Techno-economic Feasibility for Recovering Biogas in a Bio augmented Municipal Sewage Plant

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Abstract

A techno-economic assessment study was conducted to consider the feasibility of recovering biogas in a bio agumentated municipal sewage treatment plant. A sewage plant with a capacity of approximately 20 ML/day and a plant operating capacity of 60% for 24 hours were considered. The sewage sludge analysis indicated a high total solids and chemical oxygen demand content. Biogas generation was monitored over a 30 day period with Hycura as the bio augmentation media at 0.05 g/L. Biogas with a methane content of 78% was achieved and the digestate collected as bio solids was rich in nitrogen, phosphorous and potassium. The plant had the capacity to produce 1 380 KWh of electricity per day and if a total investment of 2 million is made, a payback period of 5 years at an in internal rate of return of 18% will be realized.

Keywords: Bio augmentation, biogas, bio solids, techno-economic assessment

1. INTRODUCTION

Resource recovery from municipal sewage plants is increasingly becoming popular especially in developing countries in order to make the running of sewage treatment plants for economical (Tomei et al., 2015). Biogas is being recovered in sewage plants for further upgrading and being used for heat generation as well as electricity generation (Khanet al., 2014). The amount of electricity generated from the biogas is depended on the amount of methane available hence the methane composition is of utmost importance (Rouf et al., 2013). Recently the bio augmentation of organic waste to enhance the production of high quality methane biogas has become topical (Zhu and and Jha, 2013). Engineered bio catalysts like Hycura have been reported to enhance the methane composition (Duncan, 1970; Cail *et al*., 1986). In this study, a techno-economic feasibility for enhancing biogas production from municipal sewage using Hycura as bio augmentation inoculants was done. The techno-economic assessment of generating value added products from municipal plants is essential is essential for assessing the profitability of the process and economic indicators such as the rate of return, payback period and breakeven point must be assessed (Harun et al., 2011).

2. MATERIALS AND METHODS

2.1 Materials

A biogas analyzer from GeoTech, UK was used for the biogas analysis. Sewage sludge was obtained from a neighbouring sewage wastewater treatment plant. A Hanna pH meter was used for determination. A Memmert oven, Germany was used for the total solids (TS) and volatile solids (VS) determination in the sewage sludge. A Thermo Fischer Scientific chemical oxygen demand (COD) meter was used for COD determination in the sewage sludge. An AND moisture analyser was used for moisture content measurement. The total nitrogen, phosphorus and potassium were measured using a Labtronic double beam uv-vis spectrophotometer.

2.2 Methods

Sewage sludge characterization

The sewage sludge was characterized for the TS, VS and the COD in a bid to determine its potential for usability in biogas production. The TS were measured as a percentage by noting the change in mass when a 5 g sample was oven dried at 105 °C and the VS were measured as a percentage by noting the change in mass when a 5 g sample was heated at 550 °C. Moisture content was measured by heating a 5g sample at 105 °C for 10 minutes and noting the change in weight as a percentage.

Biogas production

Biogas was produced in 250 mL bio digesters with 0.05g/L of Hycura inoculated to maximize on the methane production. Anaerobic digestion was allowed to take place under mesophilic conditions of 37 °C for a period of 30 days. Biogas composition was analysed throughout the 30 day period.

Bio solids production

Bio solids were collected as the digestate after the anaerobic digestion of the sewage sludge and were dewatered and oven dried at 105 °C before the characterization of the NPK using spectrophotometer.

Economic assessment

Capital budgeting techniques were used for the economic assessment. A local sewage plant with a bio nutrient removal plant capacity of 19.6 ML/day and an operating capacity of 60% was considered assuming it operated 24 hours a day. All values in the economic assessment are expressed in United States dollars.

3. RESULTS AND DISCUSSION

3.1 Sewage sludge features

The sewage sludge had a COD content of 737-762 mg/L and TS content of 1128-1157 mg/L. The high values in the COD and TS values were an indication that the sewage sludge had high solids content and a good raw material for biogas generation. The features of the sewage sludge are given in Table 1.

Table 1: Sewage sludge features

Parameter	**Value**
pH	6.4-8.4
COD (mg/L)	737.5-762.5
TS (mg/L)	1128.7-1157.4
VS (mg/L)	2.4-2.6
Moisture content (%)	40-80
TKN (mg/L)	239.9-250.1
TP (mg/L)	49.8-55.2
BOD (mg/L)	554.5-559.5

3.2 Biogas composition

Biogas generated from the sewage sludge was very rich in methane with composition going as high as 78%. The high methane content was attributed to the enhancement factor through bio augmentation by Hycura which also hindered the production of trace gases like hydrogen sulphide. The features of the biogas are shown in Table 2.

Table 2: Biogas composition

Gas	Composition (%)
Methane (CH_4)	72.5-78.4
Carbon dioxide (CO_2)	16.9-20.1
Hydrogen sulphide, water vapor, ammonia	5.3-9.4

3.3 Bio solids composition

The bio solids from the anaerobic digestion of sewage sludge have the potential to be used as bio fertilizers due to the presence of NPK nutrients which are required by plants. The NPK composition of the bio solids is given in Table 3.

