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Design of a Bioreactor Landfill for Delhi City

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Abstract

In India, dumping grounds or landfill areas are mainly open low-lying areas in the cities. The Municipal solid wastes consist of wastes from domestic, agricultural, commercial sources and construction debris. Municipal solid waste is generally dumped in landfill areas without segregating it into biodegradable and non-biodegradable. These organic components in the municipal refuse results in methane formation under anaerobic condition.

A Bioreactor landfill is a landfill where the decomposition of wastes occurs rapidly by providing optimum moisture to the wastes, by recirculation of leachate. An overview of the bioreactor landfill is studied in this paper. Further a bioreactor landfill is designed for the municipal solid waste of Delhi city, taking into consideration of the existing rules and regulations and the design and operational issues.

Keywords

Bioreactor landfill; Municipal solid waste; Methane; leachate; refuse; biodegradable; anaerobic.

Introduction

Land filling of municipal solid wastes is the major means of waste management processes practised in India. It has been concluded from early studies that a total of 40–60 million tons of Methane is emitted from landfills and old waste deposits worldwide, accounting for approximately 11–12% of the global anthropogenic methane emissions. This ranks landfills third after rice paddies (60 million tons per year) and ruminant livestock (85 million tons per year [4]. Methane is regarded as one of the most important GHGs because its global warming potential has been estimated to be more than 20 times of that of carbon dioxide and atmospheric methane concentration has been increasing in the range of 1–2% per year. [8].

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Method and Methodology

An Anaerobic Bioreactor landfill has been designed for a portion of the incoming municipal solid wastes of Delhi city. The site has been selected and has been divided into different phases. The active life of the landfill has been taken as 5 years and a post closure period of 10 years. Each phase is taken as a year, and each phase has been divided into 365 cells such that daily incoming wastes will be filled and covered daily. The optimum moisture is maintained inside the cells by leachate recirculation. The leachate collection system and a gas collection system (since it is an Anaerobic landfill, Landfill gas is produced) have been designed carefully. Once a whole phase gets completed, the final layer is laid and will be covered before the next phase gets started. While the waste filling processes on 1st phase goes on, the construction of the liner system on phase 2 will be done simultaneously. The wastes here are segregated here before filling for obtaining better organic content. Similarly the whole phases get completed and the land fill goes for post-closure care. The landfill gas will be collected during the active life of the landfill and will be almost negligible within 3 years of closure. The plan, section, and layout of the landfill and infra-structure facilities provided in the landfill area are shown in the paper.

Preliminary Data

In point of the view made in the introduction, a Bioreactor landfill has been designed in this project for the Delhi city.

Site description

Delhi, officially the National Capital Territory of Delhi, is the second most popular metropolitan city of India after Mumbai. With a population of 16.3 million in 2011, it is also the eighth most popular metropolitan city in the world. The annual mean temperature of Delhi is 25 ^{0}C and the monthly mean varies from 13 ^{0}C to 32 ^{0}C. The average annual rainfall is 750 mm with monsoon seasons ranging from June to September [8].

The quantity of municipal solid wastes generated in Delhi has been consistently rising over the years. The total average waste generation is about 8000 tons per day. Land filling is the main means of waste management in Delhi. At present there are 3 landfills at Bhalaswa (7.2 hectare), Okhla (7.2 hectare) and Gazipur (28 hectare) in which the Gazipur land fill site life span ends in 2014 [7]. The waste generation data is plotted for Delhi as in figure below.

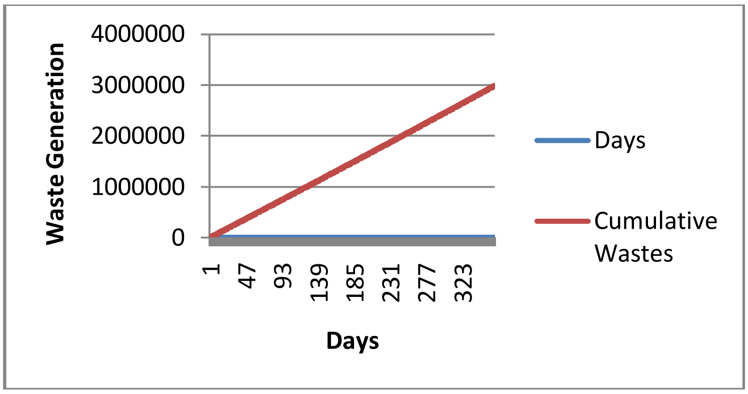

Figure 1: Waste Generation (Delhi)

Basic data:

Location : Delhi

Waste Generation : 8000 tons per day (As of year 2011)

There are 3 landfills in Delhi, assuming equal distribution of waste. Therefore waste reaching one landfill per day = 8000/3 = 2666.667 tons per day.

