Assessing Electric Power Potential of Municipal Wastewater Sludge

V. Mema, P. Hlabela, and S. Marx

***Abstract*—Energy recovered from biogas in the form of methane can reduce the usage of electricity generated from fossil fuels thereby lessening greenhouse gas deposits into environment. Sewage sludge produced by Municipal Wastewater Treatment Works composes of bacterial organisms that are able to convert the organic content of the sludge into biogas in an anaerobic environment. A feasibility study for the potential energy savings from using biogas as a renewable energy source for the production of electricity at PS-WWTW in Mogale City local municipality indicates that high energy savings potential compared to using energy from fossil fuels. Analysis of the annual energy (electricity) consumption at the PS-WWTW over the past 3 years (2011-2014) shows that on average 800kW of electricity was consumed per day. To sustain this supply at least 8 667m^3 (at 2kWh electrical output from 1m3 of biogas) volume of biogas is required. According to the feasibility study, PS-WWTW will require about 1805m^3 of influent per day to match its electricity demand through the use of biogas. Currently, PS-WWTW receives about 18 000m^3/day which clearly indicates that there is a very good opportunity for PS-WWTW to save on electricity consumption generated from fossil fuels. The paper seeks to give a detailed analysis of potential electric power generation using wastewater sludge produced from the Percy Steward Wastewater Treatment Works (PS-WWTW).**

***Index Terms*—Biogas, energy, cost savings.**

I. Introduction

Liquid municipal waste consists of a variety of organic waste materials including human waste, kitchen and food processing waste, industrial waste, pathogens parasite eggs, inorganic materials, sand and grit and many other materials [1] depending on the economic and social activities that surround the area. To avoid deposits of hazardous substances into the environment there is need to treat municipal sewage waste to the level where it poses no threat to the environment and therefore disease outbreak and life threatening environmental mutations. There are various methods by which municipal sewage waste may be treated such as aerobic biological processes in which sludge may be filtered and dried while wastewater is treated by exposure to the sun, anaerobic biological process in which biological treatment processes take place in the absence of oxygen and incineration where the sludge is dried and ignited. Anaerobic digestion is the most suitable and favouredmethod due to its multiple benefits which include above 95% pathogens removal, organic compost, methanised biogas for energy generation. In anaerobic digestion process, bacteria contained in the sludge are allowed to digest the organic material to produce water and gases, principally carbon dioxide and methane. Composition of biogas produced from sludge generated from wastewater treatment plants of typically 60% methane and 40% carbon dioxide [2]. Under correct conditions maximum conversion of organic material can be achieved, with associated maximum production of gas and minimal residual biomass. Biogas produced holds the potential of being used for energy generation to supplement at least 60% of energy received from Eskom power generators at the wastewater treatment plant [1].

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II. Aims and Objective

The aims and objectives of this study are to demonstrate the potential for power generation at Wastewater Treatment Works using primary sludge for biogas production. The main focus is on the conversion of biogas using CHP to generate electricity thus saving on energy costs which would otherwise be incurred through the use of energy generated by Eskom from fossil fuel. In this study, an analysis of PS-WWTW influent to determined potential energy conversion to electricity was conducted. A number of key parameters for biogas production were investigated and potential biogas production and conversion to electricity was conducted under the assumption that 5% of the screened sewage inflow will be the primary sludge feed into the anaerobic digester.

III. Study Site

Percy Steward Wastewater Treatment Works is located in Mogale City local municipality in Krugersdoorp. The site was selected based on the interest by the municipal officials to convert the works to anaerobic wastewater treatment process for energy generation in order to save on the energy costs. Fig. 1 below is the locality plan of PS-WWTW.

Fig. 1. Percy Steward Wastewater Treatment Works locality plan.

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PS-WWTW receives its raw sewage from Krugersdoorp, Gelita and Millside. At the head of the works the raw sewage is screened through a course automated mechanical screen. Screenings are removed dried and stored in holding bins. Grit which is also removed is dried and stored with the screenings and later disposed weekly by trenching. Screened sewage then flows into the Flow Equalization Tank (FET) and from there it gravitates to three primary settling tanks (PSTs). In the PST 40% of the COD is removed by gravity thickening. The settle primary sludge is fed to the concrete above ground anaerobic digester for stabilization by a set of pumping equipment located in a pump station downstream of the anaerobic digester. The settled sewage from the PSTs gravitates to the biological nutrient removal activated sludge (BNRAS) reactor for biological treatment. The sludge from the activated sludge modules is recycled while part of it is wasted as it is pumped to the aerobic digester for further organic matter degradation.

