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Prototype of a Waste to Energy Landfill Proposed for Kolhapur City

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***Abstract:** Landfill gas is the gas that is extracted from landfills after the waste in landfill starts degrading. Space utilization to dispose of waste is one of the major concerns in every metropolitan. The general trend of disposing of waste is by dumping it openly and then either burning it or by keeping to degrade. In this paper, we intend to design a landfill for treating the waste of Kolhapur city in 4 different landfill sites and extract the gas from each landfill to further use it for energy generation. Further, we also intend to provide a natural liner material by using a combination of bentonite and GCL. We have compared the economics of landfilling procedure and energy generation thus providing an alternative to transform waste into energy. The waste that is dumped openly proves to be hazardous as the continuous fumes due to fugitive emissions leads to degradation in the air quality and also leads to spontaneous combustion. The dumping site in Kolhapur is spread over 60 acres and the problem of spontaneous combustion is a menace for the people living in the neighbouring areas. A landfill site would solve the problem of disposing of the waste and also lead to effective space utilization.*

***Keywords:** Natural Liner, Bentonite, GCL, Economics, Hazardous, Fumes, Fugitive Emissions, Degradation, Spontaneous, Effective, Spontaneous Combustion, Utilization.*

INTRODUCTION

Landfill Gas (LFG) is generated by the degradation of waste that is buried in a landfill. This procedure is the best alternative as of now in order to counter space utilization and reduce the waste incineration that happens due to the accumulation of the waste in one place.

The presence of aerobic conditions leads to the emission of CO. In the anaerobic condition, the degradation of waste leads to the emission of methane and carbon dioxide. Out of this methane forms the major part of the emissions. The calorific value of methane is 33.95 MJ/Nm^3 which gives rise to high energy generation benefits. The amount of methane produced depends on the nature and composition of waste.

There is an accumulation of waste at Zoom Prakalp Dumping ground in Kolhapur which is the only dumping ground in Kolhapur. The creation of landfill for commercial purpose is the need of the hour as the waste generated in Kolhapur is 160 tonnes per day. The generation of the landfill will require a large area and hence to avoid the construction of a landfill in one area due to space congestion, we proposed constructing four different landfills of a smaller area of 115 x 60 meters.

These landfills would suffice the need of disposing waste from their neighboring areas. The benefits of using a landfill include using the landfill gas for energy generation, using the gas for domestic purposes, preventing pollution due to waste accumulation, space utilization, and cost effective waste disposal.
The landfills designed here have a life of 20 years thus when we compare the cost of current disposal practices with our proposed landfill process, the latter proves to be cost effective while helping protect the environment.

Existing and Proposed Waste Management Practice

Solid waste collection in the city is a well-defined and planned function. In Kolhapur city, everyday 165 tons of solid waste is generated and all 165 tons are lifted every day. The dry and wet solid wastes are collected from individual houses and public dust-bins and transported to Kasaba Bavada which is the current dumping site for the waste. The solid waste collection and transport work in done an everyday day from morning 6 to 2 in the afternoon. The solid waste from big hotels, restaurants, mess etc. is collected by the door to door collection by charging nominal fees. These hotels and restaurants are prohibited from dumping the waste in public dust bins. Plastic bags, bottles, scrap materials are separated from dry waste for recycling. The earthworm composting is planned to be implemented as a scientific method of domestic solid waste disposal.

The solid waste treatment plant to treat minimum 165 tons of solid waste generated per day in the Kolhapur city is established in an area of 38,800 sq. m. (4 hect.) on 30 year lease contract. Kolhapur Corporation has erected a treatment plant at Kasaba Bavada drainage plant through a private company, Das Enterprises. The company collects and transports the biomedical wastes from the corporation and private hospitals through closed vehicles and treats and disposes the waste scientifically at the treatment plant site. The current disposal site which is a mere dumping ground has heaps of waste rising upto 15-20 meters high and many such heaps spread over the area of dumping ground. These waste heaps are creating menace due to the fugitive emission of the waste. The leachate that is secreted is found as puddles on the ground in the dumping site. The problem of burning of waste due to spontaneous combustion of the waste materials leads to continuous burning of waste and emission of smoke thus contributing to the degradation of air quality in the area.