Design life : Active period = 5 years

Topography : Flat ground

Subsoil : Sandy silt up to 20m below ground surface, underlain by bedrock

Water table : 10m below ground surface [1]

Contents	Paper	Textile	Leather	Plastic	Metal	Glass	Ash, Fine earth & other	Compostable matter
Percentage by weight (%)	6.6	4.0	0.6	1.5	2.5	1.2	51.5	31.78

Table 1: Waste Composition of Delhi MSW [3].

Chemical formula of Municipal solid waste : $C_{25}H_{40}O_{16}N$

Design

Estimation of Landfill Capacity

Current Waste generation per day, (W) : 8000 tons

Estimated Waste generation after 5 years, per day : 10000 tons

Total waste generation in 5 years, (T) = 0.5*365*5*(10000-8000) + 365*5*8000 = $16.425 * 10^6$ tons.

Waste generation for one landfill (T_1) = T/3

= $5.475 * 10^6$ tons.

Total waste Volume, (V_w)

(Density of Indian MSW = 0.5 t/m^3) = $T_1/0.5$

= $10.95 * 10^6$ m^3

Total Volume of Daily cover for 5 years, (V_{dc}) = $0.1 * V_w$

= $1.095 * 10^6$ m^3

Total volume required for components of liner system and of cover system (assuming 1.5 m thick liner system), (V_C) = $K * V_w$

= $0.125 * 10.95 * 10^6$

= $1.369 * 10^6$ m^3

(For landfill height of 10-20 m, K value is taken as 12% of the total waste volume and for a height of 10 m, K value can be taken as 25% (USEPA., 2010).

First estimate of landfill capacity, liner and cover systems (C_i) = Total waste volume + Volume of $(10.95 + 1.369) * 10^6$

= $12.32 * 10^6$ m^3

Preliminary Design of Landfill Dimensions

Likely shape of landfill	:	Rectangular in plan (Length: Width = 2:1) Primarily above ground level, partly below ground level
Area Restrictions	:	Nil
Possible maximum land filling height	=	10 m
Area Required	=	$(12.32 * 10^6) / 10$
	=	$12.32 * 10^5$ m^2
Approximate plan dimensions	=	780 m * 1560 m

Assuming 30 % of the total area for infrastructural facilities other than land filling area,

Total Area required (Including infrastructural facilities) = $1.3 * 12.32 * 10^5$

= $16.016 * 10^5$ m^2

Total plan area of the site = 895 m * 1790 m

The actual land filling section and plan is evaluated on the basis of the following assumptions

i. 4:1 side slope for the above-ground portion of the landfill.
ii. 2:1 side slope for the below-ground portion of the landfill.
iii. Material balance for daily cover, liner and final cover material through excavation at site.
iv. Extra space around the waste filling area for infrastructural facilities [1].

Landfill Phases

Active life of landfill	=	5 years
Duration of one phase	=	one year
Number of phases	=	5. Each phase extends from base to final cover
Volume of one phase	=	Landfill capacity / 5
	=	$12.32 * 10^6 / 5$
	=	$2.464 * 10^6$ m^3

Plan area of one phase = Volume of one phase / landfill height

= 350 m * 700 m

Number of daily cells = 365

A single cell waste will be filled in a day. Thus by one year one whole phase gets completed.

Volume of one cell = Volume of one phase / 365

= 6750.685 m^2

Plan area of one cell on the basis of 2m lift of each cell = Volume of one cell / 2

= 3375.34 m^2

= 42 m * 84 m (approx.)

Check:

Cell volume = 42* 84 *2 = 7056 m^2 * 365 cells = 2.575 * 10^6 m^3

= Volume of one phase (approx.)

