ENERGY FROM SUSTAINABLE LANDFILLS

KURIAN JOSEPH*, R.NAGENDRAN*, CHART CHIEMCHAISRI, C.VISVANATHAN*****
***Centre for Environmental Studies, Anna University, Chennai, India**
**** Department of Environmental Engineering, Kasetsart University, Thailand**
***** Urban Environmental Engineering and Management Program,**
Asian Institute of Technology, Thailand

ABSTRACT

Any place where municipal solid waste (MSW) is dumped or disposed of in large quantities is, in principle, a bioreactor generating leachate and gases. Under strict anaerobic conditions, methane and carbon dioxide are the primary gases generated. When generated in a landfill, gas is often known as landfill gas (LFG).The aim of sustainable landfill management is to initiate methane formation quickly and achieve maximum rates of waste degradation at Landfill as soon as possible after waste deposition. By intentionally developing a *bioreactor* in a landfill, it is possible to enhance conditions for biodegradation and thereby decrease both the time required for organic stabilization of the waste and to increase the annual LFG yield. This optimises the economics of methane recovery and stabilises the landfill so that the land can be returned to amenity use or landfill mining, and the void space re-used for waste disposal. The focus of this paper is on the concept and utility of sustainable landfill for management of municipal solid wastes and Energy generation. This knowledge can be applied to tailor Energy recovery, landfill mining operations, and environmental protection measures.
Key words: landfills; energy recovery; sustainability; management

1.0 Introduction

Management of Municipal Solid Wastes (household garbage and rubbish, street sweepings, construction debris, sanitation residues etc.) continues to be the most neglected areas of urban development (CPHEEO, 2000). The 23 metro cities in India generate about 30,000 tonnes of such wastes per day while about 50,000 tonnes are generated daily from the Class I cities. About 95% of these wastes are currently disposed by open dumping (CPCB, 1999). Sanitary landfill is the cheapest satisfactory means of disposal, but only if suitable land is within economic range of the source of the wastes; however, resource recovery recycling and waste reduction must also be employed together with the landfill to further reduce the costs involved.

The traditional model of a landfill as a permanent waste deposit is giving way to the concept of a controlled decomposition process managed as a large-scale bioreactor. This controlled bioreactor landfill is seen as being a flexible, cost effective, and sustainable approach to current waste disposal problems, particularly when combined with material recovery either before or after the biological treatment step. Indeed, it may no longer be necessary to view land filling as a disposal system at all but rather to see it as a method for large-scale processing of waste to be combined with recovery and recycling processes.

A Research Project is in progress to address some of the issues of Landfills so that guidelines along with action plan could be developed for rehabilitation of dumpsites and construction of sustainable landfills in India and other developing countries. These guidelines would take into account the basically different physical and economic situation prevailing in developing countries. The studies being carried out by the Centre **for Environmental Studies, Anna University**, **India** focus on Rehabilitation of dump site(s) at **Chennai. Swedish International Development Co-operation Agency (SIDA)** is providing financial support for this technological research on Rehabilitation of the dump sites. This three - year study is a part of the Asian Regional Research Programme on "**Sustainable Solid Waste Landfill Management in Asia**" funded by SIDA and coordinated by **Asian Institute of Technology, Bangkok, Thailand**. Universities from India, Thailand, China and Sri Lanka are also involved in this programme.

In India, the demand for energy is rising faster due to increasing industrial and agricultural activities. The installed capacity stands at 91066 MW as on 1999 (GOI, Ministry of Power). The average gap between the demand and supply was 5.5% and is bound to rise further. According to estimates, 83000 MW of power would be required by year 2008. It is in this scenario, the New and Renewable sources of energy are poised to play an important role in the coming years. The focus of this paper is on the concept and utility of sustainable landfill for management of municipal solid wastes and Energy generation.

