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Evaluation of Landfill Cover Systems under Tropical Conditions

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EXECUTIVE SUMMARY

Malaysia receives about 3360mm of rainfall per year and as a consequence the 144 landfills generate large volumes of leachate since most of these landfills do not have proper cover system. The scenario becomes even more complicated since the components in the leachate are often toxic with numerous heavy metals, such Cd, Pb and Hg from non-separated municipal solid waste. Hence, leachate treatment is a serious problem and often the effluent released after treatment is not within the stipulated Malaysian Effluent Standards. The objective of this research is to investigate the optimum cover-system combinations suitable for tropical countries like Malaysia so that the volume of leachate generated could be minimized.

Five types of landfill cover systems (labeled as T1 to T5) containing top soil and barrier soil with various combinations of geomembrane, geo net or drainage layers were investigated for efficiency of minimum leachate generation. To determine the exact role of each component within the liner system, Type 4 cover system containing topsoil, drainage layer, geomembrane and barrier soil, in that order, were further scrutinized for parameters like soil thickness, surface slope, hydraulic conductivity etc based on water balance component (WBC) and using software Visual- HELP.

Leachate generated ranged from 1346mm for T1 cover which only had top soil and barrier soil, to 79 mm for T5 cover which had five layers including top soil, geo net, drainage layer, geomembrane and barrier soil in that order. The cost of construction increased from RM 7/m² (T1) (US$1.84) to RM 40/m² for T5 cover (US$10.53). Based on USEPA (1995) guidelines both type T4 and T5 cover systems complied with Malaysian regulations since leachate generated was less than 300mm. However, based on cost considerations, Type T4 cover, which costs RM 26/m² (US$6.84), is recommended for Malaysian conditions.

Individual component characteristics requirement in type T4 cover system revealed that the surface slope need to be less than 5% while silty loam soil with hydraulic conductivity of 0.00019 cm/s increased evapotranspiration. Gravel, with hydraulic conductivity of 0.3cm/s, was the material of choice for lateral drainage material and, clay with hydraulic conductivity of 68.0 x 10^{-7} cm/s, was an excellent barrier soil layer. The above combinations in cover type T4, gave a good final cover system, based on leachate generated.

INTRODUCTION

In early history, the disposal sites were just open dumps, and were later upgraded to controlled tipping where waste was covered by soil and compacted daily. The latest technology is sanitary landfill which has adopted engineering principles in waste containment system in order to isolate waste from the environment. The waste containment system is to protect environmental degradation by restricting infiltration and controlling gas emission (Robinson *et al*., 1992). Although waste was disposed into landfills, these landfills continuously posed short and long term hazards and risks to human being and environment due to leachate generation and migration as well as gas emission. Leachate migration caused groundwater pollution while gas emission caused air pollution and health implications. The unwanted impacts happened because there was no engineered waste containment system to restrict leachate from contaminating surface and groundwater resources (McBean et al, 1995).

Furthermore, the uncontrolled landfill leachate and methane gas produced could contaminate water resources and atmosphere. The production of leachate is mainly due to infiltration of precipitation and groundwater intrusion. The Malaysian MSW landfill produced leachate at the rate of 150-200 L/metric ton and the volume of biogas from local MSW are 100-150 m^3 /metric ton. In addition, the production of methane gas from MSW is estimated at about 1.3- 7.5 L CH_4/kg/years (Agamuthu, 2001). Therefore to minimize undesired environmental impacts and risks to an insignificant level, the waste disposal facilities need to be properly lined with engineered final-cover and bottom liner systems (Christine *et al*., 1994). Landfill leachate and gas would contaminate water resources, land and atmosphere, where toxic gas and leachate would be hazardous to human health besides floral and fauna life (Mohamed *et al*., 1995).

In view of this, a research was conducted to compute the quantity of leachate generated in a landfill after various models of landfill final-cover systems were simulated using a computer program called Visual HELP (VHELP). The effect of the cover system on water balance components was studied.

METHODOLOGY

The VHELP program was developed to conduct water balance analysis on landfill cover systems, and the waste containment facilities. The model facilitates rapid estimation on the amount of runoff, evapotranspiration, drainage, and leachate collection and liner leakage that may be expected from the operation based on the water balance.