Landfill Infrastructure and Layout

i. A site fencing provided all around the landfill
ii. Two computerized weighbridges at entry and exits, with office
iii. An administrative office building
iv. A site control office (portable cabin)
v. Access roads to the site having main roads and arterial roads all along the periphery
vi. Waste inspection and sampling facility at site
vii. Equipment workshop and garage building
viii. Vehicle cleaning facility within the workshop [2].

Design of Liner

A composite liner is the minimum requirement for a Bioreactor landfill. It may be a single composite or a double composite liner. Here a single composite liner is provided for design consisting of a Compacted Clay Liner (CCL) and a Geomembrane.

A composite liner consists of 2 components.

i. A flexible membrane liner with a minimum of 30 mm or 60 mm if HDPE is used.
ii. A compacted soil layer of at least 60 cm deep with sufficient hydraulic conductivity.

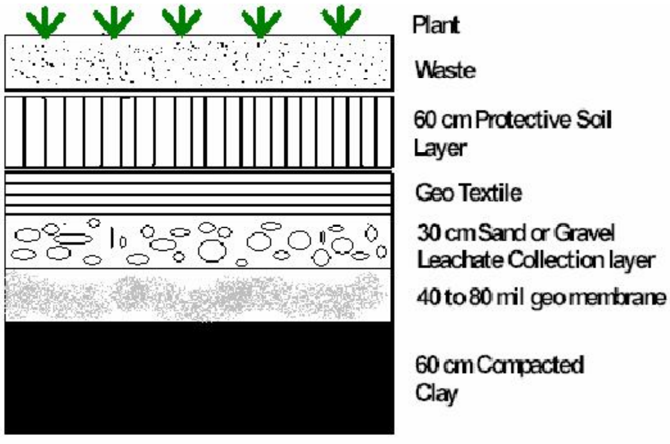

Figure 2: Composite Liner [1].

A hydraulic head of 30 cm or less should be maintained by the leachate collection system within the landfill.

Design of Leachate collection system

The leachate collection and removal systems should be designed efficiently to collect, remove and manage leachate [2]. In other words, this is the drainage system and is located above the liner system. The peak leachate that will be drained out per day is calculated, taking into account of the precipitation rate, the infiltration and the water loss due to evaporation. The leachate collection pipes are designed for this discharge.

Moisture requirement

The incoming fresh municipal solid wastes will be having a moisture content of 10 % - 25 % by weight. For accelerated decomposition of waste in Bioreactor landfills, this moisture content has to be increased to an optimum moisture content of 35 % - 45 % [12]. This requirement is satisfied by the recirculation of leachate into the waste mass. Moreover the recirculation is done by considering several factors during the lifetime of landfill. This includes the total precipitation received, the losses such as evaporation and seepage etc.

Here the moisture content of the incoming waste is taken as 15 %.

The optimum moisture content for accelerated decomposition of waste = 45%

So, each cell will be requiring additional 30% moisture which has to be supplied.

Precipitation data:

The average monthly rainfall precipitation data for Delhi from the year 1956 to 2000 was collected.

Month	Mean Rainfall (mm)	Standard Deviation
January	18.9	5
February	16.6	5
March	10.8	3
April	30.4	8
May	29	8
June	54.3	15

July	216.8	59
August	247.6	68
September	133.8	37
October	15.4	4
November	6.6	2
December	15.2	4

Table 2: 50 year Average Rainfall Data for Delhi [5].

Generation of Rainfall Probability model

If 'm' is the mean rainfall and 'v' the variance of monthly rainfall, assuming log-normal distribution, a 30 days artificial rainfall data has been generated which comply with the data given in the above table.

The computer program MATLAB has been used for the generation of the one year cumulative data (single phase).

From the graph and the data, it is clear that the monsoon period for Delhi will be for four month duration from June to September, during which a peak precipitation occurs. During the monsoons, the moisture inside the landfill is well above the optimum moisture content needed and therefore the recirculation can be avoided for the monsoon period.

A month or two after monsoon period may also be satisfied by the monsoon precipitation. Here the cells which are filled after October, recirculation is needed.

