Methane Production from Solid Waste in Lahore

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Abstract

Methane (CH4) production from landfills to the atmosphere can be utilized, or significantly reduced, by using cost-effective management methods. The gas can be used as a residential, commercial, or industrial fuel. The growth rate of Municipal Solid Waste (MSW) output in Lahore is 5.37%; union councils and towns are developing quickly in and around the city. MSW of the city which was only 3650 Mt/day in 2001 has increased to 4790 Mt/day in 2008. Since the technology for using methane for power generation is available, the recovery of methane (CH4) from landfills for power generation can lead to profitable projects in Pakistan.

Keywords: *Production, Landfill, Methane, Municipal Solid Waste.*

Introduction

Methane is an important greenhouse gas and a major environmental pollutant, second only to carbon dioxide (CO_2) in its contribution to potential global warming. In fact, methane is responsible for roughly 18% of the total contribution in 1990 by all greenhouse gases [1,2]. On a kilogram-to-kilogram basis, methane is a more potent greenhouse gas than CO_2 [3]. Methane has a shorter atmospheric lifetime than other greenhouse gases. Methane lasts for around 11 years in the atmosphere, whereas CO_2 lasts for about 120 years [4]. Due to methane's high potency and short atmospheric lifetime, stabilization of methane emissions will have an immediate impact on mitigating potential climate change [5]. At gaseous concentrations of 5 to 15 percent, methane is explosive. Thus the buildup of methane in landfills and sewage poses a serious safety hazard. Increased use of degasification systems may improve safety by lowering the methane level [2]. Modern techniques for recovering methane form landfills and sewage can significantly reduce the amount of methane. In addition to generating renewable energy, these facilities help to further reduce greenhouse gases by capturing and destroying methane (a greenhouse gas 21 times stronger than carbon dioxide).

Integrated Solid Waste Management is considered as one of the most effective approach of addressing the environmental degradation and to protect cities in a sustainable manner. After the deposition of Municipal Solid Waste (MSW), the biodegradable organic fractions undergo a series of chemical and biochemical degradations. Based on the analysis of the gases released, five distinct phases of the landfill anaerobic degradation process, i.e., initial adjustment, transition, acid formation, methane fermentation, and final maturation, can be identified. In the 4th phase, methane content and production rate of methane are quite significatnt. The methane is generally used as a source of energy in various parts of the world [6, 7]. The release of methane in U.S.A alone was 37% i.e. 11.6 Mt per year [8]. Methane is

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an important greenhouse gas and a major environmental pollutant. Methane emission reduction strategies offer one of the most effective means of mitigating global warming.

Another option to effectively utilize this untapped resource is to produce energy. This can lead to produce solid residues e.g. ash and salts that may be require subsequent landfill. The option of "Composting" of solid is not too practical as it costs 2-3 times more than landfill while the incineration costs 5-10 times higher. Methane recovered from landfills and sewage can be used as an energy source. Biogas from landfills has been used for several decades in most industrial countries. The technological advancement has led to the development of cleaner process using MSW in gasifies, retrofitting etc. with better recovery and economics. Some of the commercially employed process technologies are available in various texts [1, 2, 7, 9].

Lahore City

Metropolitan Lahore has been the capital of Punjab Province since 139 AD. City District Government has divided the city into six towns for management purposes. The map of city is shown in figure 1. Shalimar Town & Nashter Town represented fluent community, Allama Iqbal Town & Ravi Town represented middle-income class; where as Data Gung Buksh Town & Aziz Bhatti Town were considered relatively poor locality.

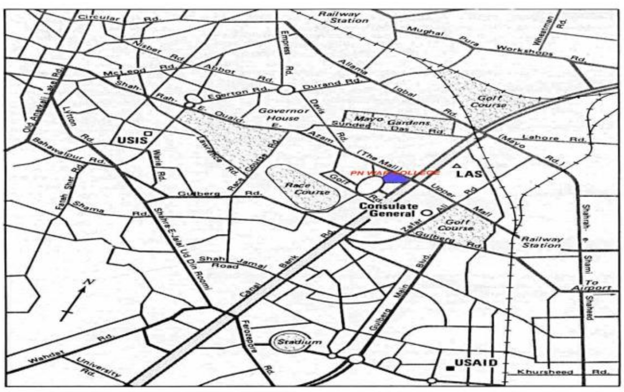

Figure 1. The Lahore City

It is situated on south of river Ravi, and defined by latitude 74o-21o East & longitude of 30o-40o North. Climate is subjected to large variations; weather can be broadly categorized into four distinct seasons. In winter season, an average minimum temperature is 17oC (35oF) and the average maximum of 23.3oC (74oF).