Table 3: Bio solids composition

Nutrient	Composition (%)
Nitrogen (N)	8.02-8.32
Phosphorous (P)	5.81-5.87
Potassium (K)	1.30-1.34

3.4 Economic assessment

Cost analysis of inputs for a conventional system

During the conventional treatment of sewage aluminium sulphate is required as the coagulant to allow the removal of contaminants in the sewage resulting in sewage sludge. Normally the bio solids are not value added but sent for land filling posing environmental and health problems. The aluminium sulphate required costs $19.22/ML of sewage treated (Dalton, 2008) and converts to about $226/day for the selected plant.

Quantity of Hycura required

A total of 588 kg is required for the treatment of sewage using Hycura in a day if the inoculation loading 0.05g/L is considered for optimal municipal sewage treatment recovering biogas and bio solids. In monetary terms $205.00/day is required for Hycura inoculants given it is available at $0.35/kg.

Biogas quantity produced

The quantity of biogas produced was based on the maximum amount of biogas that could be obtained which is 78% bio methane. After considering that solids in the sewage take about 10% of the composition and assuming at most 95% conversion of these solids, the maximum amount of biogas to be produced is 12 000kg/day and this translate to $19 000/day if a biogas selling prize of $1.50 is assumed.

Bio solids quantity produced

It is assumed that the total amount of bio solids produced is 5% of the total solids in sewage (Smith, 2009). The amount of bio solids produced per day converts to 672kg which is equivalent to $215/day if a selling prize of $16/50 kg bag is considered. If Hycura is using as a bio augmentation media in recovering biogas and bio solids from sewage sludge a daily net benefit of $19 300 can be realized which translate to $5 656 000.00 per annum.

Quantity of electricity produced

It was assumed that the bio methane has a heating value of 37.78 MJ/m^3, a biogas conversion efficiency of 29% with a conversion factor of 1KW equals to 3.6 MJ (Arthur and Brew-Hammond (2010). The biogas produced from the sewage sludge had 78% methane content and considering that biogas has a 1.15 kg/m^3 density at standard conditions, the amount of bio methane generated on a daily basis is 456 m^3/day. Considering the assumptions by Arthur and Brew-Hammond (2010) the amount of electricity generated amounts to 1 387 KWh per day. This converts to $13 679.00 given the cost of electricity in Zimbabwe is $9.86/KWh.

Electricity production costs

A total of $2 220 000.00 is required for setting up an electricity generation plant from biogas; the value is based on the fact that $5.48/KWh (Kottner, 2010) is required for investment. A plant operating capacity of 80% with 24 hours operation was considered. A summary of all estimates for cost of production which include maintenance, insurance, investment and labour cost are given in Table 4.

Table 4: Expected biogas plant operating costs

Cost	**Contribution**	**Value (US$)**	**Reference**
Maintenance	2% of investment	44 400.00	Kottner (2010)
Production	$0.035/KWh	14 178.00	Gebrezgabher *et al.* (2010)
Insurance	1-2% of investment cost	44 400.00	Kottner (2010)
Labour	$22/hr	154 176.00	Kottner (2010)
Electricity	7% of production cost	993.00	Kottner (2010)
Total plant Costs		258 147.00	

If an assumption that the investment will take up to 10 years then: $2 220 000.00*10 years amounts to $ 22 200 000.00 whilst the other cash flows are still going up to 20 years. The potential cash flows within the 20 year period are shown in Table 5.

Table 5: Cash flow analysis

Item	**Cash flow ($)**
Initial cash flow (Investment) (2 220 000.00*10)	22 200 000.00
Cash flows per year	
Electricity sold	3 994 286.00
Less: Total expected costs	258 147.00
Net Cash flow	3 736 140.00

Net present value

Assuming a discount rate of 15% and a plant operation period of 20 years the net present value (NPV) was calculated according to Equation 1. An NPV value of $1 186 000.00 was obtained and the positive value indicated it's feasible to generate biogas and bio solids from sewage sludge enhanced by bio augmentation.

$$NPV = \text{-Initial Cash flow} + \text{Net Cash flow per year}*(1 - 1/(1+0.15)^{20})/0.15 \ldots(1)$$

Internal rate of return

Assuming that the discount rate is increased to 50% the NPV becomes -14 729 000.00 and the internal rate of return is calculated according to Equation 2 and an IRR value of 18% was obtained.

$$IRR = I_a + ((NPVa/(NPVa - NPVb)*(I_b - I_a))\ldots\ldots(2)$$

An IRR of 18% shows the economic feasibility of shows that the project adds value to stakeholders since it is greater than the cost of capital which was assumed to be 15% hence proving being economical.

Payback period

The payback period was calculated considering the initial cash flow against the net cash flow. The payback period is calculated by dividing the initial cash flow by the yearly net cash flow and a payback period of 5 years was achieved.

Breakeven point

Breakeven refers to the point of balance between making either a profit or a loss and is calculated by dividing the fixed costs by the contribution per unit. Whereby the fixed costs are a sum of maintenance cost, insurance and electricity for the 20 years this amounts to $ 1 1 800 000.00. The contribution per unit is the electricity selling minus production cost, all divided by the labour cost to give $9.81/KWh. The breakeven point achieved from the study was 183 058 KWh which translates to $1 800 000 in sales.

4. CONCLUSION

The bio augmentation of sewage sludge allows for the production of high methane content biogas as high as 78%. An economic assessment for generating electricity from a bio augmented municipal sewage plant indicated that it is economically viable to generate biogas electricity as well as consider the bio solids for sale as bio fertilizers. A net present value of $1 186 000.00 was realised with a payback period of 5 years and internal rate of return of 18%.

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