From the rainfall data the graph for one year precipitation can be plotted as shown below:

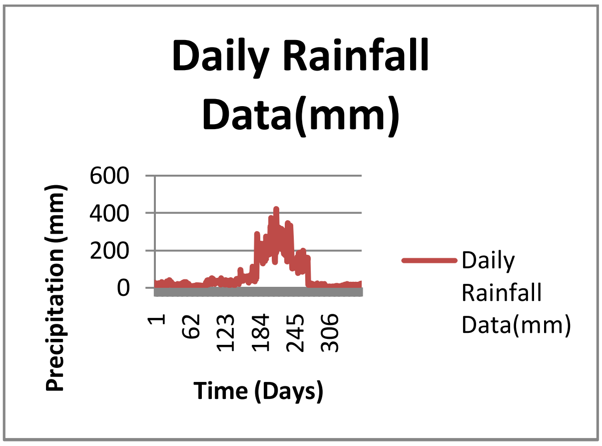

Figure 3: Daily Rainfall Data

And the cumulative rainfall for the year can be plotted as in the figure below.

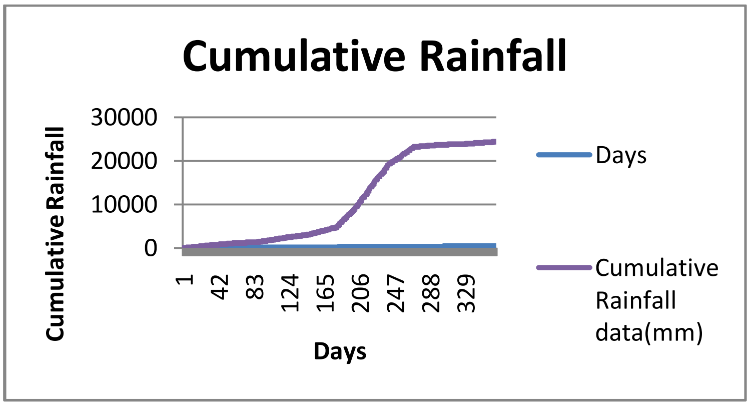

Figure 4: Cumulative Rainfall Data

Maximum percolation rate,

Coefficient of permeability for clay layer	=	0.022 gal/day/ft^2
(1 gal/day/ft^2 = 1 * 0.0408 m^3/day.m^2	=	0.022 * 0.0408
	=	$8.976 * 10^{-4}$ m^3/day. m^2
Drainage Area of one phase		
(780 m * 350 m)	=	273000 m^2
Maximum drainage for each pipe	=	$8.976 * 10^{-4} * 273000$
	=	219.912 m^3 / day
	=	219.912 / (24 * 3600)
	=	$2.5453 * 10^{-3}$ m^3 / second.

In one phase 9 cells (approx.) can be arranged. Along each layer of cells one pipe will be collecting the discharge. Therefore the above discharge can be drained out by 9 numbers of pipes.

Diameter of HDPE pipes provided = 40 mm, 9 Numbers

(HDPE = High Density Poly Ethylene)

Recirculation of leachate

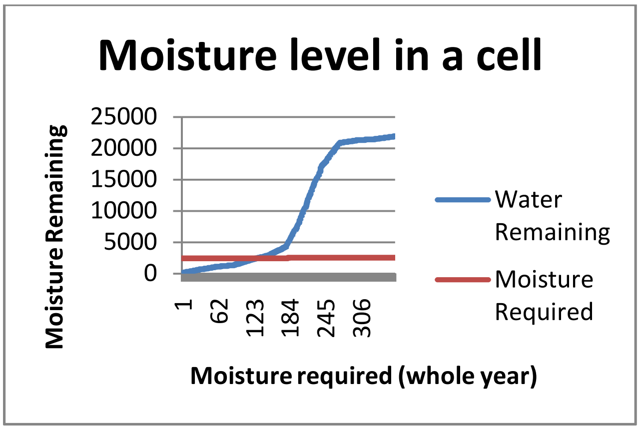

Figure 5: Moisture level in a cell (mm)

Moisture level inside the landfill keeps varying according to the precipitation received. Recirculation has to be done when the moisture content inside goes below the optimum moisture content (45%) required for accelerated decomposition. Here by plotting the moisture within a cell as per the precipitation received for a whole year (mm), it can be inferred that as the monsoons are on, the moisture inside is sufficient for controlling the required moisture content. After the monsoons again when the moisture content becomes below the optimum, recirculation has to be done to maintain it. This deficit can be known by frequent monitoring of the landfill, with the help of monitoring systems.