In order to tackle the issues of waste disposal with least harm to the surrounding environment, there can be an alternative treatment to dispose of the waste by also reducing the space consumption. By creating a landfill in the neighbourhood of the existing dumping site of a volume that would suffice the disposal of daily generated waste of 165 tons per day as mentioned above.

Design Procedures

BASIC DATA

Location: Kolhapur

Waste Generation: 165 tons per day (current)

Design Life: Active Period = 20 years (n)

Closure and Post Closure

Period=25 years

Topography: Flat ground

Subsoil: Black cotton on surface, laterite upto 20m below

Ground surface, underlain by

Bedrock

Water-table: 10m below ground surface

Average Total Precipitation: 780 mm per year

Base year

1. Current Waste generation per year = W (tons per year)

2. Estimated rate of increase (or decrease) of waste generation per year = x (percent)
(Use rate of population growth where waste generation growth rate estimates not available)

3. Proposed life of landfill (in years) = n (years)

4. Waste generation after n years = $W (1 + x/100)^n$ (tons peryear)

5. Total waste generation in n years (T) in tons
$T = 0.5 [W + W (1 + x/100)^n] n$ (tons)

6. Total volume of waste in n years (Vw) (on the assumption of 0.85 t/cm.m
Density of waste)
Vw = T/0.85 (cu.m.)

7. Total volume of daily cover in n years (Vdc) (on the basis of 15 cm soil cover on top and sides for lift height of 1.5 to 2 m)
Vdc = 0.1 Vw (cu.m.)

8. Total volume required for components of liner system and of cover system (on the assumption of 1.5m thick liner system (including leachate collection layer) and 1.0 m thick cover system (including gas collection layer)
Vc = k Vw (cu.m.)
(k = 0.25 for 10 m high landfill, 0.125 for 20 m high landfill and 0.08 for 30 m high landfill. This is valid for landfills where width of landfill is significantly larger than the height)

9. Volume likely to become available within 10 years due to settlement/biodegradation of waste
$Vs = m\ Vw$
(m = 0.10 for biodegradable waste; m will for less than 0.05 for incinerated/inert waste)

10. First estimate of landfill capacity (Ci)
$Ci = Vw + Vd + Vc - Vs$ (cu.m.)

11. Likely shape of landfill in plan and section (To be based on topography of area, depth to ground water table and other factors)
Area type, trench type, slope type, valley type, combination

12. First estimate of landfill height and area
(a) Restricted area available = Ar (sq. m.) Area required for infrastructural facilities = 0.15 Ar
Area available for landfilling = 0.85 Ar Average landfill height required (first estimate) above base level
$Hi = Ci / 0.9\ Ar$ (m) (valid for area type landfill)
(b) No limitation on Area
Possible maximum average landfill = Hi (typically between height (first estimate) 10 to 20 m, rarely above 30 m) Area required for landfilling separations
$Ai = CI / Hi$ (sq.m.) (Valid for area type landfill)
Total area required (including infrastructural facilities) (first estimate)
$Ai = 1.15\ Ai$

LANDFILL CAPACITY, LANDFILL HEIGHT, LANDFILL AREA
(a) Current Waste Generation Per Year = 60,225 t (W)

(b) Estimated rate of increase or decrease = 18% (x)

(c) Proposed life of landfill (in years) = 20 years (n)

(d) Waste generation after n years $= W (1 + x/100)^n$ (tons per year)
$= 60225(1+18/100)^{20}$
$= 1.6\text{x}10^6$ (tons per year)

(e) Total Waste Generation in 20 Years
$T = 0.5 [W + W (1 + x/100)^n]\ n$ (tons)
$= 0.5 (60225 + 1.6\text{x}10^6) \text{ x } 20$
$= 16.6 \text{ x } 10^6$ tons

(f) Total Waste Volume in n years (assumed density 0.85 t/cu.m.)
$Vw = T/0.85$ (cu.m.)
$= (16.6 \text{ x } 10^6)/0.85$
$= 19.52 \text{ x } 10^6$ cu.m.

