A SMALL WASTEWATER TREATMENT STATION BUILT WITH PVC AND ASSOCIATED TO BIOGAS POWER GENERATOR

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ABSTRACT

This work describes features related to a small wastewater treatment station installed at Sao Paulo State University, Faculty of Engineering, and Campus of Guaratingueta. An introduction about this topic is discussed focusing on its importance for environment (greenhouse effect) and for sewage treatment. Several works related to this topic are discussed. Following, a general plant is described. Concluding, some articular aspects are discussed such as CDO and BDO removal. Also, a comparison between real measured values and values recommend by Brazilian environmental legislation is discussed.

Keywords: biochemical demand of oxygen, biogas production, chemical demand of oxygen, power generation, sewerage, wastewater treatment.

NOMENCLATURE

BOD   biochemical demand of oxygen
COD   chemical demand of oxygen
c_p fluid specific heat at constant pressure, J/(kg.K)
E   energy, kW
LHV   low heat value, kJ/kg
$\dot{m}$ mass flow, kg/s
T   average fluid temperature, K

Greek symbols

ΔT variation of temperature, K
η efficiency, %

Subscripts

bg   biogas
c   combustion
eg   exhaust gases
f   fuel
ge   generation of energy
ghw   generation of hot water
gl   global
he   heat exchanger
p   production of electricity
w   water

INTRODUCTION

World has been affected by several energy crises, resulting in a search for alternative solutions to large and small size electromechanical and thermal energy generators, improving additionally the rational use of energy generated by traditional plants. Environment protection has also been one of the main goals in these researches.

This new focus on alternative energy sources (Beduschi et al., 1983) provided new modelling techniques, more accuracy for new power systems, allowing for a more rigorous and discerning technical-economical analysis. Among these techniques it is worth mentioning exergoeconomic and thermoeconomic analysis models appearing in the scenario, used as a very powerful tool for energy systems optimisation (Silveira, 1998).

Methane is the main component of biogas generated from anaerobic wastewater treatment and it is about 21 times more harmful that carbonic gas related relate to the greenhouse effect (Jordao and Alem Sobrinho, 2004). This characteristic shows that the biogas produced by sewage treatment is an interesting contribution to renewable energy generation and environmental sanitation.

Focusing on this issue, a small wastewater treatment station (SWTS), built at Sao Paulo State

University – UNESP (Fig. 1 and Fig. 2), was designed for use of biogas in power energy generation through an improved power generation system. The system comprises a water wheel connected to a twin aerobic bioreactor producing energy and injecting air into the reactors improving the final treatment. It is also possible to use a part of treated as a biofertilizer in near green areas.

Figure 1. Small wastewater treatment station at UNESP (back view).

Figure 2. Small wastewater treatment station at UNESP (front view).

Related Works

Beduschi et al. (1983) discuss about economical feasibility of bioreactor estimating the construction cost of a bioreactor system capable to produce 10m3 of biogas and 500 litres of fertilizer per day. It is also possible to approach values for biofertilizer and biogas when compared to traditional waste water treatment plants such as 0.017% for biofertilizer and 0.05% for biogas.

Silveira (1998) studied a thermoeconomic optimisation method for use in energy systems. Economics characteristics are associated to exergetic techniques to develop such optimization, which was adopted to develop a methodology to analyse small

waste water treatment plants through their economical and exergetical characteristics.

A sort of anaerobic and aerobic bioreactors characteristics were obtained by Oliveira and Forresti, (2004); Oliveira (2001); Jordao and Alem Sobrinho (2004); Guardabassi and Pires (2006); and Martins et al. (2006), such as typical values for Low Power Value of urban residues, biomass, and biogas, waste water treatment condition in Brazil, comparison between different bioreactors types, power generation and biogas production features, among others.

