RECOVERY ENERGY IN SEWAGE TREATMENT PLANT

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ABSTRACT

Energy recovery from biogas generated in the anaerobic treatment of domestic sewage meets the concept of sustainability, especially because it can generate social, environmental and economic benefits. On social point, this practice helps to minimize odors in the surrounding communities of sewage treatment plants. From an environmental standpoint, this practice avoids the release of methane into the atmosphere, a greenhouse inductor gas. From the economic point of view, the use of biogas can generate financial resources or cost avoidance that reduce the operational costs on wastewater treatment plants. In this context, this paper presents a critical analysis of the sustainability inherent in the use of biogas from the treatment of wastewater as a renewable energy source. To this end, it was evaluated the possibility of generating electricity on a large plant located in Brazil on the Paraná State.

Keywords: Biogas, methane, UASB reator, wastewater.
1 INTRODUCTION

The sanitation sector in Brazil is deficient, as only 56.1% of the Brazilian urban population is served by sewer systems. The Southeastern region of the country has the best performance, with a percentage slightly higher than 80% of Brazilians serviced by public sewage. On average, only 38.6% of the total sewage generated is treated in Brazil. Additionally, only 69.4% of the total volume of collected sewage is treated. The Midwestern region stands out as having a high rate of wastewater treatment, as there 90.0% of sewage generated is collected, out of which 44.2% is treated (SNIS, 2014).

This situation poses challenges in the management of urban centers that are associated with the main dimensions of sustainability. In the dimension of social sustainability, urban sewage generates bad odors in the vicinity of the treatment plant. It also spreads disease agent when it is not treated appropriately. In the economic dimension, sewage treatment generates costs of construction and maintenance of treatment plants. From an environmental perspective, sewer may be responsible for the pollution of hydric resources, such as rivers and lakes. Furthermore, the by-products of the treatment process can contaminate the soil and the atmosphere if not managed properly. The anaerobic sewage treatment, for example, generates biogas as a byproduct, which is made up of gases that produce the greenhouse effect – such as carbon dioxide (CO\textsubscript{2}) and methane (CH\textsubscript{4}) – and also toxic gases – such as hydrogen sulfide (H\textsubscript{2}S). Currently, there are few sewage treatment plants (STPs) in Brazil. However, with the incentive of the federal government through a program called Programa de Aceleração do Crescimento – Growth Acceleration Program (PAC), an expansion of the implementation of new STPs is expected, which will promote initiatives related to processing biogas generated from sewage.
The treatment of sewage is an activity that demands and consumes resources, which could be a problem. However, if sewage is treated and the by-products generated are efficiently managed, it could become a renewable energy source and thus help promote energetic efficiency.

In recent years in Brazil, the use of upflow anaerobic sludge blanket reactor (UASB reactor) has been implemented to perform domestic sewage treatment. These reactors promote anaerobic degradation of organic matter in the wastewater by means of a biological process, thus generating biogas, amongst other by-products.

The process of biogas generation by anaerobic decomposition in UASB reactors goes through four parallel stages in a single stage process. The first stage is hydrolysis, in which complex organic compounds, such as carbohydrates, proteins and lipids, are decomposed by substances of lower complexity, such as sugars, amino acids and fatty acids. In the second stage, the acidogenic or acidogenesis occurs by means of acidogenic fermentation bacteria. During this intermediate phase, compounds that were formed in the previous phase are broken down into short-chain fatty acids (acetic, propionic and butyric acid), hydrogen and carbon dioxide. In the following step, referred to as the acetogenesis, there is the formation of acetic acid. During this stage, the acetogenic bacteria convert the compounds into precursors to biogas (hydrogen, carbon dioxide and acetic acid). Finally, in a stage called methanogenesis, biogas is formed. During this stage, the methanogenic archaea that are strictly anaerobic convert acetic acid, hydrogen and carbon dioxide into methane (PROBIOGÁS, 2010).

