances such as large pipes for transmission of wastes. Biogas is a combustible gas consisting of a combination of methane, carbon dioxide and small amounts of other gases and trace elements [2]. The AD of hydrocarbons produces biogas. Biogas is almost 20 percent lighter than air and has an ignition temperature in the range of 650°C to 750°C. The calorific value of biogas is 6 kWh/m³ equivalents to 20 mega joule—this corresponds to about half a liter of diesel oil. Methane has nearly 20 times more greenhouse gas potential than carbon dioxide, in that the capture and burning of methane

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significantly reduces the greenhouse gas effect. Biogas is a very useful resource because it is combustible, making it a primary source of energy. It can also be used as a secondary source when its combustibility is used to generate electricity.

Study Area

The study area was Pestalozzi Education Center (PEC), a school located off twin palm road in the Ibex hill area of Zambia's capital city, Lusaka. PEC is a place in Lusaka already producing and using biogas however, not for electricity but as primary energy for the use in gas stoves. The treatment plant has two biogas digesters and an Anaerobic Baffled Reactor (ABR) with nine baffles for further treatment of the wastewater.

Figure 1: Location of Pestalozzi Education Center (PEC) in Ibex hill, Lusaka [3,4].

Technical Description

As stated above, there are two biogas digesters; a 20 m³ digester was constructed with, and as a part of the original DEWATS in 2009, whilst a 40 m³ digester was constructed in July 2013 to accommodate more treatment owing to an increase in population. The two digesters are fully operational and are the first phase of wastewater treatment at the plant. Succeeding phases of treatment are carried out in the ABR. The biogas digesters are dome shaped and buried just beneath ground level. The biogas is collected through pipes connected at the crests of the dome. A meter is also connected to the pipes to measure biogas readings daily. The pipes transport the biogas to the biogas stoves where it then used for cooking.

Methodology and Study Data

Bio Gas

For the determination of amounts of gas produced daily, meter readings were taken and recorded at specific times every day together with their corresponding temperatures. The readings were taken every day for a month. All kitchen waste added to the digester was weighed before adding it to the digester. In the following month, however, an increase in feedstock was undertaken to ascertain whether it would increase the amount of biogas produced. This was in form of an added 10 kg of banana residues to the digester every day for a whole month. Meter readings were undertaken as before. Readings were taken at 08:00 hrs and 16:00 hrs every day. Month one was called phase 1 and month two was called phase 2 [6].

HOMER (software) Application and Renewable Energy Technology, (RET) Optimization

HOMER (software) application and renewable energy technology, (ret) optimization, micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. When you design a power system, you must make many decisions about the configuration of the system, HOMER’s optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.

Wastewater Sample Collection and Analysis

Wastewater samples were collected for the month of July and these helped determine the efficiency of the treatment of the DEWATS through COD removal. The wastewater samples were collected for the effluent from the Biogas Digester, all the compartments in the Anaerobic Baffled Reactor (ABR), the compartments of the Anaerobic Filters (AF) and the effluent from the Plant Gravel Filter (PGF). Figure 3 shows the sample points [7].

The diagram above shows the proposed sampling points: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 are the proposed sampling points; BD40 refers to the 40m3 Biogas Digester; BD20 is the 20m3 Biogas Digester; ABR 1, 2, 3, 4, 5, 6 is the Anaerobic Baffle Reactor (with 6 baffles); AF is Anaerobic Filter; PGF is Planted Grass Filter and CC is Collection Chamber.

Factors Which Led to Reduction in Biogas Yield in the Second Phase
The reduction in biogas yield in the second phase in which an increase in feedstock decreased the amount of biogas produced instead of increase could be attributed to the following factors:

a. The increase required that the feedstock be aided down but that was not done often enough. The accumulation of feedstock would lead to premature digestion at the inlet, thus some of the gas would bubble out through the opening at the inlet. There was therefore need for frequent aiding of feedstock and minimization of premature digestion could also be vital.

b. The COD was only measured after the initial project to measure the efficiency of the DEWATS [8].