MATERIAL AND METHODS

Plant Description

Biogas is produced in three anaerobic bioreactors. This biogas is transferred to a gasometre maintaining a pressure previously established to be fed an air cooled internal combustion engine, which forms the generation system. Figure 3 shows the small waste water treatment station associated to biogas self-generation and to water wheel.
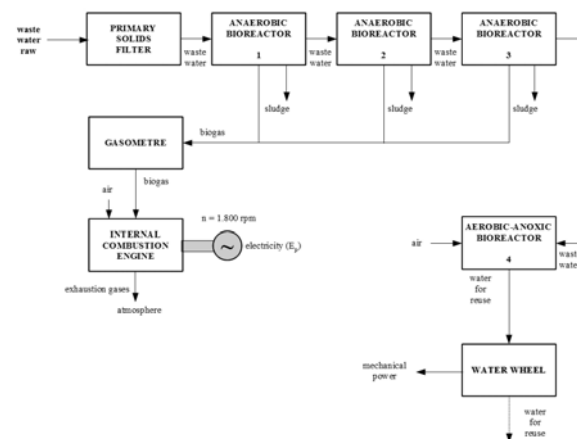

Figure 3. Small wastewater treatment station block diagram.

Wastewater from administration and cafeteria buildings (Fig. 2) enters through primary solids filter. This preliminary treatment eliminates the rudest solids, such as fat blocks.

Waste water follows through three up-flow sludge blanket anaerobic bioreactors, which separate solid residues (sludge), biogas, and wastewater (preliminary treatment) through a helical phase flow. In this stage, part of the sludge is removed and used as biofertilizer. Another part is maintained because micro-organisms present in there, predominantly of *Methanosaeta* gender (Oliveira e Forresti, 2004), digest organic material present in sludge to produce biogas. This biogas is transferred to a gasometre, where it is stored at an appropriated pressure for engine fiding, responsible for the generation of sufficient power energy to maintain associated small

energy systems such as a control room, illumination, a pump etc.

Wastewater flows until a fourth bioreactor (aerobic-anoxic), where aerobic micro-organisms digest any organic material that was not digested by anaerobic organisms, besides transforming amoniacal nitrogen in nitrate. Anoxic micro-organisms transform nitrate in gaseous nitrogen and remove part of phosphorous in sludge bacterial biomass form. At that stage, treated water falls on a water wheel and generates mechanical power as well as air for aerobic bacteria treatment. This reusable water may be used in green areas ferti-irrigation.

Power Generation

Power generation system is constituted by a market available small motor-generator set, designed to use diesel as fuel and it is necessary to be converted for biogas.

This motor-generator set had been chosen after an engine selection procedure that is explained in section "Engine Selection". Fig. 4 shows this motor.
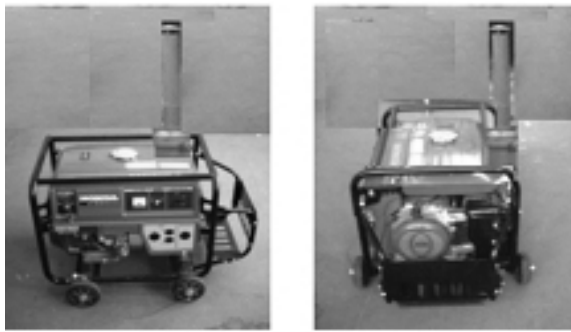

Figure 4. ICE converted for the of biogas.

Engine Selection

The selection of the engine has to be considered very carefully because the range of efficiency is very wide. Several factors should be taken in account.

First of all, there are three main categories of engines which possibly could be used; Otto engines running with gasoline or diesel, or diesel engines. By using an engine with diesel as fuel, the problem will occur that the engine needs a mixture of 20% diesel and 80% biogas to run without problems. Also, as diesel engines do not have spark plugs, pressure has to be applied to produce combustion. As biogas has a lower flaming point than diesel and the behaviour of biogas is more alike gasoline, an ignition device has to be used. Engines running with gasoline are much easier to transform to biogas because their chemical behaviour is more similar. In this study a large varieties of engines with powers between 3-6 kW were considered and compared.

Two engines, one diesel and one gasoline, with good efficiencies were selected and an economy

analysis was applied to see the payback efficiency. In the case of this study, as the plant is just a pilot project, also very small engines had to be chosen. For a larger plant additional facts should be considered, such as pressure and the efficiency and shape of the heat exchangers.

The selection of an engine from different manufacturers has been made showing the best systems in terms of energy efficiency. We had to make a definite choice of an engine for each case, normally on basis of economy, the main concern of the project. The costs evaluations and investments necessary for the motors served as a basis for this selection. The main factor for the selection of the motor was the pay-back of the total investment and the efficiency.