The VHELP model required data on the climate including growing season, average relative humidity, mean monthly temperatures, maximum leaf area index, evaporate zone depth and latitude (Table 1). Default values for these parameters were complied from climates of the states. Nevertheless, daily rainfall data may be input by user or generated stochastically, taken from model's historical database. The VHELP model provides default values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of numerous soil and waste materials, as well as, geosynthetic material. The default value of soil material types were complied for program usage (Schroeder *et al*., 1994a & 1994b). In addition, VHELP model requires landfill design which includes slope surface, maximum drainage distance, layer thickness and subsurface materials characteristics. These parameter values were taken and used to compute WBCs for the model of cover systems tested.

Water Balance Components

The components of water balance are surface runoff, evapotranspiration, and subsurface water routing which include lateral drainage and leachate generation. These will be explained in the following section.

- Surface Runoff

Daily surface runoff is equal to the sum of rainfall, minus the sum of infiltration, and evapotranspiration.

- Evapotranspiration

The VHELP model uses a modified Penman method to compute evapotranspiration (Ritchie, 1972). The method involves a two-stage square-root-of-time routine. In stage one, the soil evaporation equals the evaporative demand placed on the soil. Demand is based on energy and is equal to the potential evapotranspiration discounted for surface evaporation and shading from ground cover. A vegetative growth model is used to compute the total quantity of active and dormant vegetation that provide shade.

- Subsurface Water Routing

Subsurface water routing includes vertical unsaturated drainage, percolation through saturated soil liners, leakage through geomembrane, and lateral drainage in drainage layers.

Table 1: Input Data Required of VHELP Model

Category	Details
Climatic Data	Daily precipitation-three options exist: 1. Use a default precipitation option 2. Input precipitation data; 3. Generate a sequence of precipitation events
Soil Data	Saturated hydraulic conductivity Soil porosity Evaporation coefficient Field capacity Wilting point Minimum infiltration rate SCS runoff curve number Initial soil water content
Vegetation data	Crop type Crop cover Leaf area indices Evaporative zone depth
Design data	Numbers of layers Layer thickness Layer slope Lateral flow distance Surface layer of landfill Leakage fraction Runoff fraction from waste

Mc Bean (1995)

Types of Cover System Design

The cover system models namely T-1, T-2, T-3, T-4 and T-5 are illustrated below.