Gas collection System

Since, the design is considered to be an anaerobic bioreactor, methane gas is produced during the entire life of the landfill. The volume of methane generated for one tonne of waste can be calculated by the chemical reaction:

$$\underset{610}{C_{25}H_{40}O_{16}N} + \underset{139.5}{7.75\,H_2O} \longrightarrow \underset{210}{13.125\,CH_4} + \underset{522.5}{11.875\,CO_2} + NH_3$$

So, CH_4 produced per tonne of waste = 344.2622 kg of CH_4 /tonne of waste generated.

= 688.52 tonnes / day

Similarly, CO_2 produced per tonne of waste = 856.550 kg of CO_2 / tonne of waste generated

= 1713.1 tonnes / day

Therefore, the total mass of gas generated per day = 688.52 + 856.550

= 2401.62 tonnes / day.

(i.e. In a day almost 2500 tons of Landfill gas (LFG) will be produced.

Methane and Carbon di-oxide constitutes the major portion of LFG and other gases can be

neglected for calculation).

So, the gas collection system should be designed to collect 2500 tonnes per day.

Cover Material

Cover material is an essential element of land filling operations. A daily cover material has to be provided above the waste at the end of the day after each cell has been completed. A daily cover of 30 cm of soil layer is provided for the design. Daily cover should ideally be permeable to allow water to pass through thereby preventing ponding/perched water build-up. The total volume of daily cover used up for this design would be approximately $1.095 * 10^6$ m^3 of soil and for a single phase would be almost 219000 m^3 of soil material.

Intermediate cover refers to placement of material (minimum 300mm if soil used) for a period of time prior to restoration or prior to further disposal of waste. Intermediate cover should significantly reduce rainfall infiltration. Here an intermediate cover of 60 cm is provided.

Alternative Final Covers (AFC's) are best preferred for Bioreactor landfills. Since the bioreactors need moisture, Alternative final covers can be designed and constructed in such a way as to control all types of infiltrations as required by the landfill. During monsoons also, this final covers can allow allowable infiltration as well as shut sown infiltration if precipitation is too high [2].

Cover system Design

The cover system comprises of the following layers above the waste.

i. A 0.60m thick gas collection layer comprising of gravel. (stone dust with no fines).
ii. A 0.60m thick barrier layer. (sandy silt + 5 % bentonite)
iii. 0.30 m thick surface layer of local top soil for vegetative growth [6].

Environmental Monitoring System

Monitoring of Bioreactor landfills is one of the important process during the active life of the landfill. Monitoring should be done frequently and efficiently for the active functioning of the landfill. Ground water monitoring wells, gas monitors etc. should be installed. Keeping the records of the liquid balance, both the liquid added and the amount of leachate removed is critical. Also keeping record of the moisture content inside the landfill is important. Technologically improved mechanical instruments can be installed at the site for accurate monitoring of data. For example pressure transducers can be installed for measuring the head on liner, which is an important parameter. Similarly moisture sensoring instruments can also be installed which senses the status of moisture inside the landfill. Trained or experienced labour should be employed at the landfill site, mainly for data recording and monitoring.

Post Closure Care

The closure of a landfill begins with the installation of final covers. Once a phase is completed, the final cover will be placed over it and the phase will be shut down before the next phase is started. Regular monitoring and record keeping is to be continued for a closed phase or a landfill until it is made sure that it will no longer affect the environment in any means. Ground water monitoring, quality of leachate, amount of gas produced etc has to be constantly monitored during the post closure period. The post closure period for Bioreactor landfills can be reduced immensely compared to a dry convectional landfill due to its accelerated decomposition and stabilization of the waste mass.