For each case we selected the engine representing the shortest time of investment refunds, although all selected motors satisfy the required mechanical, thermal and electrical conditions of the processes. The global efficiency of the systems under analysis does not determine the final selection of the engine, but contributes to the economical efficiency or operational level.

In this work, a sort of assumptions have been considered, such as: specific heat of exhaust gases (1.094 kJ/kg.K), specific heat of water in steam phase (2.02 kJ/kg.K), specific heat of water in liquid phase (4.187 kJ/kg.K), specific density of biogas (0.7 kg/m^3 for 60% of CH_4, 35% of CO_2, and 5% of N_2), specific density of air (1.1614 kg/m^3), specific density of gasoline (0.72 – 0.76 kg/m^3), low heat value of biogas (20,935 kJ/m^3), low heat value of gasoline (34,856.8 kJ/m^3), and low heat value of diesel (38,348.7 kJ/m^3). The LHV values for CO_2 and N_2 are zero in this case, because they do not contribute to the energy output.

The efficiency of an engine or a heat exchanger has been evaluated by taking the fuel efficiency and the amount of heated water. Equations (1) to (7) are used to obtain the global efficiency of the engine.

$$E_c = \dot{m}_{eg} \cdot cp_{eg} \cdot \Delta T_{eg} \qquad (1)$$

$$E_w = \dot{m}_w \cdot cp_w \cdot \Delta T_w \qquad (2)$$

$$E_f = \dot{m}_{bg} \cdot LHV_{bg} \qquad (3)$$

$$\eta_{he} = \frac{E_w}{E_c} = 0.8 \qquad (4)$$

$$\eta_{ge} = \frac{E_P}{E_{fl}} \qquad (5)$$

$$\eta_{ghw} = \frac{E_w}{E_f} \qquad (6)$$

$$\eta_{gl} = \eta_{ge} + \eta_{ghw} \qquad (7)$$

The mass flow of exhaust gases is evaluated from the addition of mass flow of biogas used and mass flow of air. The air/biogas mass ratio the biogas combustion is one part of fuel and twelve parts of air.

Biogas consumed in combustion is higher than gasoline, because its LHV is lower than gasoline's LHV. So, it is possible to evaluate biogas demand to produce the same energy that gasoline produces, evaluating energy produced with gasoline. Tables 1 to 3 (Bohme, 2004) relate characteristics of engines evaluated and values obtained to produce energy with gasoline and its correspondence with biogas demand.

H₂S Filter

The biogas filtering system is intended for H2S removal, which is corrosive and emits an unpleasant odour, increases working life of ICE to be used in the power self-generation sub-system and the biogas unpleasant smell mitigation (Spinola, 2007).

This filtration is obtained with a filter composed by PVC pipes with oxide steel wool and fine powder as filtering materials for H_2S retention. Fig. 5 shows this filtration system through sequential filters and Fig. 6 shows this filter installed in mini-ETE's gasometre output.

After filter installation, composition analysis of biogas produced in mini-ETE was obtained by sampling biogas collected in points before and after filter connections. This composition analysis considered O_2, N_2, CO_2, CH_4, and H_2S as biogas, not considering any other gas. Table 4 lists their percentage values.

Four weeks later, a new analysis for biogas composition was done in order to validate preliminary results, as shown in Table 5.

Figure 5. Filtration system.

Figure 6. Filtration system installed in gasometre.

Table 1. Features of different engine models evaluated.

Engine model	Tank volume (L)	Ep (kW)	Temp. of exhaust gases [°C]	Type of fuel	Demand of fuel [g/kW.h]
Agrale M73	3.8	4.4	450	Gasoline	310
Honda GXH50	1.5	1.76	450	Gasoline	310
Honda GX120	2.64	2.82	450	Gasoline	310
Honda GX200	3.8	4.576	450	Gasoline	255
Yanmar L40AE-S	2.7	3.1	450	Diesel	275
Yanmar L48AE-S	2.86	3.5	450	Diesel	270
Yanmar L60AE-S	3.7	4.5	450	Diesel	255
Yanmar L70AE-S	4	5.2	450	Diesel	260
Yanmar NSB50	6.5	3.3	450	Diesel	280
Yanmar NSB75	9	4.4	450	Diesel	260
YanmarNSB11	10.5	6.9	450	Diesel	260
Honda EP5500	17	5	450	Gasoline	474

Table 2. Values for fuel and exhaust gases flows.

