Int. J. Environ. Res., 6(2):493-498, Spring 2012
ISSN: 1735-6865

Electricity Generation from Leachate Treatment Plant

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Received 19 May 2011; Revised 12 Aug. 2011; Accepted 20 Dec. 2011

ABSTRACT: Tehran has a population of over 12 million and produces more than 7500 tons of waste every day. Tehran's municipal solid waste is processed and landfilled at Kahrizak disposal center. Due to inappropriate waste management, a lake with a leachate volume of 180,000m^3 has been formed. To solve this problem a leachate treatment plant is currently under construction. A byproduct of leachate treatment is biogas. In this study, the feasibility of electricity generation using biogas has been investigated. Considering that 68.81% of the waste is degradable, the produced leachate has a high organic load (COD = 53900 mg/L and BOD = 34400mg/L). The results showed that a power plant with a capacity of 1.8 MW could be constructed in the site. This electricity can be utilized in Kahrizak Disposal Site and also sold to the network (10 US cents/ kilowatt). Financial analysis using ProForm software shows 1.3 years of payback period and emission reduction of carbon dioxide equal to 5752 tones/year in comparison with the natural gas power plant. Therefore this project is financially feasible for private investors with internal rate of return equal to 77% or more.

Key words: Municipal Solid Waste, Leachate, Biogas, Electricity, Environment

INTRODUCTION

Municipal Solid Waste (MSW) disposal has always been an important issue for governments all over the world. Due to the cumulative growth of population, rapid urbanization, changes in patterns of lifestyle and acceleration in commercial and industrial developments in the past decades, many countries have experienced a dramatic growth in the municipal and industrial solid waste generation. For instance, in Norway and USA, between 1992 and 1996 waste production rate showed an increasing rate equal to 3% and 4.5% per year respectively (Renou *et al*., 2008). The rapid growth of MSW generation could be seen in Iran too; for instance, between 2002 and 2009 waste generation increased by 7.3% and in 2006 waste production was about 746 gr per person per day. Economically, the acceptable method for MSW disposal has been landfilling (Safari *et al*., 2011). Two major issues about MSW disposal should be considered: biogas and leachate resulted from organic compound degradation of waste (Safari *et al*., 2011). Leachate is a high-strength wastewater that is formed due to solid waste moisture and percolation of rainwater through landfills (Hesar *et al*., 2009). Therefore, leachate contains various organic and inorganic compounds that might be dissolved or suspended as biodegradable or non-biodegradable (Bilgili *et al*., 2008; Qygard and Gjengedal, 2009). Leachate is an environmental hazard for the surface water and groundwater (Maqbool *et al*., 2011); for instance, a contaminant plume with a length of 700 m, maximum width of 600 m and maximum depth of 20 m was found in the groundwater table in Borden landfill located in Canada (McFarlane *et al.*, 1983). Furthermore, mainly composed of CO_2 and methane, biogas escaped to the atmosphere can potentially accelerate global warming. Intergovernmental Panel on Climate Change (IPCC), estimates the potential of certain volume of methane is 23 times larger than that of CO_2 in the same volume (Themelis and Ulloa, 2007).

One approach for leachate management is leachate treatment. Due to reliability, economic advantage and high quality of outlet wastewater, biological treatment process is commonly used for removal of leachate in high concentrations of BOD