Quantity & Quality of MSW

Since the MSW collected from various towns of Lahore depend upon the population spectrum, the degradation rate also varies. Table 1 shows that the MSW output per person in each town of the Lahore city in 2008, this data is also presented in percentage in figure 2. It may be observed that due to fast developing towns and location of some small industries in these residential towns the rate of MSW generation is quite significant [10].

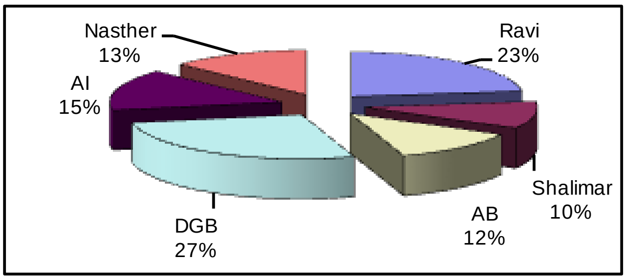

Figure: 2. The MSW output in different regions of the Lahore city in 2008, Mt.

Table 1. MSW Output for the Towns of Lahore

Towns	MSW Output Rate per Person (kg/d.person)
Ravi Town	1.16
Shalimar Town	0.99
Aziz Bhatti Town	0.87
Data Gung Buksh Town	1.23
Allama Iqbal Town	1.01
Nashter Town	0.94
Total	***1.03***

Composition of Biomass in MSW

Proximate Analysis of the same is presented in Table 2 and the Physical Composition of the MSW data of Lahore city is shown in Table 3. The average maximum daytime temperature in summer is about 45.6oC (114oF). The MSW collected from different towns varying in composition and quantity.

Table 2. Proximate Analysis of Lahore MSW

Items	Percentage
Moisture	46.00
C/N Ratio (Dry Basis)	19.80
Volatile Content	10-25
Ash Content	15-25
Calorific Value	Upto 1000 k.cal/kg

Table 3: Physical Composition of Municipal Solid Waste of Lahore [10]

Sr. No.	Description	% Weight	Tons / day
1	Vegetable & Fruit residues	30.72	1296.67
2	Paper	2.70	114.02
3	Plastic & Rubber	5.63	237.69
4	Leaves, Grass, Straws etc.	20.02	845.07
5	Rags	7.45	314.44
6	Wood	1.24	52.30
7	Bones	1.03	43.52
8	Animal Waste	2.35	99.22
9	Glass	0.70	29.61
10	Metals	0.32	13.49
11	Dust, Dirt, Ashes, Stones, Bricks etc.	27.83	1174.75
12	Unclassified	0.01	0.44

Processes of Methane Production In Landfills

Broadly, landfills can be classified into two types. The most common ones, still used throughout the developing world, consist of dumps where the MSW is deposited until it reaches a height that for esthetic or technical reasons is considered to be the desirable maximum. After closing a landfill, some soil is deposited on top. Regulated landfills are provided with impermeable liners and caps, and leachate collection and treatment systems. Also, a system of gas wells and pipes collects as much as possible of the landfill gas (LFG) and conveys it to a boiler or turbine where it is combusted to generate heat or electricity, or is simply flared. When the landfilled area reaches its maximum height, it is covered with an impervious layer so as to minimize entry of rainwater and, thus, continuation of the bioreactions within the landfill. Also, landfill operators are required to continue collecting and treating gas and liquid effluents for a period of 30 years after closure of the landfill.

Global landfills

The per capita generation of MSW in the US of 1.19 tonnes is twice as large as the total generation (i.e. before any recycling) of MSW per capita in the affluent nations of E.U. and Japan. This is expected because the consumption of materials and fossil fuels in the US, with 5% of the world population, amounts to 20–25% of the total global consumption. To arrive at a rough estimate of global landfilling, we started with the known rate of landfilling in the US (220 million tonnes). The European Union (EU), and the rest of the "golden billion" who enjoy a high standard of living generate an estimated 420 million tonnes of MSW of which at least 210 million tonnes (50%) are landfilled. Waste management studies in developing nations, including some in Africa, have shown that the MSW generation is always higher than 0.2 tonnes per capita, most of which is food and yard wastes and is landfilled. This results in the estimate of 1080 million tonnes for the 5.4

billion people in the developing world. Adding up these estimates indicates that the global MSW landfilled is somewhere close to 1.5 billion tonnes of MSW.

