THE ELECTRICITY GENERATION POTENTIAL USING THE BIOGAS PRODUCED IN THE RIO FORMOSO SEWAGE TREATMENT PLANT

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Abstract. *The Rio Formoso sewage treatment plant is located in the outskirts of the Rio Formoso town, in the state of Pernambuco, northeastern Brazil. The sewage treatment plant consists of three UASB reactors that treat the sewage generated by 16,000 people. The average inward and outward BOD were 151.4 and 44.4 mg/L, while, average inward and outward COD were 366.25 and 93.57 mg/L, from January to August 2010. The potential of electricity generation using biogas in the Rio Formoso sewage treatment plant was determined using the biogas physical chemical data and the methodology developed by Chernicharo, which estimates the biogas production in sewage plants based on COD reduction. Using this methodology, the estimated methane production was 244.53 m^3 per day. The three UASB´s biogas were sampled in all the UASB reactors and analyzed using a biogas analyzer GEM-2000. The average methane content in the biogas produced was 40.85% methane (v/v). The lower heating value of this biogas was 13.8 MJ/m^3. Hence, using a 22% efficient IC engine-electricity generator device, the potential electricity that can be generated in the sewage treatment plant is 8.5 kW, enough to supply 88% of the plant electricity needs. However, if the sludge level in the UASB reactors is optimized, the biogas methane content would be 73% and 11,065 kWh/moth could be produced at the RF-STP using biogas engines. This amount of energy would turn the RF-STP self-sustained energetically.*

Keywords*: biogas, electricity production, sewage plant, UASB, anaerobic digestion*

1. INTRODUCTION

This work describes the potential use of the biogas generated in the COMPESA Sewage Treatment Plant (STP) located in Rio Formoso (Pernambuco- Brazil) to reduce the operational costs to run the STP and its greenhouse gases (GHG) emissions. Hence, it was necessary to sample and analyze the effluent gases coming out the STP and to calculate the biogas flowrate, in order to enable a fair estimation of the potential of electricity production. COMPESA is a state government company responsible for the water supply and sewage collection and treatment in the state of Pernambuco – Brazil.

This is the first work which estimates the potential of biogas and electricity production in a STP in the state of Pernambuco. This is the first step for the creation of a databank containing the biogas and electricity production of all STPs located in the state of Pernambuco. The continuity of this work may put COMPESA in the frontline of the green technology development, using a harmful effluent to generate electricity to reduce its operational costs and the environmental impact caused by the STPs.

2. RIO FORMOSO SEWAGE TREATMENT PLANT

The Rio Formoso Sewage Treatment Plant (RF-STP) is located 80 km south of Recife (Pernambuco´s capital). Its incoming affluent flowrate is approximately 40 L/s (9.1298 MGD), which benefits a population of 16.000 inhabitants.

2.1 Rio Formoso STP Characteristics

The RF-STP treats sewage through anaerobic digestion system followed by a polishing lagoon. The treatment plant consists of three UASB (Up-flow Anaerobic Sludge Blanket) units. According to the data provided by COMPESA (The Pernambuco´s Water and Sewage Company), it has a hydraulic retention time of 6.75 h and it is designed for a maximum flowrate of 40 liter per second, upstream velocity of 0.66 m/h and a sedimentation rate of 25.9 m^3/m^2 per day. The RF-STP dimensions are given on Table 1, and the RF-STP is shown in Figure 1.

Table 1: STP – Rio Formoso Dimensions

Length	Width	Height
12.00 m	6.00 m	4.5 m

Figure 1. The Rio Formoso sewage treatment plant

2.2 Rio Formoso STP Operational Data

COMPESA also provided the RF-STP operational data from January 25 to August 25, 2010. These data were the temperature, pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total solids (TS), fixed solids (FS), volatile solids (VS) and phosphorus content in the UASB incoming sewage and the treated UASB exiting effluent. The data was averaged over a seven months period, while the energy demand was averaged over the whole year of 2010. These averaged data are shown on Table 2.