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and COD (Renou *et al*., 2008). This process is more suitable than physicochemical methods (Marttinen *et al*., 2002) to remove organic and nitrogenous matter from fresh leachate when BOD/COD ratio is higher than 0.5 (Abbas *et al*., 2009). Among aerobic and anaerobic methods, the anaerobic process is preferable because less sludge and biogas are produced. Anaerobic Baffled Reactor (ABR) is a relatively new, high rate anaerobic reactor in biological treatment of leachate and strong industrial wastewater. ABR was initially developed by McCarty and coworkers (McCarty, 1981). In an ABR, wastewater is forced to flow through a series of baffles (Metcalf and Eddy, 2003). The most important advantages of ABR include its ability to separate acidogenesis and Methanogenesis (Barber and Stuckey, 1999; Vossoughi *et al.*, 2003), and to act as a two-phase system that can increase acidogenic and methanogenic activities (Barber and Stuckey, 1999). Biogas mainly contains 40-75% methane, 15-60% carbon dioxide and also trace elements such as 5-10% water, 0.005-2% hydrogen sulfide, 0-0.02% siloxanes, 0-1% oxygen and less than 0.6%, 0.6% and 1% carbon monoxide, halogenated hydrocarbons and ammonia respectively (Ryckebosch *et al.*, 2011). A research showed that 70% of methane production in Hybrid anaerobic baffled reactor (HABR) caused by the first compartment and only 10% of VSS remained in this compartment (Barber and Stuckey, 1999). Biogas can be utilized as a renewable energy source for clean electricity generation. The storage and transportation of biogas are also economical, and their handling appears to be less hazardous than fossil fuels (Nwabanne *et al.*, 2009).

There are various technologies for converting biogas to electricity such as gas turbines, micro turbines, reciprocating engine, steam turbines and fuel cells (EPA 2008). Biogas should be pretreated before entering to each system. Biogas calorific value and flammability depend on methane volume; higher methane content leads to higher energy generation. Biogas will not burn in more than 75% of CO_2 (Noyola *et al*., 2006), thus removing CO_2 seems necessary for increasing biogas calorific value. Also, hydrogen Sulfide in biogas is corrosive and malodorous. Therefore, H_2S levels should not surpass the permitted range (500 to 700 ppm) for use in conventional internal combustion engines (Haren and Flaming, 2005).

The age of Kahrizak disposal site is near to 40 years. The site (longitude=51° and latitude=35°) is located 25km away from Tehran and in Aradkooh territory. Tehran currently has more than 12 million in population which produce more than 7500 tones MSW per day, processed in the site and about 3500 tones of MSW go to landfills. In Kahrizak disposal site, there is a lake of leachate with 180,000 m^3 volume that is due to absent of a waste management system. This lake contains organic and inorganic pollutant materials that can migrate to groundwater and is a real environmental hazard for contaminating soil and water. To overcome this problem, the Kahrizak leachate treatment plant is under construction. Upon completion, the plant will cover an area of 2 hectares and will be the largest plant in the Middle East. The plant can treat up to 1400 m^3 of leachate everyday. Biogas will be produced in the anaerobic units.

On the other hand, according to World Bank report, electricity consumption in Iran is high (2,000 kWh per capita). In the last decades, the demand has been increasing about 8% per year at a steady rate (World Bank, 2007). Moreover, since fossil fuel sources are limited, renewable energies are increasingly gaining more attention. Therefore, the purpose of this study is to estimate the amount of biogas that can be produced from anaerobic units of the Kahrizak leachate treatment plant, and to evaluate the feasibility of generating electricity from the biogas. Hence, the generated biogas can be regarded as an energy source, and by will pose no or limited environmental risk avoid escaping to the atmosphere. This plant is the first one that has been designed for leachate treatment in Iran.

MATERIALS & METHODS

The Leachate Treatment Plant is located in Kahrizak and contains two hybrid anaerobic baffled reactors. Leachate comes to the reactors after mechanical and manual cleaned bar screens. The reactors operate in 35ºC, Hydraulic Retention Time (HRT) is 3.7 days and they have been designed for 75% COD removal efficiency. Reduction of temperature is very effective on COD removal efficiency.

In order to estimate the potential of biogas production of MSW leachate at anaerobic units, characteristics of fresh leachate was measured according to the Standard Methods (APHA, 2005), and elemental analysis was conducted using CHNS analyzer (Elementar, Vario EL III). Additionally, the amount of biogas that can be generated is estimated using mass balance conversion of COD (Metcalf and Eddy, 2003) to Methane gas. Also, environmental and financial assessment of the project is examined by Proform software.

RESULTS & DISCUSSION

Physical analysis of Tehran MSW is shown in Table 1. Since 68.81% of Tehran solid waste consists of biodegradable materials, high volumes of leachate can be potentially generated in landfill sites. Moreover, since the solid waste has high organic and biodegradable matters, the produced leachate has high organic loads. According to the contents, water moisture rate was calculated 50% and waste chemical formula (Tchobanoglous *et al.*, 1993) was found as: $C_{555.8}H_{856}O_{277.3}N_{15.9}S$.