(g)Total volume of daily cover in n years (Vdc) (on the basis of 15 cm soil cover on top and sides for lift height of 1.5 to 2 m)
$Vdc = 0.1\ Vw$ (cu.m.)
$= 0.1 \text{ x } 19.52\text{x}10^6$
$= 1.9\text{x}10^6$ cu.m.

(h) Volume of Liner and Cover Systems
$Vc = k\ Vw$ (cu.m.)
$= 0.125\text{x}19.52\text{x}10^6$
$= 2.44\text{x}10^6$ cu.m.

(i) Volume likely to become available within 10 years
$Vs = m\ Vw$
$= 0.10\text{x}19.52\text{x}10^6$
$= 1.9\text{x}10^6$

(j) First Estimate of Landfill Volume
$Ci = (19.52 + 1.9 + 2.44 – 1.9) \text{ x } 10^6$
$= 21.96 \text{ x}10^6$ cu.m.

(k) Likely Shape of Landfill
Rectangular in plan (length: width = 2:1)
Primarily above ground level, partly below ground level.

(l) Area Restrictions: Nil

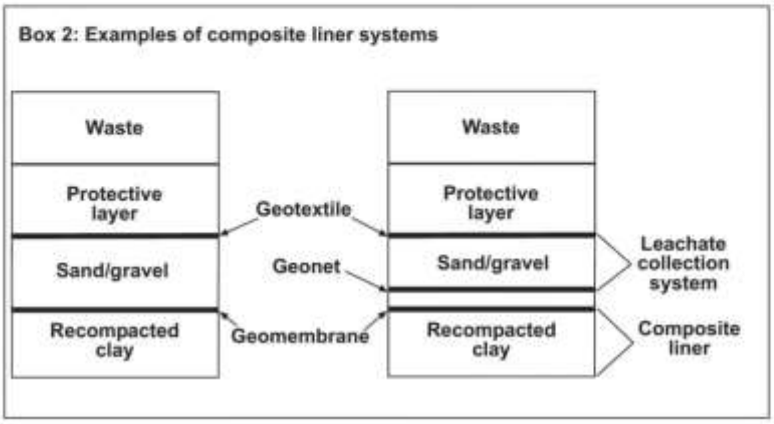
(m) Possible Maximum Landfill Height = 10 m

(n) Area Required = $(21.96 \times 10^6)/20$
$= 1.09 \times 10^6$ sq.m. = 270 acres
Dividing the whole landfill into four sections for the ease of construction and land considerations.
68 acres= $6800 m^2$

(o) Approximate Plan Dimensions = 116m x 58m
Rounding up to = 115m x 60m.

Composite-Liner Systems

A composite liner consists of a geomembrane in combination with a clay liner. Composite-liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer. Composite liners are required in municipal solid waste (MSW) landfills. Municipal solid waste landfills contain waste collected from residential, commercial, and industrial sources. These landfills may also accept C&DD debris, but not hazardous waste. The minimum requirement for MSW landfills is a composite liner. Frequently, landfill designers and operators will install a double liner system in MSW landfills to provide additional monitoring capabilities for the environment and the community.



Materials

A GCL is a relatively thin layer of processed clay (typically bentonite) either bonded to a geomembrane or fixed between two sheets of geotextile. A geomembrane is a polymeric sheet material that is impervious to liquid as long as it maintains its integrity. A geotextile is a woven or nonwoven sheet material less impervious to liquid than a geomembrane, but more resistant to penetration damage. Both types of GCLs are illustrated in Figure 1. Although the overall configuration of the GCL affects its performance characteristics, the primary performance factors are clay quality, amount of clay used per unit area, and uniformity. Bentonite is an extremely absorbent, granular clay formed from volcanic ash. Bentonite attracts positively charged water particles; thus, it rapidly hydrates when exposed to liquid, such as water or leachate. As the clay hydrates, it swells, giving it the ability to "selfheal" holes in the GCL. In laboratory tests on bentonite, researchers demonstrated that a hole up to 75 millimeters in diameter will seal itself, allowing the GCL to retain the properties that make it an effective barrier system. Bentonite is affixed to synthetic materials in a number of ways to form the GCL system. In configurations using a geomembrane, the clay is affixed using an adhesive. In geotextile configurations, however, adhesives, stitch bonding, needle punching, or a combination of the three, are used. Although stitch bonding and needle punching create small holes in the geotextile, these holes are
Sealed when the installed GCL's clay layer hydrates.