Mass flow of fuel [kg/h]	E_{fuel}, gasoline [kW]	η_{ge}, gasoline	E_{fuel}, biogas [kW]	Mass flow of exhaust gases [kg/h]
1.364	13.2069	0.332	20.3798	56.0725
0.5456	5.2827	0.3332	8.1519	22.4290
0.8742	8.4644	0.3332	13.0616	35.9373
1.16688	11.2983	0.4050	21.1950	58.3154
0.8525	9.0812	0.3414	14.3585	39.5056
0.945	10.0665	0.3477	16.2112	44.6031
1.1475	12.2237	0.3681	20.8430	57.3468
1.352	14.4021	0.3611	24.0852	66.2674
0.924	9.8428	0.3353	15.2849	42.0543
1.144	12.1864	0.3611	20.3798	56.0725
1.794	19.1105	0.3611	31.9592	87.9318
2.368	39.079	0.1279	23.1589	51.77

Table 3. Values for biogas flow.

Mass flow of air[kg/h]	E_c [kW]	E_w [kW]	η_{ge}, biogas	η_{ge}, hot water	η_{global}, biogas	Mass flow of biogas kg/h
52.5679	3.7488	2.9990	0.3032	0.1081	0.4503	3.5045
21.0272	1.4995	1.1996	0.3032	0.1081	0.4503	1.4018
33.6913	2.4026	1.9221	0.3032	0.1081	0.4503	2.2461
54.6706	3.8987	3.1190	0.3750	0.1081	0.5222	3.6447
37.0365	2.6412	2.1129	0.3114	0.1081	0.4585	2.4691
41.8154	2.9820	2.3856	0.3177	0.1081	0.4648	2.7877
53.7626	3.8340	3.0672	0.3381	0.1081	0.4853	3.5842
62.1257	4.4303	3.5443	0.3311	0.1081	0.4782	4.1417
39.4259	2.8116	2.2493	0.3053	0.1081	0.4524	2.6284
52.5679	3.7488	2.9990	0.3311	0.1081	0.4782	3.5045
82.4361	5.8787	4.7030	0.3311	0.1081	0.4782	5.4957
47.789	3.1292	2.5034	0.2159	0.1081	0.3240	3.9824

Table 4. First biogas composition analysis.

	Without filtration [%]	With filtration [%]
O_2	0.8	0.6
N_2	2.4	2.0
CO_2	40.0	34.4
CH_4	54.0	61.8
H_2S	2.8	1.2

Table 5. Second biogas composition analysis.

	Without filtration [%]	With filtration [%]
O_2	0.6	0.4
N_2	2.4	2.0
CO_2	40.0	34.4
CH_4	54.0	61.8
H_2S	3.0	1.4

DISCUSSION

Small wastewater treatment station started about middle of 2007. It was inoculated with 12 m3 of a flocculent sludge from an anaerobic effluent treatment station of a local brewery. After that, several analyses were done for chemical demand of oxygen (CDO) and bio-chemical demand of oxygen (BDO), as showed in Tables 6 and 7 (Spinola, 2007).

Table 6. COD analysis.

Date	Anaerobic System Entrance [mg/L]	Anaerobic System Exit [mg/L]	Aerobic-Anoxic System Exit [mg/L]	Total Removal [%]
4/20/07	177	105	72	59.00
5/20/07	260	111	75	71.10
9/11/07	518	239	83	83.97

Table 7. BOD analysis.

Date	Anaerobic System Entrance [mg/L]	Anaerobic System Exit [mg/L]	Aerobic-Anoxic System Exit [mg/L]	Total Removal [%]
9/11/07	334	94	33	71.85

CONCLUSIONS

This system initiated operations about February 2008 with a donated sludge from a brewery facility. Up to the present time, results are 83% of reduction for CDO, 72% of reduction for BDO, and 33 mg/L of outcome BDO.

According to Brazilian environmental legislation a wastewater treatment plant should reduce at least 80% of BDO or its treated water should leave the system with less than 70 mg/L of BDO.

Comparing results obtained up to now with the minimum values demanded by Brazilian environmental legislation, they are considered satisfactory because only one digester was operational while the others were not operational for several reasons, such as little time of operation, low temperatures in most of the time, and low effluent volume.

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