Table1. Physical analysis of Tehran municipal solid waste (Tehran Organization of Waste Recycling and Composting, 2008)

Components	Mass%
Food waste	68.81
Papers	4.41
Cardboards	3.72
Rubbers	0.71
Plastics	8.9
Pets	0.71
Textiles	4.04
Debris	2.07
Woods	1.66
Glasses	2.4
Metals	2.56

For estimating the potential of biogas generation, a sample of leachate was taken from fresh leachate on July 2011. The characteristics of Leachate were found as: COD = 53900 mg/L, BOD = 34400 mg/L and pH=6.8. In an anaerobic digester, chemical compounds of input material are effective for the purpose of quality and efficiency of biogas. The results obtained from elemental analyses of the sampled leachate solid matter revealed the chemical composition in this study to be $C_{23}H_{43.37}O_{6.8}NS_{0.29}$.

For calculating biogas production in anaerobic conditions, an empirical equation, Eq. (1), (Ghani and Idris, 2009) was used. As a result, one liter of the leachate has 25.2 gr of solid and can produce 0.018 m^3 of methane at standard temperature and pressure (STP, i.e., 0°C and 760mmHg). A study in Korea on garbage leachate (TCOD=172500 mg/L) showed 39m^3 methanen/m^3 leachate (Bae *et al.*, 2010).

$$C_vH_wO_xN_yS_z + \left(v - \frac{w}{4} - \frac{x}{2} + \frac{3y}{4} + \frac{z}{2}\right) H_2O \rightarrow \left(\frac{v}{2} + \frac{w}{8} - \frac{x}{4} - \frac{3y}{8} - \frac{z}{4}\right) CH_4 + \left(\frac{v}{2} - \frac{w}{8} + \frac{x}{4} + \frac{3y}{8} + \frac{z}{4}\right) CO_2 + z\,H_2S$$
Eq.(1)

Considering 1400m^3 of input leachate per day, potential of methane calorific value of the biogas was estimated to be 90.3×10^7 kj/m^3.

Furthermore, rate of biogas and methane can be calculated by mass balance equations, Eq.2 to 7 (Metcalf and Eddy, 2003).

$$COD_{in}\ (g/d) = Cin \times Q \qquad \text{Eq.(2)}$$

$$COD_{eff}\ (g/d) = (1 - RE/100) \times Q \qquad \text{Eq.(3)}$$

$$COD_{vss}\ (g/d) = (1.42\ gCOD/gVSS)\times(0.04\ gVSS/gCOD)\times(1\text{-}RE/100)\times(COD_{in}) \qquad \text{Eq.(4)}$$

$$COD_{methane}\ (g/d) = COD_{in} - COD_{vss} - COD_{eff} \qquad \text{Eq.(5)}$$

$$CH_4\ (m^3/d) = COD_{methane} \times (0.00035) \qquad \text{Eq.(6)}$$

$$\text{Total gass}\ (m^3/d) = CH_4 / 0.65 \qquad \text{Eq.(7)}$$

HABR has been designed for 75% COD removal efficiency in HRT=3.7days. Based on the equations, the rate of biogas and methane generation was 29897m^3 and 19433m^3, respectively. An engine with an average efficiency of 40% produces 2.5kwh/m^3 of biogas. The capacity of the power plant was assumed to be 1.8MWusing 2 sets of 838kW and 1055kW biogas engines. The average temperature of Kahrizak is about 18°C, and the mean altitude of the treatment plant is 1020m, thus output electrical efficiency is 96%. The power plant can operate 328 days annually (availability factor = 90%) and as a result, the plant can generate 14,180,236 kWh of energy annually.The electricity can be sold to the network at a rate of 10 US cents/kW, yielding a revenue of 1,418,024$. 10% of this annual revenue is for in-plant consumption requirements and 90% (i.e., 1,276,220$) can be purchased by Renewable Energy Organization of Iran.