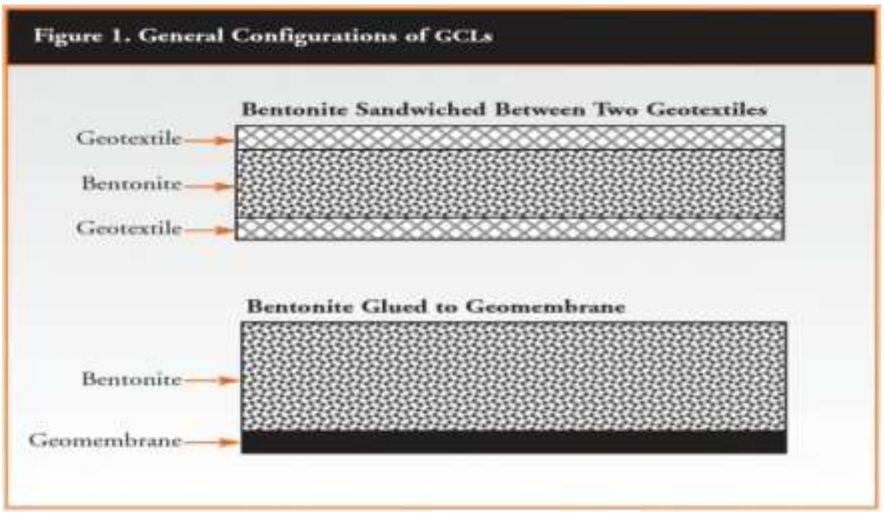
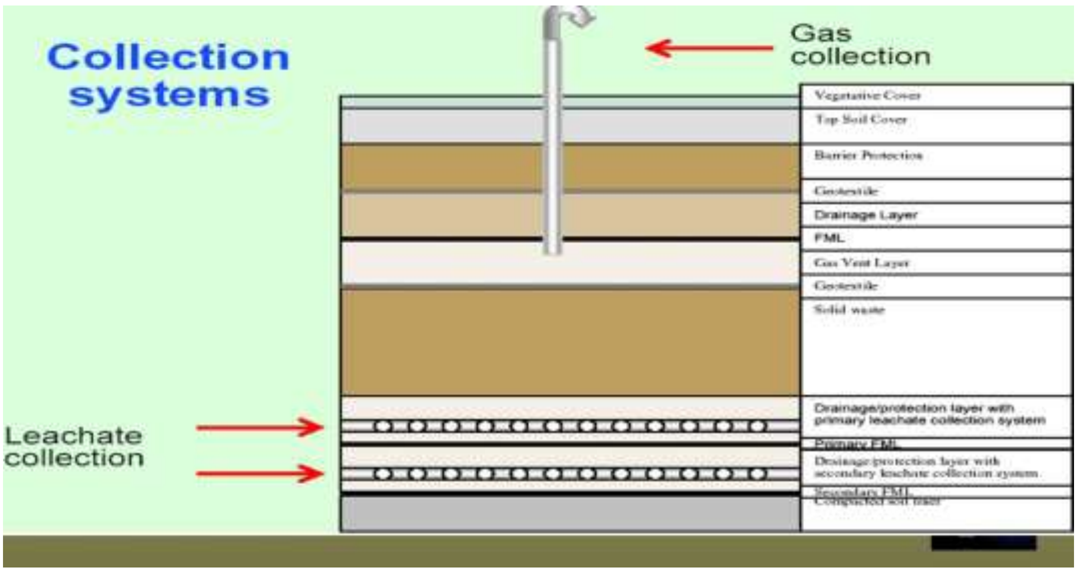