Anaerobic biodegradation of MSW in landfills

Shortly after MSW is landfilled, the organic components start to undergo biochemical reactions. In the presence of atmospheric air that is near the surface of the landfill the natural organic compounds are oxidized aerobically, a reaction that is similar to combustion because the products are carbon dioxide and water vapor. However, the principal bioreaction in landfills is anaerobic digestion that takes place in three stages. In the first, fermentative bacteria hydrolyze the complex organic matter into soluble molecules. In the second, these molecules are converted by acid forming bacteria to simple organic acids, carbon dioxide and hydrogen; the principal acids produced are acetic acid, propionic acid, butyric acid and ethanol. Finally, in the third stage, methane is formed by methanogenic bacteria, either by breaking down the acids to methane and carbon dioxide, or by reducing carbon dioxide with hydrogen. Two of the representative reactions are shown below.

Acetogenesis: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

Methanogenesis: $CH_3COOH \rightarrow CH_4 + CO$

$CO_2 + 4H_2 \rightarrow CH_4 + 2\ H_2O$

The maximum amount of natural gas that may be generated during anaerobic decomposition can be determined from the approximate, simplified molecular formula that was, presented above:

$$C_6H_{10}O_4 + 1{:}5\ H_2O = 3{:}25\ CH_4 + 2{:}75\ CO_2$$

This reaction releases a very small amount of heat and the product gas contains about 54% methane and 46% carbon dioxide. The biogas, or landfill gas, also contains water vapor near the saturation point corresponding to the cell temperature, plus small amounts of ammonia, hydrogen sulfide and other minor constituents. Therefore, in order for anaerobic reaction to continue, it is necessary to supply the principal reagent, water.

Methanogenesis

At the methanogenesis stage the typical landfill gas composition is about 60% methane and 40% carbon dioxide. Low level of hydrogen is required to promote both mesophilic and thermophilic organisms for methane formation at earlier stages. Ideal conditions noted for methanogenic effective microorganisms are at pH range from 6.8-7.5. The rate of degradation of Lahore MSW resulting in the production of methane is shown in figure 2 and table 4 shows average composition of landfill gas.

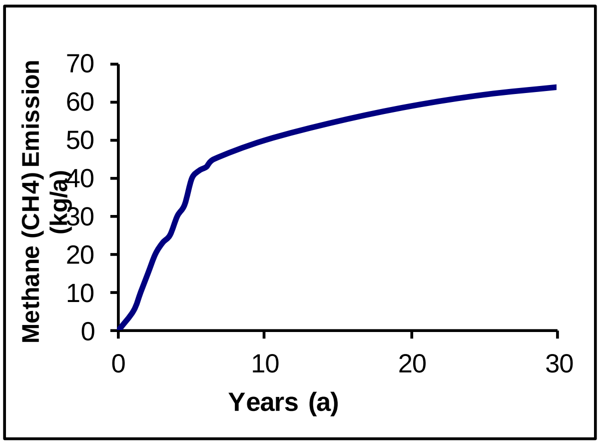

Figure:3. The total accumulative output of methane (CH_4) in the landfill of Lahore

Table 4: Composition of landfill gas [11]

Sr. No.	Compound	Average concentration (%)
1	Methane (CH4)	50
2	Carbon dioxide (CO2)	44
3	Nitrogen (N2)	5
4	Hydrogen sulphide (H2S)	1
5	Non-methane organic compounds (NMOC)	2700ppmv

Models for Methane Production From Landfills

There are two models for methane emission / production form landfills.

First Order Decay Model

"First Order Decay Model" is the most popular model to estimate the gas generation in landfills [1, 2].

$$\boldsymbol{P} = \boldsymbol{C}_d \boldsymbol{X} \sum \mathbf{F}_i (\mathbf{1}\text{-}\mathbf{e}^{-K_i t})$$

Where

P = Total amount of land fill gas generated so far (t. CH_4 / t MSW)

C_d = Content of degradable organic carbon in the waste

F_i = Content of different organic carbon in waste

K_i = Decay constant for the rate of methane generation (1/year)

t = Time since land filling (years)

The "First Order Decay Model" describes varying gas generation rates over the lifetime of the landfill, the model, therefore, takes into account various factors, which influence the rate and extent of gas generation. The Model requires that the above variables be known or estimated [2]. The extrapolated total accumulative methane (CH4) emission from landfills data in Lahore is plotted in accordance with above model in Figure 3.