Financial assessment of the project was done by ProForm4.0 software using switch fuel option. Fuel switching projects involve the substitution of a less carbon intensive fuel with a more carbon intensive one. By assuming biogas displaced natural gas, scenarios are made based on internal fuel price for project life time of 15 years. Escalation rate of fuel price was 12%, equity fraction of total capital investment was 100% during the first year and loan dept term was 4 years arising from interior and abroad loan debt interest rate of 15% and 3%, respectively. Scenarios for carbon credit prices were 13$, 25$ and 36$ per ton of CO_2. Annual monitoring and verification costs were 10,000$, adaptation fund costs share was 1% and administrative costs were 7,000$ per year. Discount rate was 12% and marginal income tax rate was 10%. Investment costs were 2,400,000$, net savings in O&M costs were

120,000$ and technology depreciation period was 15 years. Scenarios were made according to Table 2. Table 3 shows energy results of the project.

Table 4 shows the avoided emissions. According to ProForm4.0 software, emission reductions were calculated based on the amount of baseline and project fuels required to produce equal amounts of useful energy. Additionally, the simple payback period was calculated as the expected number of years required to recover the original investment. Table 5 presents the simple payback period according to the five scenarios.

According to Table 2 and 5, initial investment costs for power plant construction appeared to be cost-effective and the payback period was approximated as 1.3 years. Moreover, the project aimed at Kyoto Protocol goals for reducing greenhouse gas emissions. The major feature of the Kyoto Protocol is to set binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions. Since Iran is a developing country,

Table2. Input Information for various scenarios

Scenarios	Biogas engine GJ $\times 10^3$	Lone Dept Term (year)	Abroad Lone Dept Interest Term (%)	Interior Lone Dept Interest Term (%)	Lone ratio, interior to abroad	Share of Carbon Credit Retained by Host Country Government (%)	Carbon Credit Price (A) US \$/ton CO_2	Carbon Credit Price (B) US \$/ton CO_2	Carbon Credit Price (C) US \$/ton CO_2
1	51	4	0	15	100-0	100-0	13	25	36
2	51	4	3	0	0-100	0-100	13	25	36
3	51	4	3	15	50-50	50-50	13	25	36
4	51	4	3	15	25-75	25-75	13	25	36
5	51	4	3	15	75-25	75-25	13	25	36

Table 3. Energy Results

	Annual Average GJ$\times 10^3$	Total project GJ$\times 10^3$
Baseline Fuel Savings-Nautral Gas	146	2186
Project Fuel Inputs- Biogas	128	1913

Table 4. Avoided Emissions Results

Pollutant	Annual Average (tones/year)	Total Project (tones/15 years)
Carbon Dioxide	5752	86281
NO_x	12	176

Table 5. Simple Payback Periods

scenarios	Simple Payback Period (Carbon Credit Price A)	Simple Payback Period (Carbon Credit Price B)	Simple Payback Period (Carbon Credit Price C)	Simple Payback Period (Without Carbon Credits)
1	1.3	1.3	1.3	1.3
2	1.3	1.2	1.2	1.3
3	1.3	1.3	1.3	1.3
4	1.3	1.3	1.2	1.3
5	1.3	1.3	1.3	1.3

it has not committed to reduce GHG emissions from 2008-2012.

The Clean Development Mechanism (CDM) allows industrialized countries under the Kyoto Protocol to implement an emission-reduction project in the developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each one equivalent to one tone of CO_2, which can be counted towards meeting Kyoto targets. Therefore, CER credits of this project can be sold to the industrialized countries.

CONCLUSION

Kahrizak Leachate Treatment Plant is the biggest one in the Middle East. The potential of biogas production at kahrizak leachate is 18m^3 methane/ m^3 leachate. Calculations showed that biogas and methane generation in anaerobic unit of Kahrizak leachate treatment plant with 1400m^3 flow rate was 29897m^3 and 19433m^3 per day, respectively. Therefore, constructing a power plant with a capacity equal to 1.8MW can generate clean electricity, and the payback investment will be about 1.3 years with internal rate of return equal to 77% or more.

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