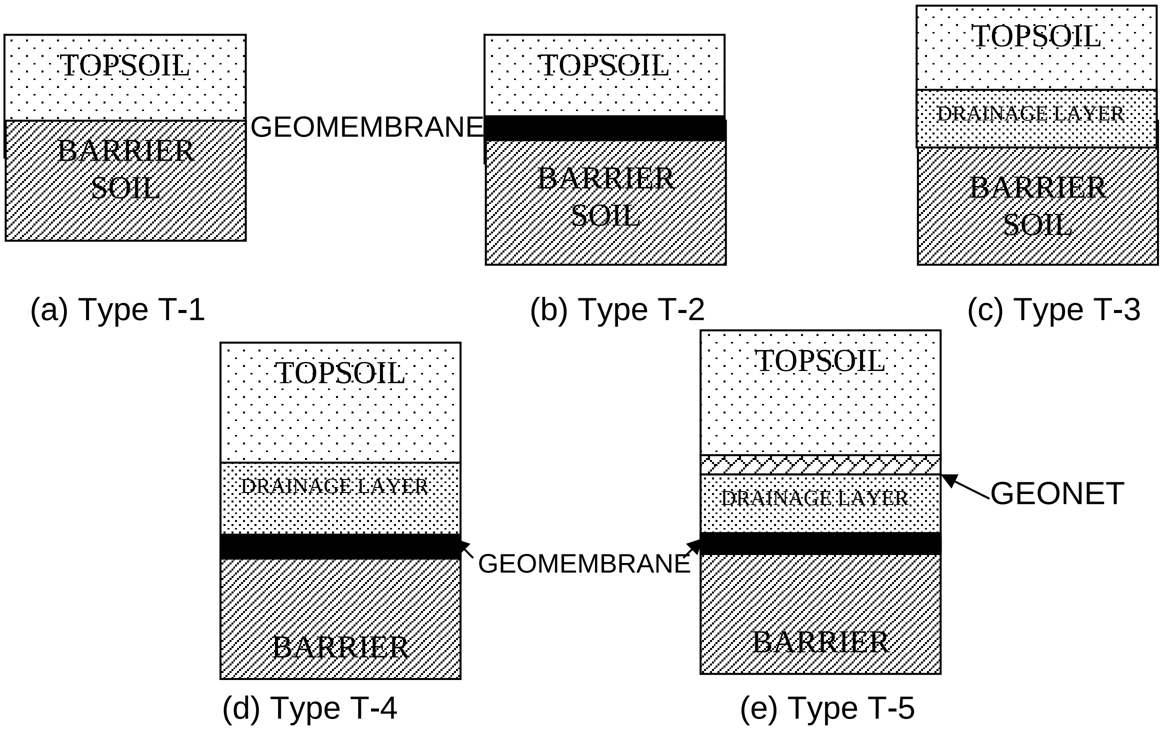

Figure 1: Types of cover systems

Five cover systems from T-1 to T-5 were tested. Each of these models was tested and it was assumed that an excellent stand of grass and a surface slope of 5% were adopted. Topsoil of thickness 0.4m and saturated hydraulic conductivity of 0.00019 cm/s was used.

Model T-4 cover system was selected for further scrutiny to determine the effectiveness of the functions required. Among the parameters studied were topsoil thickness, surface slope and level of vegetation, saturated hydraulic conductivity of topsoil, saturated hydraulic conductivity of lateral drainage and saturated hydraulic conductivity of soil barrier layer.

RESULTS & DISCUSSION

Influence of Cover Systems on Water Balance Components (WBCs)

Table 2 shows the quantity of each WBC versus the type of cover systems (i.e. T-1, T-2, T-3, T-4, and T-5). It can be seen that type T-1 showed maximum volume of leachate generated whereas T-5 gave the minimum, and their values are 1345.53 mm and 78.6 mm, respectively. Type T-2 showed maximum runoff. The average value of evapotranspiration (1833 mm) showed very small differences among the type of cover systems. Type T-5 cover gave the maximum value (1265.92 mm) of water collected from lateral drainage, and least value of leachate generated (78.6 mm). The model type T-4 and T-5 generated acceptable value of leachate according to USEPA (1994a), where depth is less than 300mm.

Table 2: Influence of cover systems on WBCs

Water Balance Components (WBCs) (mm)	Type of Cover Systems				
	T-1	T-2	T-3	T-4	T-5
Precipitation	3364.05	3364.05	3364.05	3364.05	3364.05
Surface Runoff	168.93	557.05	269.07	244.49	189.47
Evapotranspiration	1849.59	1846.57	1833.06	1832.02	1830.06
Lateral Drainage Collected	-	-	597.32	1162.48	1265.92
Leachate Generated	1345.53	960.43	668.67	125.06	78.6

Influence of Cover Systems on Surface Runoff
The type T-2 cover system showed maximum quantity of surface runoff with a depth of 557.05 mm. Other cover systems, T-1, T-3, T-4, and T-5 showed the amount of runoff value of 168.93 mm, 269.07 mm and 189.47 mm, respectively (Table 2).

Type T-2 consisted of geomembrane barrier of low hydraulic conductivity and it is overlaid on a barrier soil layer. The topsoil gets saturated when there is rainfall, resulting in more surface runoff. McBean et al (1995) pointed out that due to composite action of the cover system the additional or contributing layers assisted the primary function to minimize the downward passage of surface water into the refuse.

Influence of Cover Systems on Evapotranspiration
The influence of cover systems on evapotranspiration does not indicate much difference. The quantity of water evaporated and transpired were consistent at an average value of 1838 mm for all cover types T-1 to T-5.

Influence of Cover Systems on Lateral Drainage
The type T-5 cover showed maximum quantity (i.e. 1265.92mm) of lateral drainage collected because T-5 had geotextile filter material to enhance passage of drainage liquid (Fang, 1996). The other types of cover systems T-1 and T-2 have no drainage materials and no water is collected at the end of the drainage length (Table 2). It can be seen that lateral drainage material significantly reduced water infiltrating into waste layer therefore reducing leachate generation, as mentioned by (Schroeder *et al*, 1987a).

Influence of Cover Systems on Leachate Generation
The highest volume of leachate was generated when T-1 cover systems was used (1345 mm), followed by the second highest value of leachate generated for type T-2 followed by T-3, T-4, and T-5 (Table 2). Results of T-4 and T-5 displayed small difference in volume of leachate generated; however the cover system T-5 is more costly. High leachate volume was generated for T-1 because there is no drainage material provided while for type T-3 no geomembrane barrier layer was added in the cover system. Bagchi (1994) concluded that lesser amount will infiltrate into a landfill if it is covered with a composite cap, such as

geomembrane, over a layer of compacted clay (GM/GCL). Qasim & Chiang (1994) also added that a properly designed cover will eventually halt leachate generation after landfill closure.