IV. Methodology

The existing infrastructure and technology at the Percy Steward Wastewater Treatment Works in Mogale City local municipality was assessed and a feasibility study of its biogas energy production potential was conducted based on the CSIR developed automated gas production plant. Two key factors of the sludge at the WWTW were determined- average wastewater influent (primary sludge) and effluent and; characterisation of the influent. The inflow and outflow rates for influent and effluent were conducted from October 2012 until October 2014 and the results are presented in the form of a graph.

Characterization of the influent was conducted by looking at a number of parameters such as pH, TAlk, EC, Cl, TDS, COD, NO_3-N, total kjehal nitrogen (TKN), O-PO_4, T-PO_4, SO_4, settleable solids (SS) and F & O. These parameters were investigated by using the Standard Method for the Examination of Water and Wastewater [3]. Analysis of these parameters was useful in predicting potential of biogas production at the PS-WWTW. The most important of these factors for biogas production was the COD which plays a major role in the anaerobic digestion process. Finally, potential biogas energy for electricity generation at the PS-WWTW was predicted based on the following assumptions [4]:

- 1l of influent primary sludge produces 7.13 litres of CH_4
- Average calorific value of biogas is about 21-23 MJ/m^3
- 1m^3 of biogas produces 2kWh.

When the consumption of energy at the PS-WWTW was established, the generator size required for methane gas to power conversion was determined. This process assisted in the determining the feasibility of using biogas for power generation and potential savings thereof.

V. Results and Discussion

A. *Influent and Effluent Rates*

To be able to determine biogas production potential for a WWTW one of the key parameters is the influent and effluent rates at the treatment plant. Knowledge of these two parameters assists in the planning phase and would provide information on the availability of raw material required for biogas production process. It is important to understand the potential loading rate of raw material into the biogas plant as this will determine the stability of the biogas production process. At PS-WWTW Fig. 2 below indicates potential hydraulic loading for the biogas plant per day.

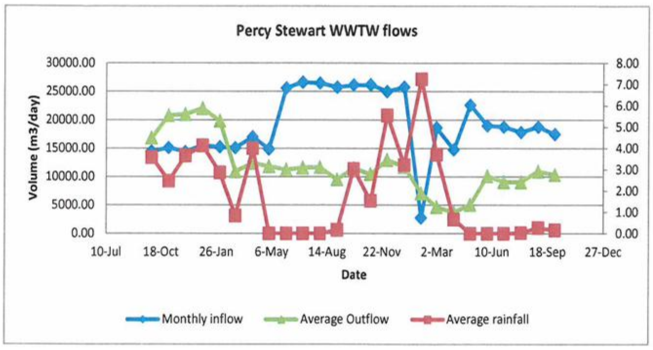

Fig. 2. Influent and effluent flow rates at Percy Steward Wastewater Treatment Works.

According to Fig. 2 between October 2012 and October 2014, at PS-WWTW there was an average inflow rate of 15 000m^3/day however there was a sharp increase in the average inflow rate around May 2013 from 15 000m^3/day to approximately 25 000m^3/day. The sharp increase is associated directly with the completion of a new housing development that was connected to the works. Although the works was upgraded in 2012 to take 36 000m^3/day, the current inflow received is at about 18 000m^3/day which is 50% below its capacity.

B. *Raw Sewage Characterization*

Raw sewage was characterised to determine its suitability for biogas production. Table I below indicates raw sewage characteristics for priority parameters. The quality and characteristics of the raw sewage at the PS-WWTW are indicated. The Chemical Oxygen Demand (COD) concentration is particularly of interest since it plays a major role in the anaerobic digestion process. The COD (organic content of the influent) strength has significant effect on the ultimate amount of biogas yield, as well as the methane content.

TABLE I: Summary of Predictions According to BioWin Model

Analysis	Average
pH	7.66
TAlk (mg/l CaCO3)	294.71
EC (mS/m)	108.48
Cl (mg/l)	80.52
TDS (mg/l)	589.18
COD (mg/l)	1121.26
NO_3-N (mg/l)	5.57
NH_3-N (mg/l)	39.56
TKN (mg/l)	N/D
O-PO_4 (mg/l as P)	8.91
T-PO_4 (mg/l as P)	9.85
SO_4(mg/l)	137.27
SS (mg/l)	593.54
F & O (mg/l)	66.41

Average COD indicates that the source of the sewage sludge that feeds into PS-WWTW is mainly domestic. This can be observed through COD which averages at 1121.26 mg/l. Thesewage COD for domestic sludge normally ranges between 900 mg/l and 1200 mg/l. The Free and Saline Ammonia (FSA) of 39.6 mg/l is also common in domestic wastewater. However, the total phosphate of 9.85 mg/l is slightly lower than the expected value for domestic sewage.