E-mail address of first author: kuttiani@vsnl.com

2.0 SUSTAINABLE LANDFILL

In order to be sustainable, modern waste management must consider the waste stream in a holistic manner combining several techniques such as waste reduction, reuse, recycling, composting, treatment and disposal in order to optimise the use of natural resources and reduce environmental impacts. The fundamental aim of the sustainable landfill is to optimise the natural degradation processes of wastes in the Landfill, treating waste within a lifetime and containing the products of degradation to prevent pollution of the environment. This is also called *Landfill Bio-reactor* (Figure 1) and requires the breakdown of the biodegradable fraction to be controlled and, in order to accelerate the degradation process and to increase efficiency. The Landfill bioreactor, is similar in design to a modern "dry tomb" landfill (Figure 2).

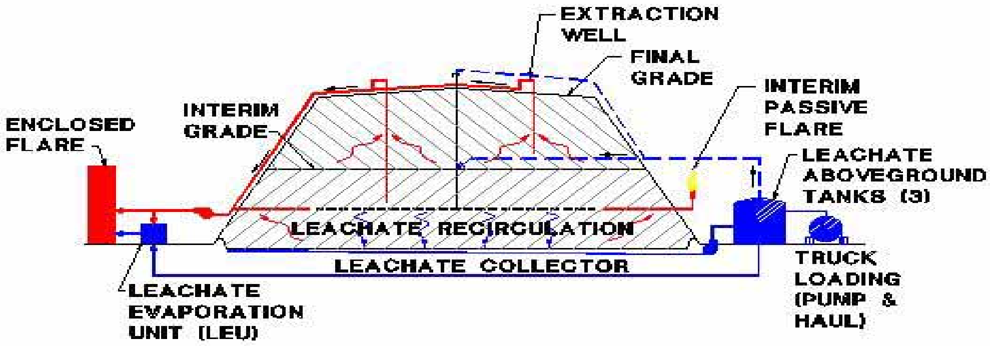

Figure 1 Bioreactor Landfill

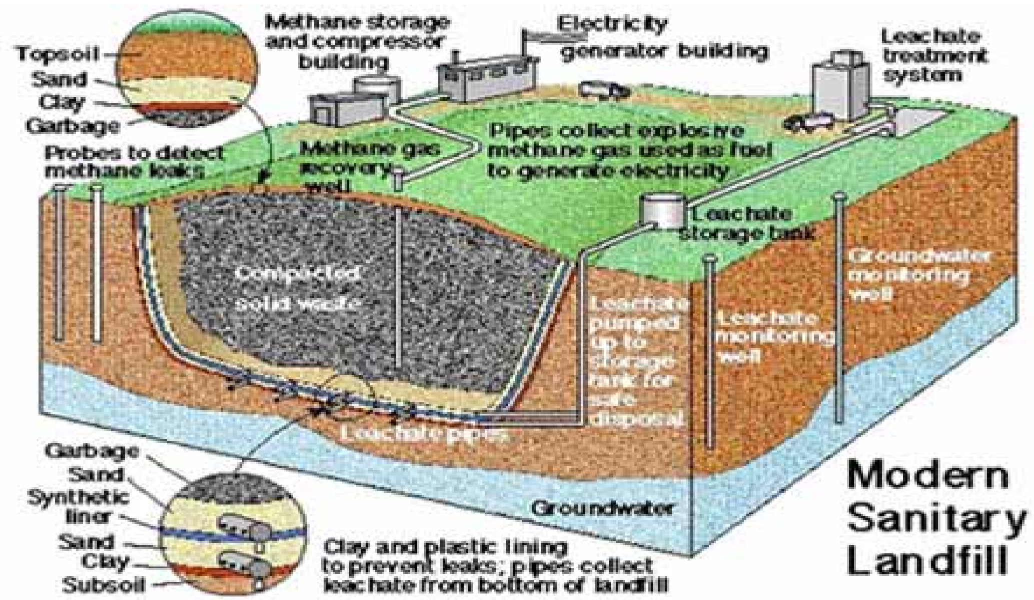

Fig 2 Schematic of a Modern "Dry Tomb" Landfill

The Landfill Bio Reactor has a leachate collection and recirculation system, geomembrane liners, final cover, and gas collection system. In this system, the predominant gas produced is methane which can be collected and purified for sale and/or use. The level of methane production is related to the level of organic waste present in the landfill. If the organic stream is diverted from the landfill, the resulting methane will be lesser. Another advantage of this design is that it has the capability of stabilizing the waste much faster than the dry tomb landfill. Waste may not stabilize for thirty years in dry tomb landfills while in an anaerobic bioreactor that may occur in less than ten year.