Influence of Level of Vegetation on WBCs

Table 3 shows results of the influence of the level of vegetation on WBCs using type T-4 cover system. Bare soil gave the highest run-off, as well as, the leachate generation. Excellent stand of grass reduced the run-off and leachate.

Table 3: Influence of different types of vegetation on WBCs using type T-4 cover system

Water Balance Components (WBCs) (mm)	Level of Vegetation				
	Bare Soil	Poor Stand of Grass	Fair Stand of Grass	Good Stand of Grass	Excellent Stand of Grass
Precipitation	3364.05	3364.05	3364.05	3364.05	3364.05
Runoff	477.71	347.11	226.21	117.53	87.56
Evapotranspiration	1810.53	1832.01	1840.9	1848.7	1855.5
Lateral Drainage Collected	770.32	908.15	1110.05	1275.27	1325.58
Leachate	305.49	276.78	186.86	122.55	95.41

Influence of Topsoil Thickness on Water Balance Components

The results shown in Table 4 were obtained from water balance analysis. Thickness of topsoil cover varied from 0.2 m to 0.4 m, 0.6 m, 0.8 m, and 1m, to find the effect of landfill cover system on the WBCs using type T-4. Thick topsoil reduced leachate drastically, while the evapotranspiration is also highest in the 1.0m thick topsoil.

Table 4: Influence of different topsoil thickness on WBCs using type T-4 cover System

Water Balance Components (WBCs)(mm)	Topsoil Thickness (m)				
	0.2	0.4	0.6	0.8	1.0
Precipitation	3364.05	3364.05	3364.05	3364.05	3364.05
Runoff	260.83	251.14	222.69	206.9	169.71
Evapotranspiration	1759.8	1783.6	1812.3	1826.06	1843.06
Lateral Drainage Collected	1160.5	1201.53	1273.62	1302.9	1331.4
Leachate	182.92	127.78	55.44	33.19	20.08

Influence of Surface Slope on Water Balance Components

The effect of surface slope on WBCs was studied using model T-4 cover system. The topsoil cover with 0.4 m thickness was considered in the simulation to avoid overburden pressure and to minimize cost. The surface slope was increased from 0 % to 30 % at intervals of 5 %. The main purpose of the surface slope is to allow water flow as surface runoff rather than accumulating and infiltrating into the landfill, hence producing leachate. The surface slope is built by the topsoil surface. If this surface slope is constructed at a steeper gradient (more than 5 %), less leachate was produced. Unfortunately, more runoff was collected and consequently erosion of topsoil would occur. From the result of the study it was recommended that surface slope of 5 % is to be adopted for the construction of landfill cover system. The results of the analysis are shown in Table 5.

Table 5: Influence of different surface slope on WBCs using type T-4

Water Balance Components (mm)	Surface Slope (%)						
	0	5	10	15	20	25	30
Precipitation	3364.05	3364.05	3364.05	3364.05	3364.05	3364.05	3364.05
Runoff	0.000	204.71	275.23	341.61	416.11	472.16	512.39
Evapotranspiration	1822.9	1832.67	1842.45	1852.14	1862.64	1872.2	1882.89
Lateral. Drainage Collection.	1045.13	1014.72	1007.04	961.46	891.05	835.53	803.32
Leachate	480.02	312.3	239.33	208.84	194.25	184.16	165.45

Cost Analysis of Landfill Cover Systems

In this work, five models of final-cover systems were tested. Model T-1, consisted of topsoil and clay barrier soil layer. The unit price including labor cost for topsoil was estimated RM 2/m², and the barrier soil layer was RM 5/m². The total cost of landfill final-cover system for model T-1 was RM 7/m² including laying, but excluding the cost of transportation.

The model T-2 type consisted of topsoil, geomembrane and clay barrier soil layer. In this final-cover system flexible geomembrane layer was added, where the cost was RM 15/m². Therefore the total cost of model T-2 was RM 22/m². Model type T-3 comprised of topsoil, lateral drainage materials and soil barrier layer, where the cost of lateral drainage layer was RM 4/m². The total cost of this model was RM 11/m².

Model T-4, which consisted topsoil, cost RM 2/m², lateral drainage was RM 4/m², flexible geomembrane, at RM 15/m² and compacted soil barrier layer was RM 5/m². Therefore the total cost for type T-4 final cover system was RM 26/m².