The biogas produced by UASB reactors consists mainly of methane (CH\(_4\)), ranging typically from 50 to 80% in volume. This biogas also contains nitrogen, carbon dioxide, hydrogen sulfide, hydrogen, ammonia, and other trace gases in a lesser amount. Methane is colorless, odorless,
flammable, and it has a high calorific power. The higher the methane content in biogas, the larger the amount of chemical energy is stored therein. For that, biogas can be used to generate electricity, thermal energy as well as vehicular and domestic gas.

The biogas produced in Brazil is still not present in the federal National Energy Balance, because its current contribution is not significant when compared with other energy sources (BEN, 2014). However, the current impact potential of biogas as an energy source tends to change in the coming years, as the government is encouraging the inclusion of alternative energy sources through incentive programs, such as the Brazil-Germany Project to Use Biogas Energy in Brazil (PROBIOGÁS).

Within a long-term planning, the Ministry of Mines and Energy (MME) – through the National Energy Plan (PNE 2030) - stimulates the search for renewable energy sources to contribute to the national energy matrix (PNE2030, 2007). The use of biogas produced in STP through UASB reactor is a way to reflect the contribution of the sanitation sector towards a renewable energy source from domestic sewage, with the potential ability to transform the challenges of wastewater treatment into a solution for the energetic national sector. In this context, the biogas energy usage from STP is an alternative to the growing Brazilian demands for clean and sustainable energy.

The concern about energy efficiency has increased due to the oil crisis of 1973 - 1974 and 1979 -1981. The world became aware of how scarce these energy resources are and that, consequently, resulted in the increase of the oil price globally (PNEE, 2011). A number of initiatives to promote a more efficient use of such energy source were developed as a result, as well as the diversification of energy sources in order to meet the increasing demands. During that period, Brazilian government
developed an initiative called PROALCOOL, which ended up being internationally recognized as a successful program (PNEE, 2011). Later, due to the several movements towards protection of the environment across the world, there was a stronger concern about the emissions of gases that induce the greenhouse effect. Another motivating factor for the search of alternative sources of energy is the increasing electricity rates that have been recently imposed by governments. As an example of such increases, between June/2014 and June/2015, electricity rates charged by COPEL in the Paraná State soared 96.96% (COPEL, 2015a).

The generation of electricity through biogas is an initiative towards energy generation that is clean and renewable, unlike thermal power generation, which has been built in Brazil in recent years in order to meet domestic demand. Thermal power generation consumes non-renewable sources, such as oil and coal, and it is highly polluting when compared to hydroelectric plants, wind power plants and biogas (SILVA, 2015).

In this context, the aim of this work is to evaluate the energy use of biogas generated in a large scale anaerobic treatment of sewage plant as a means for promoting economic, social and environmental sustainability.

2 METHODOLOGY

The present study was developed with information obtained from the STP Atuba South, a large plant in the city of Curitiba - Paraná - Brazil. Biogas production was measured in the period between October 2011 and October 2012 (SILVA, 2015). This STP has the capability to treat 1,120 L/s of domestic sewage, by using 16 UASB reactors distributed in four equivalent lines (POSSETTI et al.,
2013). Biogas measurements were performed at the end of one line (line 2) in the vicinity of an open burner.

Once obtained the flow of biogas \(Q_{\text{BIOGAS}}\), the methane production \(Q_{\text{METHANE}}\) was calculated by multiplying the methane content \(C_{\text{METHANE}}\) measured by the flow of biogas:

\[
Q_{\text{METHANE}} \ [\text{Nm}^3/\text{day}] = C_{\text{METHANE}} \ [\%v/v] \cdot Q_{\text{BIOGAS}} \ [\text{Nm}^3/\text{day}] \tag{1}
\]