Electricity Viability
The standard values used for estimation pertain to a volume of biogas per entity per day are as follows:

a. 30 litres biogas/person. day
b. 80 litres biogas/Kg Kitchen waste. day
c. 60 litres biogas/Kg Agricultural waste. day

These values are related to known quantities of the above stated entities to give an estimation of how much biogas is expected [5].

Tables 1, 2 and 3 show the standard values of estimation per unit and the total estimated biogas quantities per combination.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Biogas Quantity, Q (m³/unit. Day)</th>
<th>No. of Units</th>
<th>Total Biogas quantity (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human beings (Persons)</td>
<td>0.03</td>
<td>200</td>
<td>6</td>
</tr>
<tr>
<td>Kitchen waste (Kg)</td>
<td>0.08</td>
<td>22</td>
<td>1.76</td>
</tr>
<tr>
<td>Agricultural waste (Kg)</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td>-</td>
<td><strong>7.76</strong></td>
</tr>
</tbody>
</table>

*Table 1: Expected gas yields for phase one (February 17, 2014 - April 03, 2014).*

<table>
<thead>
<tr>
<th>Unit</th>
<th>Biogas Quantity, Q (m³/unit. Day)</th>
<th>No. of Units</th>
<th>Total Biogas Quantity (m³/day)</th>
</tr>
</thead>
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<td>1.76</td>
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<tr>
<td>Agricultural waste (Kg)</td>
<td>0.06</td>
<td>10</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td>-</td>
<td><strong>8.36</strong></td>
</tr>
</tbody>
</table>

*Table 2: Expected gas yields for phase two (April 04, 2014 - May 28, 2014).*

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The values of biogas used for HOMER analysis were entered in tonnes. Biogas produced was converted to tonnes as shown in table 3.

<table>
<thead>
<tr>
<th>Phase</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>m$^3$/day</td>
<td>3.300</td>
</tr>
<tr>
<td></td>
<td>Tonnes/day</td>
<td>1.165</td>
</tr>
<tr>
<td>Expected</td>
<td>m$^3$/day</td>
<td>7.760</td>
</tr>
<tr>
<td></td>
<td>Tonnes/day</td>
<td>2.740</td>
</tr>
</tbody>
</table>

*Table 3: Conversion of biogas produced from m$^3$/day-tonnes.*

These values were entered in HOMER to create simulations that would show the feasibility of electricity generation as shown in figures 3 and 4 below. The average price of biomass feedstock per tonne was taken to be zero as it is produced by the would-be consumers of the electricity at no cost.

Figure 4 above takes the average amount of biogas produced in phase one as an average value of biogas produced for the whole year to investigate the feasibility of generating electricity from the average amount of biogas produced in phase one (1.165 tonnes/day = 3.300 m$^3$/day).

Figure 5 above takes the average amount of biogas produced in phase two as an average value of biogas produced for the whole year to investigate the feasibility of generating electricity from the average amount of biogas produced in phase two (0.918 tonnes/day = 2.600 m$^3$/day).

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Table 9: Comparison between survival time post-KPE in successful and failed outcome groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Survival Time post KPE (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful outcome N = 15</td>
<td>41.25</td>
</tr>
<tr>
<td>Failed outcome N = 45</td>
<td>16.41</td>
</tr>
</tbody>
</table>

P value: 0.0001 >

Figure 5: Phase 2 actual biogas produced.

Figure 6 shows the feasibility results for phase one, phase two and phase three actual biogas produced and phase one, expected biogas produced. The biogas produced from the aforementioned is infeasible for electricity generation.

Figure 7 shows the feasibility results for phase two expected biogas produced. The biogas produced from the aforementioned is feasible for electricity generation.

The results obtained are tabulated in tables 2 and 3 below.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Result</th>
<th>Generator Capacity (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Actual</td>
<td>Infeasible</td>
</tr>
<tr>
<td></td>
<td>Expected</td>
<td>Infeasible</td>
</tr>
<tr>
<td>2</td>
<td>Actual</td>
<td>Infeasible</td>
</tr>
<tr>
<td></td>
<td>Expected</td>
<td>Feasible, 60</td>
</tr>
</tbody>
</table>

Table 4: Feasibility of electricity generation.

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Figure 6: Phase 1, Phase 2 actual and phase 1 expected biogas Electricity feasibility.