IPCC Model

According to IPCC Guidelines, the formula for calculating GHG emission form solid waste landfills is as follows [5, 12].

$$\boldsymbol{E}_{\text{Methane}} = \boldsymbol{MSW} \times \boldsymbol{n} \times \boldsymbol{DOC} \times \boldsymbol{r} \times \mathbf{(16/12)} \times \mathbf{0.5}$$

Where

E_{CH4} = Methane emission from landfills.

MSW = Urban waste quantity, determined from statistical reference.

N = Percentage of urban waste actually land filled; in this paper MSW equals the quantity of urban waste sent to landfills, so n = 100%.

DOC = Content of degradable organic carbon in the waste, recommended to be 15% by IPCC.

R = Percentage of actually decomposed DOC in the waste (recommended to be 77% by IPCC)

Methane Gas Production

The production of methane gas in the Lahore city has been estimated through Darcy's law. The estimation of CH4 through the above law is only an estimate and it includes parameters like climate, refuse mass, age etc. [13]. Although test wells provide real data on onsite gas production rate at a particular time point, models are properly employed to estimate the gas production. These models typically require the time period of land filling, the amount and types of waste being dumped. In this paper the usefulness of two models of methane generation from landfills are analyzed and both the models calculated the same results.

Mathametaical Modelling

Using the basic data of the city estimation of Methane emission is estimated and shown in Table 5. Calculated results leads empirical mathematical model, which is very helpful in calculating the economic aspects of Methane emission from MSW, as the accumulated total Methane emission does not change much. The empirical mathematical model of Methane emission from landfill of MSW is:

$$\text{MethaneProduction} \cong 0.0786\ MSW^{0.9973}$$

The Methane gas that may be recovered from the landfills can be used in various applications. Theoretically, any equipment using natural gas as fuel can be operated using landfills methane. The preferred methane use option at each landfill will depend on a variety of factors including the quantity and quality of the methane recovered. The generation heat rates varies somewhat among generation technologies, but can be assumed to be about 11.6 MJ/m3 [11] because its value varies with process.

Table 5: CH_4 emission for the Towns of Lahore

MSW Output (Kt/a)	Methane (CH_4) Emission (kt/a)	Annual Increase Rate
158	12.25	1.01 %
316	24.46	0.76 %
272	21.06	0.98 %
300	23.22	1.13 %
311	23.83	0.82 %
183	14.18	0.67 %
1540	**119**	**5.37 %**

The most attractive emission reduction projects are those in which the energy in recovered gas can be utilized in it vicinity. There are important approaches like cogeneration technology e.g. IGCC, MEET, etc [9]. using steam, hot water, LPG/CNG and in certain cases direct use of methane is suitable. However, many more landfills can implement economically viable Methane recovery. Important issues to be discussed including energy production and pricing, environmental policies, financial issues and technology transfer problems are also valuable for optimum process design. Oxygen blown gasifires capable of processing a minimum of 500t/day at operating pressure 15-20 bar [9, 14, 15]. Methane comes from landfills commonly used for number of purposes as follows [11]:

- Utilization of landfill gas
- Direct heating applications
- Use for industrial boilers
- Space heating and cooling (e.g. greenhouses)
- Industrial heating/cofiring
- Electricity generation applications
- Processing and use in reciprocating internal combustion (RIC) engines (stoichoimetric or lean combustion)
- Processing and use in microturbines, gas, and steam turbines
- Processing and use in fuel cells
- Feedstock in chemical
- Manufacturing processes
- Conversion to methanol (industrial or vehicular use)
- Conversion to diesel fuel (vehicular fuel)
- Purification to pipeline quality gas
- Utilization as vehicular fuel
- Incorporation into local natural gas network
- Soil remediation
- Leachate evaporation system.
- Heat recovery from landfill flares
- Using organic Rankin cycle
- Using Stirling cycle engines

Conclusion

On the basis of the theoretical and experimental information presented above, it can be predicted that, under the right conditions, at least 50% of the "latent" methane in MSW can be generated within one year of residence time in a landfill, while the landfilled area is not capped and rainfall can penetrate into the landfilled mass. The energy content of the gas is estimated from methane content. Pure methane has a heating value of approximately 37 million Joules per cubic meter (MJ/m3) at STP. The gas from landfill generally has a heating value of about 18 MJ/m3 (about 50%). The rest is flared, because it is not considered to be of economic use. There are nearly 100 landfills that do not capture any biogas. If it were possible to build and operate bioreactor landfills, where water is added and nearly all the generated methane is captured. The gas can be burned in modified versions of commercially available gas turbines. Methane fueled integrated gasification and combined cycle technology and multistage enthalpy extraction technology for power generation are superior economic and solid waste management techniques.

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