Figure 1. General Configurations of GCLs

Hydraulic Conductivity

GCL technology can provide barrier systems with low hydraulic conductivity (i.e., low permeability), which is the rate at which a liquid passes through a material. Laboratory tests demonstrate that the hydraulic conductivity of dry, unconfined bentonite is approximately 1 x 10^{-6} cm/sec. When saturated, however, the hydraulic conductivity of bentonite typically drops to less than 1 x 10^{-9} cm/sec. The quality of the clay used affects a GCL's hydraulic characteristics. Sodium bentonite, a naturally occurring compound in a silicate clay formed from volcanic ash, gives bentonite its distinct properties. Additives are used to enhance the hydraulic properties of clay containing low amounts of sodium bentonite. The hydraulic performance also relates to the amount of bentonite per unit area and its uniformity. The more bentonite used per unit area, the lower the system's hydraulic conductivity. Although the amount of bentonite per unit area varies with the particular GCL, manufacturers typically use 1 pound per square foot. As a result, the hydraulic conductivity of most GCL products ranges from about 1 x 10^{-5} cm/sec to less than 1 x 10^{-12} cm/sec. That is, the permeability of finished GCL products depends on a combination of factors, including the type and amount of bentonite, the number of additives, the type of geosynthetic material, and the product configuration (i.e., the method of affixing the geosynthetic to the clay).

Leachate Collection System in a Landfill



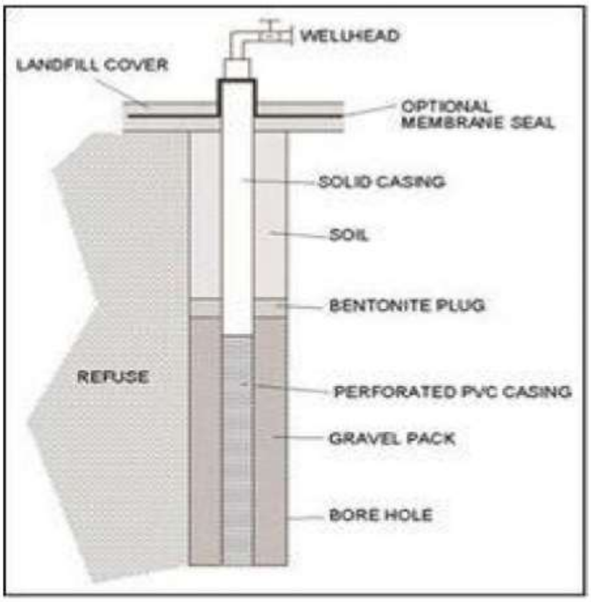
In order to optimize leachate drainage and collection, the bottom of the landfill should be gently sloped, channeling leachate to centralized locations from where it can be effectively removed. Landfills situated on flat sites can be expensive to construct, as a slope needs to be created by excavating and/or filling. Consequently, landfills that are located on sites with a gentle slope can reduce costs. A landfill that is equipped with a bottom line system, but which has no functioning leachate collection/management system in place, will rapidly fill up with fluids as there is no way for liquid to escape from the landfill. This is undesirable as it can cause problems in terms of slope stability, and can negatively impact the functionality of the landfill gas management system. Leachate pipes are typically spaced 45-60 meters apart, with the bottom contours depending largely on the geometry of the site and on groundwater depth. Leachate drains from the landfill are funneled to a sump, from where it is extracted by a submersible pump. In certain scenarios, such as side slope landfills, canyon fills, and above-ground mounds that require no excavation, gravity systems may offer a feasible alternative to the sump/pump extraction method.

In the proposed site, the dimensions of the landfill are 115x60 meters. So we provide 2 drainage pipes at a distance of 55 meters apart. The collection drain is provided with a gravity system that will have a slope of 1:10-1:20 depending on the gradient. Thus the collection system will have two pipes that will collect leachate from a single landfill site in two drains which can further be collected in one leachate collection tank.