A schematic of the proposed Sustainable Landfill concept is presented in Figure 3. In sustainable landfills, airspace, processes, control and/or use of products and residues are at an optimum and where minimal negative effects on the environment takes place. The aim of a sustainable landfill management regime is to initiate methane formation quickly and achieve maximum rates of waste degradation as soon as possible after waste deposition. This optimises the economics of methane recovery and stabilises the landfill so that the land can be returned to amenity use or the residual material extracted and the void space re-used for waste disposal. Waste once stabilised in a landfill could be unearthed (landfill mining), sorted and all usable items and residues (e.g. compost) removed. The remaining unwanted waste material left after this process could be re-landfilled. In this way landfill space can be used more than once and the workable life of landfills could be extended. Landfill mining is a relatively new concept to prolong the life of given landfills and to recover marketable recyclables (Suflita et al 1992).

3.0 Landfill Gas

Effective sustainable landfill management requires an appreciation of both the engineering imperatives and the geo-biochemical processes that can, and do, occur in the landfill environment. The decomposition processes taking place in waste deposited in landfill depend on the type of waste, particularly the proportion of degradable organic compounds and on the water content. In general, high moisture content and a high proportion of biodegradable organic compounds, lead to rapid microbial decomposition. The stabilisation of waste in a landfill takes place *via* five distinct phases of degradation *viz*., aerobic, acid, transition, methanogenic and maturation. The processes, which occur during these different phases, comprise essentially the biological fermentation of carbohydrate, lipid and protein substrates. The bioreactions in the landfill are dependent upon a series of conditions (e.g., moisture content of waste composition, availability of oxygen, temperature, micro flora, and compaction rate).

The anaerobic degradation of organic matter under anoxic conditions to methane and carbon dioxide can be represented by the equation of Buswell and Hatfield:

$$C_a H_b O_c N_d S_e + [a-b/4-c/2+3d/4+e/2]\ H_2O = [a/2+b/8-c/4-3d/8-e/4]\ CH_4 + [a/2-b/8+c/4+3d/8+e/4]\ CO_2 + d\ NH_3 + e\ H_2S$$

This equation predicts a yield of 50% CO_2 and 50% CH_4 from carbohydrates and carbohydrate polymers and is reasonably accurate for *in vitro* studies of methanogenic degradation. If the chemical composition and proportion of the biodegradable fraction of the waste is known it should be theoretically possible to use the Buswell equation to calculate the potential yield of methane. Theoretical biogas generation from Indian refuse was estimated to vary from 150 to 265 m^3/t (Bhide, 1994). It is estimated that net methane of 2.05 million kcal of energy can be harvested per year from 5000 t of Garbage/day in Mumbai (Sudhakar, 2000). With coal equivalence of 0.92 and cost of coal at Rs.800 /t the energy potential will have a worth of Rs.245 million/year. Additionally, use of methane gas reduces the production of oxides of nitrogen and sulphur produced in coal fired boilers by over 67 and 78%, respectively. It is reported that approximately 500t of methane and carbon dioxide are released daily from the MSW dumpsites in India (Hebbliker and Joshua, 2001).