Table 2: RF-STP Data

Data Measured	Width
Sewage Flowrate	40 L/s
Temperature	29ºC (302 K)
pH	7.11
$BOD_{incoming}$	151.40 mg/L
$BOD_{exiting}$	44.40 mg/L
BOD removed	107 mg/L
$COD_{incoming}$	366.25 mg/L
$COD_{exiting}$	93.50 mg/L
COD removed	272.75 mg/L
Phosphorous	1.5 mg/L
Energy demand	7,007 kWh

Even though the averaged energy used monthly was 7,007 kWh, as shown on Tab. 2, during this period, there were three months that had peak loads varying from 8,027 to 11,031kWh.

3. BIOGAS PRODUCTION CALCULATIONS

This section describes the method used to analytically compute the amount of gas produced in RF-STP. The method was suggested by Chernicharo (1997). The Chernicharo´s method is widely used in Brazil to estimate the methane production in sewage treatments plants.

The Chernicharo´s method uses the following formulas and coefficients to estimate the amount of methane produced:

$$COD_{CH4} = Q \ . \ [(S_o – S) - Y_{obs} \ . \ S_o)] \quad (1)$$

COD_{CH4} is the portion of COD used to produce methane gas , in kg/day

Q is the incoming sewage flow rate to the UASB reactor, in m^3/h (40 L/s =3,456 m^3/dia)

S_0 is the incoming BOD, in kg/L

S is the exit BOD, in kg/L

Y_{obs} is the solids production coefficient in kg of COD per day

$Y_{obs} = 0.21$

K(t) = (P x K)/ (R . T) (2)
K(t) is the amount of COD necessary to produce 1 m^3 of methane , in kg of COD/m^3
P is the ambient pressure, in atmosphere (atm)
K is a conversion factor used to convert COD in moles
K = 64g COD/mol (given by Chernicharo)
R is the Universal Gas constant, in atm.L/(mol.K), hence
R = 0.08206 atm.L/(mol.K)
T is the sewage temperature in the UASB reactor, in K
T = 29ºC (302 K)

The estimated methane production per day (Q_{CH4}) is given by,
Q_{CH4} = COD_{CH4}/K(t) , in m^3/day (3)
Q_{CH4} is the estimated methane production in m^3/day
COD_{CH4} is the amount of COD that was converted to methane, in kg/day
K(t) is the conversion factor solid to gas

Hence, using the data provided, the values for COD_{CH4} , K(t) and Q_{CH4} were calculated as follow:

COD_{CH4} = 3,456. [(0.36625 – 0.0935) – (0.21* 0.36625)]
COD_{CH4} = 1482.62 kg of COD/day

K(t) = (1 atm . 64 g of COD/mol)/(0,08206 atm.L/mol.K . 302K)
K(t) = 676,814 kg of COD/m^3

Q_{CH4} = COD_{CH4}/K(t)
Q_{CH4} = (676.814 kgCOD/dia)/ 2.583 kg COD/m^3
Q_{CH4} = 262 m^3 CH_4 /day

However, Souza (2010) suggest that about 30% of the methane production cannot be used, as methane is discharged dissolved in the UASB exiting sewage. Hence, the total amount of methane that can be used is

Thus, according to Chernicharo´s method the estimated daily methane production in the RF-STP is 183.4 m^3, i.e., 7.64 m^3/h.

Also, Chernicharo´s estimates 75 % methane content in UASB produced biogas. Hence, the amount of biogas estimated to be produced in the RF-STP is 244.53 m^3/day (10.19 m^3/day). Hence, this value of biogas production was estimated to be produced in the RF-STP.

4.0 THE DETERMINATION OF METHANE CONTENT IN THE RF-STP BIOGAS

In order to determine the methane in the biogas produced in the RF-STP, it was used a biogas analyzer, the GEM-2000, manufactured by Geotechnical Instruments. The GEM 2000 analyzer available at POLICOM is capable of simultaneously measure the percentage of CH_4, CO_2 , H_2S and O_2 present in the biogas (Figure 1).

Figure 2. Gem 2000 – Biogas Analyzer

The biogas produced in all three reactors at RF-STP were collected and analyzed using the GEM-2000. In order to verify how the sludge discharge affects the biogas production, GEM-2000 was used to analyze the biogas in each UASB reactor before the sludge was removed and two hours after the discharge. Figures 3 and 4 illustrate the sewage discharge points and the sludge sand drying bed, respectively.