Landfill Gas Extraction and Utilization

Gas extraction system

Landfill gas is extracted from the landfill using extraction wells depending on the size of the landfill. Roughly one well per acre area of the landfill is generally used. The given figure shows a basic extraction well



Landfill gas can be collected by either a passive or an active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area. As gas is generated in the landfill, the collection wells offer preferred pathways for gas migration. Most collection systems are designed with a degree of redundancy to ensure continued operation and protect against system failure. Redundancy in a system may include extra gas collection wells in case one well fails. The system-specific components for passive and active gas collection systems are discussed below.

Passive gas collection systems use existing variations in landfill pressure and gas concentrations to vent landfill gas into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after closure. Passive systems use collection wells, also referred to as extraction wells, to collect landfill gas. The collection wells are typically constructed of perforated or slotted HDPE and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill. Horizontal wells may be appropriate for landfills that need to recover gas promptly (e.g, landfills with subsurface gas migration problems), for deep landfills, or for active landfills. Sometimes, the collection wells vent directly to the atmosphere.

The efficiency of a passive collection system partly depends on how well the gas is contained within the landfill. Gas containment can be controlled and altered by the landfill collection system design.

Active Gas collection systems are considered the most effective means of landfill gas collection. Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however, wells in the active system should have valves to regulate gas flow and to serve as a sampling port. Sampling allows the system operator to measure gas generation, composition, and pressure. Active gas collection systems include gas boosters or pumps to move gas out of the landfill and piping that connects the collection wells to the flare. Gas boosters or pumps pull gas from the landfill by creating low pressure within the gas collection wells. The low pressure in the wells creates a preferred migration pathway for the landfill gas. The size, type, and a number of gas boosters required in an active system to pull the gas from the landfill depend on the amount of gas being produced. With information about landfill gas generation, composition, and pressure, a landfill operator can assess gas production and distribution changes and modify the pumping system and collection well valves to most efficiently run an active gas collection system. The system design should account for future gas management needs, such as those associated with landfill expansion.

Economics and Comparison

The total costing that involves rates for every process from surveying to the creation of landfill and finally to extracting the landfill gas and leachate from the landfill. The costing also involves operation and maintenance and thus provides a total costing for the proposed site of the landfill on a commercial purpose for the city of Kolhapur.

Costs

As of 1994, the cost of an installed GCL ranged from $0.42 to $0.60 per square foot. Factors affecting the cost of a GCL include Shipping distance, Size of the job, Market demand, Time of the year.

Total Costing

Sr. No	Item	Cost Rs x 10^5
1	Data Collection	0.50-0.75
2	Environmental Impact Assessment	4.00-6.00
3	Preliminary Bore Holes	1.50-2.25
4	Geotechnical Investigation for Design, Borrow Material, Ground Water Investigation	7.50-11.25
5	Topographical Investigation	1.50-2.25
6	Hydrological Investigation	2.00-3.00
7	Geological Investigation	2.00-3.00
8	Traffic Investigation	0.50-0.75
9	Water and Leachate Investigation	2.00-3.00
10	Design and Detailed Engineering	15.00-20.00
11	Cost of Infrastructure	102.70
12	Leachate Management Facility	23.85
13	Environmental Monitoring Facility	8.00
14	Daily Cover Laying, Spreading and Compaction	19.45
15	Pollution Prevention During Operation	4.00
16	Final Cover System	130.25
17	Surface Water Drainage System on Cover	10.30
18	Monitoring Facility on Cover	1.00
19	Vegetation Growth on Cover	4.40
20	Post Closure Care Cost	37.00

TOTAL - 386.2 x 10^5

CONCLUSION

In the traditional landfills, the common practice is of dumping where in most cases open dumping is carried out which leads to the generation of hazardous gases & uncontrolled leachate generation. Compared to these traditional practices, in our research, we have proposed proper design methods & leachate extraction methods.

Also, an LFG system is proposed which will be beneficial for the generation of electricity from methane. Also, the division into 4 phases will be beneficial for a continuous energy generation where in the waste will be generated efficiently. The estimation and costing proposed are lower as compared to the traditional construction practices.

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