C. Anaerobic Digestion Predictions at the Percy Steward Wastewater Treatment Works

Anaerobic digestion (AD) predictions were conducted sing BioWin model. From the concentrations out predicted by the model, volumetric quantities of the expected gas production were calculated. The table below shows the summary of the AD model predictions.

TABLE II: RAW SEWAGE CHARACTERISTICS AT PERCY STEWARD WASTEWATER TREATMENT WORKS

Parameter	Volumetric /percentage quantity
% FSA released	50.97
% OP released	0.00
%COD removed (mgCOD/l)	71.58
Gas production (litres)	21786.20
Gas prod. (l gas/l influent)	12.10
Gas composition : CH_4 fraction	7.13
Gas composition: CO_2 fraction	4.97
COD of CH_4 (gCOD/l feed)	22650.34
pCO_2 (atm)	0.41

Table II above indicates a gas production rate of 12.10 l gas/l influent which is equivalent to 0.012 m^3 per 0.001m^3 influent. According to the CSIR's automated digester the gas should comprise of 70% methane (CH_4), 27% carbon dioxide (CO_2), 1.6% nitrogen (N_2) with the remaining amount associated with the traces of other gases such as carbon monoxide, oxygen/argon, etc. Assuming that 5% of the careened sewage inflow will be the primary sludge (see equation 1) feed rate into the anaerobic digest (AD), this will give a feed approximately 900 m^3/day.

$$5\% \text{ of } 18000 = 18000m^3 \times 0.05 = 900m^3 \quad (1)$$

D. Methane Gas to Power

To determine the generator size required for power conversion at the PS-WWTW two methods were compared.

- A connected electrical equipment audit was conducted to determine the connected load
- Analysis of consumption data was also considered

From the above information, estimated monthly consumption was established and is indicated in Table III below:

TABLE III: SUMMARY OF PREDICTIONS ACCORDING TO BIOWIN MODEL

Description	Consumption	Units
Total Load/kW from above	1 143.98	kW
Assume Operation of 24hrs throughout the year (365days)	8760	hrs
Annual Energy	10 021.26	MWh
Monthly Consumption	835.11	MWh
Assume 70% Operation	584.57	MWh per month

E. Electric Consumption at the Percy Steward Wastewater Treatment Works

From the power consumption displayed in Table III an electrical load analysis at the PSWWTW over a period of three years i.e. 2011 to early 2015 was performed. The analysis of the electricity consumption data indicates that on average PS-WWTW consumes about 320.6 MWh per month. The graphical representation of electricity consumption per month in PSWWTW is indicated in the Fig. 3 below:

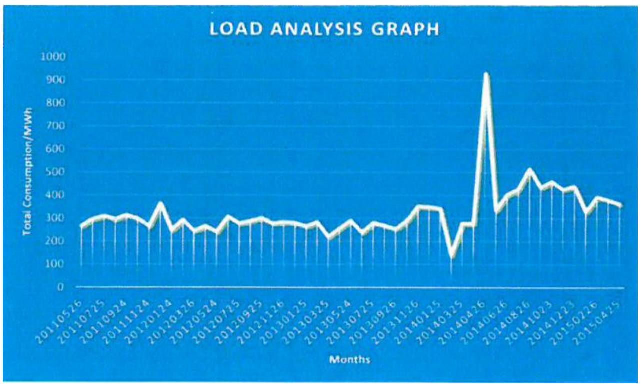

Fig. 3. Consumption of electricity per month at PS-WWTW.

According to Fig. 2 between May 2011 and January 2015 the average consumption of electricity at PS-WWTW was averaging at 286 MWh per annum at an average annual cost of R0.86/kWh excluding yearly price increases of 8%. From the graph, the spike in April 2014 arose due to resting and commissioning after the refurbishment and extension of the plant. The consumption increased from around 309 MWh per month to just above 400 MWh per month, the highest being 520 MWh in August.