Figure 3. Sludge discharge points in the UASB reactor

Figure 4 – Sludge sand drying bed

In order to determine the biogas composition in the RF-STP UASB reactors, several measurements were made, before the sludge´s discharge and two hours after. Those measurements were made to have an estimation of the biogas methane content variation in all three reactors, and, to verify the effect of the UASB sludge content on methane. The averaged results are shown on Tab. 3.

Table 3. RF-STP Biogas composition

RF-STP							
	UASB-1		UASB-2		UASB-3		Average Content
Gases	BD	AD	BD	AD	BD	AD	
CH4 (%)	32.2	13.6	53.4	20.5	40.2	11	40.85
CO2 (%)	4.9	1.8	6.9	2.8	5.1	1.4	5.2
O2 (%)	10.2	17.1	6.5	15.3	10.9	18.3	13.05
N_2 (%)	47.7	67.5	33.2	61.4	43.8	69.3	43.45
H_2S ppm	16	8	0	4	142	3	28.7

BD – before sludge discharge AD – after sludge discharge

As observed on Tab. 3, there were variations on the biogas composition produced in all three reactors, before and after the sludge discharge to the sand drying bed. Also, Tab. 3 shows that after the sludge was discharged the amount of methane content in the biogas reduced significantly. Hence the amount (or level) of sludge in the UASB reactor affects the methane content and biogas production. The average methane content for the whole RF-STP was 40,85%. This biogas´methane content is way below the ones reported by Chernicharo (1997) and Souza (2010), 75% and 70% respectively. However, a 73% methane content was obtained in one of the measurements in UASB-3.

4. THE POTENTIAL OF ELECTRICITY PRODUCTION IN THE RF-STP

The electricity production potential was calculated, in the RF-STP, using a biogas production of 244.53 m^3/day (10.19 m^3/h), by the Chernicharo´s method, and the average methane content of 40.85% obtained in the field´s experiments. Richmond Valley Power Station report that the high and low heating values (HHV and LHV) of methane are 33.7 MJ/m^3 and 37.1 MJ/m^3, respectively. Hence, the biogas produced at the RF-STP has a HHV and LHV of 13.8 and 15.2 MJ/m^3.

Thus, the energy that can be obtained daily using the RF-STP biogas is 3,375 MJ. Hence, if the biogas is used as a fuel in an Otto-cycle engine generator, which has approximately 22% efficiency (Ravikrishna & H. N. Chanakya), the electrical power capacity would be 8.6 kW, and it could generate 6.192 kWh per month. On the other hand, the biogas methane content could be optimized to 73%, as obtained in UASB-3, by adjusting the sludge level in all three UASB reactors. In this way, the amount of power generated in the RF-STP could be augmented. Thus, the power produced, when using the highest 73% biogas methane content, would be 15.37 kW, which could produce 11,065 kWh monthly.

As the average power demand to operate the RF-STP is 7,007 kWh and its maximum demand is 11,031 kWh, it would be possible to supply 88.4% of the energy using a 40.85% methane biogas content. If the sludge level is optimized the amount of energy supplied would be enough to enable the RF-STP to be energetically sustainable.

5. CONCLUSIONS

The results on the use of the biogas produced to produce electricity in the RF-STP were very promissing. The estimated biogas production of 244.53 m^3/day with 40,85% methane content, has the capacity of produced 88% of the energy needed to operate the sewage plant. However, it was also noticed that the level of sludge in the UASB reactors influences the biogas methane content. The highest methane content measured was 73%. If an adjustment of the UASB sludge level is done, it would enable the biogas to have 73% methane content. Hence, the 73% methane biogas would be able to produce 11,031 kWh a month, which turns the RF-STP energetically self-sustained. Also, if a higher efficiency Otto-cycle motor-generator is used, the power produced could be augmented.

Analyzing of data provided, it will be wise to invest in a power plant at the RF-STP to enable it to be self-sustainable energetically.

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