The mass of methane \(m_{\text{METHANE}}\) produced was determined by multiplying the methane production for its respective specific mass \(\rho_{\text{METHANE}} = 0.72 \ \text{kg/Nm}^3\):

\[
m_{\text{METHANE}} \ [\text{kg/day}] = Q_{\text{METHANE}} \ [\text{Nm}^3/\text{day}] \cdot \rho_{\text{METHANE}} \ [\text{kg/Nm}^3] \tag{2}
\]

The total equivalent carbon dioxide \(E_{\text{CO2eq}}\) from the methane produced was computed by multiplying the mass of methane \(m_{\text{METHANE}}\) by the carbon dioxide equivalent of methane \((\text{GWP}_{\text{METHANE}} = 25)\):

\[
E_{\text{CO2eq}} \ [\text{ton/day}] = m_{\text{METHANE}} \ [\text{kg/day}] \cdot \text{GWP}_{\text{METHANE}} / 1,000 \tag{3}
\]

The chemical energy potential \((\text{EP}_{\text{CHEMICAL}})\) was obtained by multiplying the methane production \(Q_{\text{METHANE}}\) by its respective lower heating value \((\text{LHV} = 9.9 \ \text{kWh/Nm}^3)\):

\[
\text{EP}_{\text{CHEMICAL}} \ [\text{kWh/day}] = Q_{\text{METHANE}} \ [\text{Nm}^3/\text{day}] \cdot \text{LHV} \ [\text{kWh/Nm}^3] \tag{4}
\]
The amount of electrical energy (EE) was computed by multiplying the chemical potential energy by conversion efficiency ($\eta = 42\%$):

$$EE \text{ [kWh/day]} = EP_{\text{CHEMICAL}} \text{ [kWh/day]} \cdot \eta$$  \hspace{1cm} (5)

For carbon dioxide emission compensation calculation in the atmosphere, it was used the amount of 7.14 Atlantic forest trees for every ton of carbon dioxide equivalent emitted.

In the financial analysis over STP to produce electric energy from biogas, it was calculated an investment of R$ 3,005 million (VALENTE, 2015), considering the engine, the generator, the gasometer, the biogas purification system and measuring systems and other accessories. As expenses were calculated R$ 12,523.30/month during 20 years as depreciation over investments, plus R$ 4,158.78/month for engine and generator overhaul, plus R$ 5,009.32/month for equipment maintenance and plus R$ 11,333.33/month for 3 maintenance employees (VALENTE, 2015). The energy costs in July 2015 with taxes are R$ 1.43936/kWh in a peak hour (6 to 9pm from Monday to Friday) and R$ 0.47397/kWh as standard fare for all other time for conventional hour-seasonal fare for Public Services for Sanitation Services at Green Class A4 (COPEL, 2015b). Goods Sales Tax (ICMS) “Imposto Sobre Circulação de Mercadorias” of 5.2% was added to energy values, plus R$ 0.089015/kWh with taxes as Red Flag Tariff due to energy production condition stipulated by Brazilian federal government (COPEL, 2015b).

3 RESULTS AND DISCUSSIONS
The average monthly biogas production in 16 UASB reators measured in a year was $(84.30 \pm 26.64) \text{Nm}^3/\text{h}$ with an average content of methane $(63.03 \pm 17.89\%) \text{v/v}$ (SILVA, 2015). This represents an average production of $38,256.7 \text{Nm}^3$/month of methane, which corresponds to chemistry power production of $378,741.2 \text{kWh}$/month, resulting in $159,071.31 \text{kWh}$/month of electricity energy production.

In the economic dimension, it was considered to use this energy in the STP itself, which would result in cost avoidance. This potential energy corresponds to a generation of R$ 103,265.62/month as revenue, as calculated by the amount charged in July 2015 (COPEL, 2015b). The implementation costs of the generating plant is an estimated investment of R$ 3,005 million and the monthly expenses are estimated in R$ 33,024.73. Therefore, investment in electricity generation from biogas in STP under study presents a positive result of R$ 70,240.89/month corresponding to a financial return of 212.7%/month.