Figure 7: Phase 2, expected biogas produced electricity feasibility.

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<table>
<thead>
<tr>
<th>Phase</th>
<th>Bio (kW)</th>
<th>Initial Capital ($)</th>
<th>Operating cost ($/year)</th>
<th>Total NPC ($)</th>
<th>COE ($/kWh)</th>
<th>Ren. Fra.</th>
<th>Biomass (t)</th>
<th>Bio (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Expected</td>
<td>60</td>
<td>60000</td>
<td>77,586</td>
<td>1,051,814</td>
<td>36.36</td>
<td>1</td>
<td>1028</td>
<td>8759</td>
</tr>
</tbody>
</table>

*Table 5: Total costs of operating and running electricity plant.*

**Treatment Efficiency**

The COD in the DEWATS was measured and results were tabulated and graphed as shown in table 4 and figure 8. There was a decline in COD from beginning of treatment to end of treatment showing the DEWATS is operating normally.

![COD in DEWATS](image)

*Figure 8: COD in DEWATS [5].*

<table>
<thead>
<tr>
<th>Sample Point</th>
<th>BG40 (in)</th>
<th>BG40 (out)</th>
<th>BG20 (out)</th>
<th>ABR 1</th>
<th>ABR 2</th>
<th>ABR 3</th>
<th>ABR 4</th>
<th>ABR 5</th>
<th>AF 1</th>
<th>AF 2</th>
<th>AF 3</th>
<th>Final ABR/AF</th>
<th>PGF</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/l)</td>
<td>693</td>
<td>512</td>
<td>440</td>
<td>415</td>
<td>402</td>
<td>380</td>
<td>344</td>
<td>315</td>
<td>308</td>
<td>292</td>
<td>282</td>
<td>259</td>
<td>162</td>
</tr>
<tr>
<td>COD Removed (mg/l)</td>
<td>0</td>
<td>181</td>
<td>72</td>
<td>25</td>
<td>13</td>
<td>22</td>
<td>36</td>
<td>29</td>
<td>7</td>
<td>16</td>
<td>10</td>
<td>23</td>
<td>97</td>
</tr>
<tr>
<td>Removal Efficiency (%)</td>
<td>0</td>
<td>35.4</td>
<td>16.4</td>
<td>6.0</td>
<td>3.2</td>
<td>5.8</td>
<td>10.5</td>
<td>9.2</td>
<td>2.3</td>
<td>5.5</td>
<td>3.5</td>
<td>8.9</td>
<td>59.9</td>
</tr>
</tbody>
</table>

*Table 6: COD removal in DEWATS.*

a. PEC is currently spending K2600-K3000 each month on electricity costs = K31, 200-K36,000 per year.

b. These values translate to $ 4,457.14-$ 5,142.86 per year.

c. The current running costs are much less than the operating costs; $ 77,586 that would be incurred if electricity is generated at the school.

As can be seen from the results, PEC is not able to generate electricity in current conditions and even in ideal conditions at 100% efficiency, generating electricity would still be costly on the school.

The treatment efficiency has also been noted to be low as all but one compartment of the DEWATS have under 50% COD removal efficiency.

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Recommendations
The biogas at PEC is currently not only insufficient for electricity generation but also not meeting its expected output. Ways to increase biogas production are:

- Increase the feedstock to the bi-o-digester
- Increase overall efficiency of the treatment system
- Increase the population of the waste generators
- Change the feedstock to one that generates more biogas (e.g. Pig or chicken waste)

PEC is an organization already in operation. As such, increasing or changing the feedstock or increasing the population might be difficult to attain. Increasing the efficiency of the system is thus the best solution to increase the biogas production for the center. Efficiency can be increased in the following ways:

- Ensuring that influent is of the standards the BD was designed for e.g. no non-biodegradable material in the digester.
- The influent flow is within design specifications. This is especially important in this case as the flow in BD and ABR is currently 23m$^3$/day which is much greater than the 6m$^3$/day it was designed for.
- Gas pipes are checked frequently to ensure there are mitigation and reduction of gas leaks
- Ensuring the feedstock is kept moving to avoid blockages or clogging by de-clogging the system or backwashing regularly.

Bibliography