Traditionally, landfill gas was considered as part of the landfill nuisance together with other noxious gases, leachate, odours and vermin that inhabit waste dumps. Methane, the most dominant gas in a landfill, is a particularly potent “greenhouse” gas, having roughly 21 times the global warming effects of carbon dioxide. Methane is also highly explosive and has been responsible for 40 landfill fires and explosions that resulted in 10 deaths. A mixture of 5% to 15% (by volume) methane in air will explode if ignited. A methane concentration of 5% in air is considered to be the Lower Explosive Limit (LEL) and 15% as the Upper Explosive Limit (UEL).The calorific value of LFG with 50% methane is estimated to be 4450kCal/m^3 which is about 50% of that of piped industrial gas supply. LFG emissions contribute to local smog and can cause unpleasant odors and trigger complaints from neighbors. In 1991, the U.S. Environmental Protection Agency designated municipal solid waste landfill emissions as a pollutant because the volatile organic compounds in landfill gas interact with nitrous oxides to form ozone, a primary cause of smog.

4.0 Energy from Landfill Gas

There are three main options for utilization of LFG, namely, direct use in a kiln or boiler, use for electricity generation and upgrading of the gas to pipeline supply quality. Burning landfill gas has been proven to be just as easy and safe as natural gas. In addition to environmental benefits, the competitive cost savings are substantial. The most potential use of LFG is for on-site electricity generation. Typically, spark ignition engines are used for 0.2 – 1.0 MW capacity, Gas turbines for 3-4 MW capacity and dual fuel engines in the range of 1-3 MW Capacity (Bhide, 1994).There is little difference between an electric generating plant using landfill gas and one using natural gas or diesel fuel, aside from the need for more extensive gas processing and more careful monitoring of equipment because of the potentially corrosive nature of landfill gas. An LFG-to-electricity system has three basic components: (i) the gas collection system, which gathers the gas being produced within the landfill, (ii) the gas processing and conversion system, which cleans the gas and converts it into electricity, and (iii) the interconnection equipment, which delivers the electricity from the project to the final user.

LFG is typically collected by a series of wells strategically placed throughout the landfill, as gas from decomposing garbage exists at all levels of the landfill (US Army, 1995). The number and spacing of wells depend on specific landfill aspects such as volume, density, and geometry. Wells are constructed by drilling holes into the landfill, to within 2 to 5 meters from the bottom. Perforated plastic pipes are inserted into the wells. The area around the pipes is filled with large gravel to prevent wastes from plugging the perforations. Horizontal underground trenches can also be used to recover LFG as layers of the landfill are added. The wells are connected by a series of pipes leading to larger, header pipes that deliver the gas to the processing and conversion stations. The entire piping system is under a partial vacuum created by blowers or fans at the processing station, causing landfill gas to migrate toward the wells. Once blowers or fans deliver the gas to a central point, it can be processed or converted to another energy form. At a minimum, the gas needs to be filtered to remove any particles and condensate that may be suspended in the gas stream. After moisture removal, additional gas processing may involve the use of refrigerators or absorbers, such as activated carbon filters, to remove trace contaminants. Either internal combustion engines or turbines can be used to power on-site generators, which convert the gas into salable electricity. After the gas is converted to electricity, a dedicated line is used to deliver the electricity to utilities. Interconnection usually includes metering equipment necessary to monitor sales and system protection equipment with emergency shutdown capability to prevent either party from damaging the other's equipment, or operations, or injuring personnel.

The design of gas recovery systems must consider several factors: (Edward et.al, 1995) such as (i) The extraction must be completed in an environment subjected to differential settlement, (ii) Condensate blockage in header pipe as the LFG is saturated and (iii) Spacial variability of gas generation. The opportunities for utilization of LFG depend on the degree to which the gas is cleaned, which is mainly a function of the economics of the application. The nature and extent of processing systems include condensate and particulate removal, dehydration, CO_2 removal, H_2S removal and Nitrogen removal. The utilisation of landfill gas for its energy potential is a relatively new endeavor, having begun in the USA seriously in 1975 and in the UK only in mid-1980. Pilot studies at a site of 32 ha in Delhi filled with Solid wastes to a depth of 6-10m at the rate of 30 t/ha/day gave a sustained flow rate of 0.59 m^3/min through five 50mm diameter wells. The methane concentration in the LFG varied between 50 and 55% giving an energy value of 4449 kCal/m^3.The recovered gas was utilized in a 30kW generator. The site was expected to generate about 8MW electricity (Bhide, 1994).