Model T-5 consisted of topsoil RM 2/m², lateral drainage materials, geonet RM 12/m², natural lateral drainage material, RM 4/m², flexible geomembrane RM 15/m² and compacted soil barrier layer, RM 5/m². The total cost of this final-cover system was RM 38/m². When comparison of cost was made, type T-4 model of final cover system was selected, where it is of moderate and appropriate cost i.e. RM 26/m². This model (type T-4) is quite efficient when compared to T-5.

CONCLUSION

Types of cover systems had great influence on the quantity of leachate generated and on other WBCs. Excellent stands of grass vegetation helps to promote evapotranspiration. It also minimized erosion impacts when having surface slope at 5%. Type T-4 and T-5 cover systems were the most efficient based on leachate generated. Type T-4 offers an economical advantage over type T-5. Cover systems of type T-1 and T-2, without lateral drainage layer within the system caused 50% of the precipitation to infiltrate into the wastes and became leachate. When geomembrane layer was installed for cover system type T-2, an increase runoff occurred, and erosion was high due to increased runoff because there was no lateral drainage provided to drain out water laterally. By providing excellent stand of grass vegetation on landfill final-cover the quantity of leachate generated was minimal since water evapotranspired through vegetation. Topsoil type silty loam helped to enhance evaporation through suitable condition for growth of vegetation. The surface slope of 5% gave very low soil erosion impacts, when runoff was minimal. Drainage materials such as coarse sand, gravel and geonet are efficient in serving their function as lateral drainage materials, where maximum quantity of water was collected and therefore leachate generated was minimal. Barrier soil materials that served efficiently to reduce infiltration into the landfill to prevent leachate generation are clay, silty clay and clay loam. It was concluded that the model type T-4 with combinations of the best selected parameters of topsoil materials, lateral drainage, barrier soil with excellent stand of grass vegetation, surface slope of 5% and topsoil thickness 400 mm was found to be the most efficient and economical at a cost of RM 26/m².

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REFERENCES

Agamuthu, P., (2001). *Solid Waste: Principles and Management*. University of Malaya Press, Kuala Lumpur.

Bagchi, A., (1994). *Design, Construction, and Monitoring of Sanitary Landfill,* John Wiley & Sons, Inc. New York. pp 56-78.

Christine, T.H., Cossu, R. and Stegman, R. (1994).*Landfilling of Waste Barriers*. E & FN Spon, London. pp 445-503.

McBean, E.A., Frank, F.A., & Farquhar G.J. (1995). *'Solid Waste Landfill Engineering and Design."* Prentice Hall PTR, Englewood Cliffs, New Jersey 07632. pp 201.

Mohamed A.M.O, Yong R.N.and Galvez-Cloutier R. (1995*). Land Disposal and Dredged Mud.* In *Proceeding of the Waste Disposal by Landfill.* Balkema, Rotterdam and Brookfield. pp 649-654.

Qasim, S.R. and Chiang, W. (1994*) Sanitary Landfill Leachate.* Technomic Publishing Company, Inc.,851 New Holland Avenue, Box 3535,Lancaster, PA, 17604

Ritchie, J.T., (1972). *A Model for Predicting Evaporation from a Row Crop with Incomplete Cover,* Water Resources Research, Vol.8.No 5 pp 1204-1213.

Robinson, H.D., Barr, M.J. and Last, S.D.(1992). *Leachate Collection, Treatment and Disposa*l. J. Inst. Waste Env. Management. **17**:321-331.

Schroeder, P.R., Lloyd.C M., Zappi, P. A. and Aziz,N.M., (1994a). *The hydrological Evaluation of Landfill Performance (HELP) Model, User's Guide for version 3*, EPA /600/R-94/168a,Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. environmental Protection Agency, Cincinnati, OH, September.

Schroeder, P.R., Dozier, T.S., Zappi,P.A., Mc Enroe, B.M., Sjostrom,J.W., and Peyton, R.L., (1994b). *The hydrological Evaluation of Landfill Performance (HELP) Model, User's Guide for version 3,* EPA /600/R-94/168a, Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. environmental Protection Agency, Cincinnati, OH, September.

USEPA (1994). Landfill Bioreactor Design and Operation. EPA/600/R-95/146, *Seminar Publication*, Risk Reduction Engineering Laboratory, Cincinnati OH pp203.

USEPA (1995). Code of Federal Regulations,40 CPR parts190-259, Revised of July 1, 1995, U.S. Environmental Agency, Washington DC.

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