Under the aspect of environmental sustainability, in order to minimize the damage caused by the greenhouse effect resulting from the reduction of methane emissions, which potentially induces greenhouse effect 25 times more than carbon dioxide. With the use of biogas in STP analyzed to generate electricity, it avoids the emission of 27.5 tons of methane per month in the atmosphere. In a period of 20 years, this amounts to 6,610.8 tons of methane released into the atmosphere. It would take 47,201 trees off the Atlantic Forest to compensate for this emission.

From the social sustainability standpoint, biogas generation and transformation into electricity at the STP eliminates much of the odor generated by hydrogen sulfide (H$_2$S), a colorless gas with a strong odor (rotten egg odor). In the composition of biogas there is between 1,000 and 3,000 parts per
million (ppm) of H₂S (SILVA, 2015). Human or animal inhalation of high concentrations (more than 2,000 ppm) can be fatal within seconds or minutes (STRICKLAND et al., 2003). The odor of H₂S is not so perceived when its concentration is smaller than 0.13 ppm (EUROPEAN COMMISSION, 2007). Furthermore, when H₂S is released in the atmosphere, it can become sulfurous acid, sulfuric acid, sulfites and sulfates sulfur, among other substances. The process of desulphurization can reduce the H₂S emissions to less than 20 ppm (VALENTE, 2015), minimizing problems with bad odors next to STP.

Table 1 summarizes the social, environmental and economic results of the analysis performed in this study.

Table 1: Advantages in recovering the biogas energy into the STP.

<table>
<thead>
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<th>Sustenability dimension</th>
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| Environment             | - Methane burn minimizes the greenhouse emissions (~27.5 ton/month).  
                          | - Avoid the use of energy from non renewable sources, such as firewood, coal and fossil fuels. |
| Social                  | - Reduction of complaints resulting from minimizing bad odors nearest STP.  
                          | - Reduction of the H₂S contamination risk nearest the STP. |
| Economic                | - Renewable source of electrical energy production into the STP (159,071.2 kWh/month).  
                          | - Cost avoidance for electrical energy in the STP (103,265.62 R$/month).  
                          | - Revenue entry (70,240.89 R$/month).  
                          | - Financial return (212.7 %/month) |

Source: Authors.

4 CONCLUSIONS
The generation of biogas from sewage has already been carried out in various urban centers in STPs provided with UASB reactors. However, in general, the potential energy inherent to biogas from these reactors is not being used.

The analysis of the recovery of the biogas produced in UASB reactors of STP under study showed that this practice can be a source for promoting social, economic and environmental sustainability. From a financial point of view, it was identified a profit of R$ 70,240.89/month, which corresponds to a return investment rate of 212.7%/month.

From an environmental aspect, a total of 6,610.8 tons of methane will stop being released into the atmosphere within a 20-year period, which would otherwise take 47,201 trees off the Atlantic Forest to offset such emissions if they were to occur.

From the social perspective, it eliminates a lot of the odor by reducing H₂S from until 3,000 to less than 20 ppm, minimizing the contamination risks and decreasing the number of complaints by the residents living nearest of STPs.

This work focused on the economic, social and environmental analysis of the recovery of biogas generated in a STP. Therefore, it does not address other forms of treatment and use of biogas and energy production. It is suggested that in future works the following topics be covered: technical and financial feasibility for production of electric energy in other STPs of Paraná State; the financial analysis for the implementation of UASB reactors in STPs that do not have this technology; the use of biogas for drying and cleaning of sludge; the use of biogas as a vehicle and/or household fuel; the recovery of heat coming from the transformation of biogas into electricity.
REFERENCES


BEN. **Balanço Energético Nacional.** Ministério de Minas e Energia. Brasília, p. 288. 2014. (CDU 620.9:553.04(81)).


SNIS. **Diagnóstico dos Serviços de Água e Esgotos.** Ministério das Cidades. Brasília, p. 164. 2014. (CDD 352.6).