A survey of 481 LFG exploitation works, supposedly in activity in the world has estimated that about 5000 million m^3 of LFG was exploited annually in 1990 (Nyns and Gendebein, 1993).This represents around 2.4 million tones of oil equivalent enough to fuel a power plant with an output of 1GW electricity. A review has shown that internal combustion engine is applied in 61 landfill plants in America, turbine is used in 24 plants, the total installed capacity is 344MW. In Europe, there are 50 sets of internal combustion engines on operation, the capacity of big unit ranges from 400 to 2,000 kW. Which kind of engine will be applied is determined by the production of biogas. Internal combustion engine is suitable for the capacity from 1,000 to 3,000 kW, if the installed capacity needs to be more than 3,000 kW, turbine is the better choice with higher efficiency. At present, the efficiency of landfill biogas power generation is about 1.68-2 kWh/m^3 in China. In Raleigh, North Carolina, a boiler fueled by landfill gas generates steam at an average rate of 24,000 pounds per hour to meet the needs of a pharmaceutical plant. The energy conversion system uses gas collected from the city-owned landfill. The private developers, Natural Power, Inc., and Raleigh Landfill Gas Corporation, invested $1.6 million in the project. The developers’ annual gross revenue from steam sales ranges from $450,000 to $500,000, of which the city of Raleigh receives annual royalties of $65,000 to $75,000. (US DOE, 2000) Currently available technology for harnessing landfill gas is expensive and may be economically viable in circumstances where either alternative energy is expensive, the end user is close to the landfill site and possibly with government policy intervention in energy pricing.

5.0 Conclusion

About 20% of the total methane emissions from global anthropogenic sources are from Landfills. Landfill Bioreactors not only reduce the methane emissions from Landfills but also produce more methane over a short period which can be harvested. Power generation from LFG can be promoted through pricing policies for power generation from non-conventional sources. Most of the landfill sites in India are not properly designed or operated. Rehabilitation of these dumpsites based on the sustainable landfill concept to harvesting this Landfill gas can convert the environmental problem to an energy solution.

6.0 References

- Bhide A.D., "Methane Emissions from Landfills", Journal IAEM, vol.21, pp 1-7 (1994)
- CPHEEO, "Manual on Municipal Solid Waste Management", Central Public Health and Environmental Engineering Organisation and Ministry of Urban Development, Government of India, New Delhi (2000)
- CPCB, "Status of solid waste generation, collection, treatment and disposal in metro cities", Central Pollution Control Board, Delhi (1999)
- Edward A. Mcbean, Frank A Rovers and Grahame J Farquhar, "Solid waste Landfill engineering and Design " Prentice Hall (1995)
- Hebbliker S and Joshua V, "How well equipped are we?" Decan Herald, 26 August, 2001 (2001)
- Nyns E.J and Gendebien, "Landfill Gas –From environment to energy", Wat.Sci.Tech, Vol.27, No.2, pp 253-259 (1993)
- Suflita, J.M., Gerba C.P., Ham, R.K., Palmisano, A.C.Rathje W.L. and Robinson, J.A., "The World's largest landfill - a multidisciplinary investigation", Environ. Sci Technol.v.26, no. 8 (1992)
- Reinhart, D.R., "Full-scale experiences with leachate recirculating landfills: case studies. Waste Management& Research, 14, 347 – 365 (1996)
- Sudhakar Yedla, "Purpose built landfill system for the control of methane emissions from municipal solid waste", Indira Gandhi Institute of Developmental Research, Mumbai, India (2000)
- US Army, "Landfill off gas collection and treatment systems – Engineering and design" Department of Army, Technical Letter No.1110-1-60, US Army corps of Engineers, Washington (1995)
- US DOE, "Capturing and converting Landfill Gas" Technical leaflet ,U.S. Department of Energy (DOE), The National Renewable Energy Laboratory, DOE/GO 10094-015 DE953000208 (2000)