By comparing the two methods used, a conclusion that the electrical consumption at the plant was approximately 520 MWh per month was reached. The utilised load as taken from the Equipment Audit was 585 MWh per month compared to 520 MWh per month from the data analysis. To determine the size of the generator and the amount of gas required 520 MWh was then used. The calculated power output from the above information is 722kW (1)

$$\text{MWh per day} = 520\text{MWh}/30\text{days} = 17.3 \text{ MWh/day} \quad (2)$$
$$\text{MWh per hour} = 17333 \text{ kW}/24\text{h} = 722.2\text{kW/h}$$

From Table IV below the CHP plant required is 800 kW.

TABLE IV: SIZING OF THE COMBINED HEAT AND POWER PLANT FOR PS-WWTW

Electrical Output kW	Thermal Output kW	Fuel Input kW
100	165	340
150	242	505
200	317	669
300	465	995
400	610	1318
600	895	1959
800	1174	2596
1000	1449	3229

The CHP plant requires 2596kW of fuel to produce 800kW (31%) electricity and 1174kW (45%) of thermal heat (shown in Fig. 4).

TABLE V: THE EFFICIENCY OF ELECTRICAL GENERATION

Parameters	Input fuel	Electrical output	Thermal output	Total efficiency
Energy	2596kW	800kW	174kW	
Efficiency		31%	45%	86%

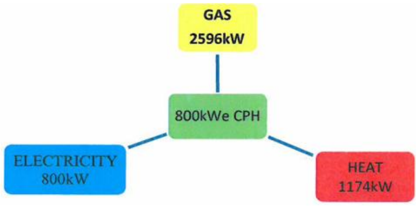

Fig. 4. The CHP heat and electrical generation.

The efficiency of 31% on electrical generation from the above Table V is in accordance with EPA Combined Heat and Power Partnership (Biomass CHP Catalog). In this study, the heat generated from the CHP was targeted for use to maintain the temperature in the digester via heat exchangers. To determine the amount of gas required to generate sufficient electricity for PS-WWTW the average calorific value of biogas was estimated to range between 21-23MJ/m^3 [5]. According to a report produced by the Council for Scientific and industrial Research [3] 1m^3 of municipal sludge produces 1.25 kWh to 2 kWh of electricity. The amount gas required to produce sufficient electricity for the PS-WWTW is indicated in Table VI below:

TABLE VI: THE CHP HEAT AND ELECTRICAL GENERATION

Electrical Output from 1 m^3 of Gas	1.25kWh of Electricity	2kWh of Electricity
Long Term Consumption per month/kWh	520 000	520 000
Volume of gas required per month (30days)/m3	416 000	260 000
Volume of gas required per day	13 867	8 667

Table VI above indicates that the volume of gas required to produce 722kW of electricity is approximately 8 667m^3 per day (24hours). This is based on the assumption that 1m^3 of gas produces 2kWh of electricity. Since PS-WWTW is already capable of producing 900m^3 of sludge it was possible to estimate potential gas production (3).

$$0.001m^3 \text{ influent sludge} = 0.00712\ m^3 \text{ gas}$$
$$900\ m^3 \text{ influent sludge (produced at PS-WWTW)} = Xm^3 \text{ gas}$$

$$900m^3/0.001m^3 \times 0.00712m^3 \text{ gas} = 6408m^3/\text{day gas production} \approx 267m^3/\text{hour} \quad (3)$$

At 31% electricity production of per fuel input equation 4 gives an indication of electricity production at PS-WWTW per day

$$6408m^3 \text{ gas} \times 0.31 \approx 1987\text{kW per day} \quad (4)$$

Since PS-WWTW requires about 722kW power output per day it is evident from this study that this power can be supplied through anaerobic digestion (4). If Percy Steward Wastewater Treatment Work would convert its Works to generate biogas for electricity more than 100% of its electricity supply could be provided.

VI. CONCLUSION

The results and analysis carried out in this study clearly indicate that Percy Steward Wastewater Treatment Works is capable of generating its electricity supply through anaerobic digestion of its inflow. There is a great deal of cost saving through using biogas driven CHP to generate electricity. The sludge produced from this process could easily be used for composting which makes this approach environmental friendly. If PS-WWTW is able to generate its electricity this could bring some relief from Eskom who is already over-burdened by high electricity demands in South Africa. It is there recommended that municipal WWTW should consider investigating the benefits of using their wastewater sludge especially for generating energy.

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