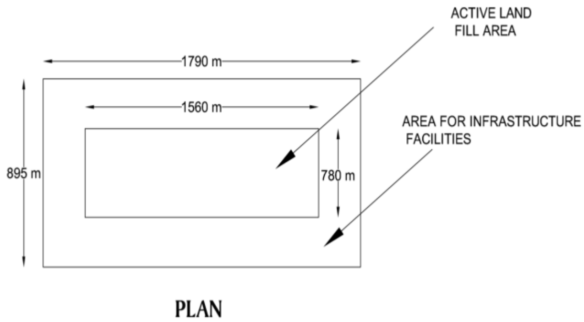

Figure 6: Plan of the Bioreactor Landfill

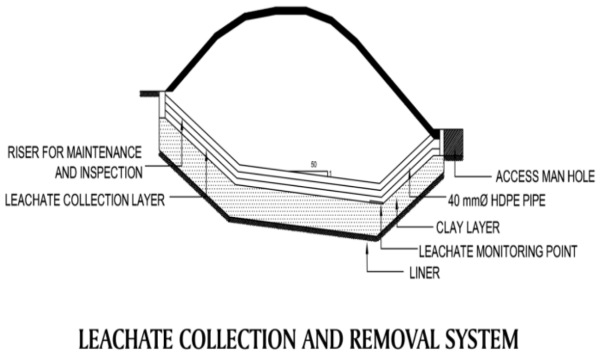

Figure 7: Leachate Collection system

Conclusion

The Bioreactor landfills are successful in gaining attention in the field of Solid Waste Management and are becoming a next level to the engineered sanitary landfills. The potential for these landfills for accelerated waste stability and the time for land recovery are the view points. A Bioreactor landfill can stabilize the whole waste within 5-10 years compared to 30-60 years in case of convectional landfills. For a developing country like India, where population growth is far beyond controlling, and availability of land is a big issue, the implementation of Bioreactor landfills can really help in the land controlled and an efficient Waste Management system.

An Anaerobic Bioreactor landfill is designed here according to Indian waste conditions for Delhi, for the year 2011 data. It shows that the total area required for land filling of the 1/3 rd of the total waste of Delhi (incoming waste to this landfill) is around $12.32 * 10^5$ m^2. Almost 2500 tonnes of landfill gas per day can be generated from this system. A single composite liner of thickness 1.5 m, consisting of a compacted clay liner (60 cm) and a geomembrane (40-80 mm) is provided for the design. The total volume of material required for cover material would be around $1.095 * 10^6$ m^2. All necessary infrastructures are also provided and the total area of landfill including infrastructural facilities would be approximately 16.016 * 10^5 m^2.

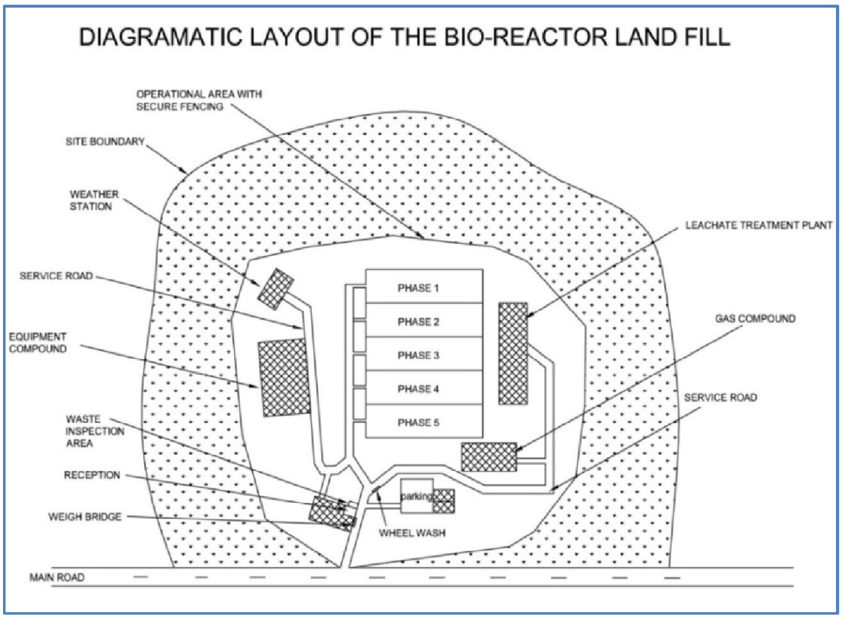

Figure 8: Layout of the Bioreactor Landfill

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