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Hydraulic Characteristics of Municipal Solid Waste: Findings of the Yolo County Bioreactor Landfill Project

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ABSTRACT

Yolo County, Division of Integrated Waste Management, is conducting a Landfill Bioreactor Demonstration Project at its Central Landfill. The project consists of two fully contained landfill cells, each containing about 9,000 tons of municipal solid waste. One cell, the "enhanced cell" receives controlled liquid additions and recirculated leachate, while the second cell is a control cell that receives no liquid additions. Because both cells were filled during the dry season and covered with a linear low density polyethylene membrane, all liquid inputs and outputs to the cells have been measured. Additionally, the cells are instrumented to monitor both moisture and temperature conditions throughout the waste mass. Gas production from each cell is also measured. This paper uses data from this project to estimate waste permeability, degree of liquid channeling through the waste, and uniformity of moisture distribution. Conclusions are drawn as to the implications of this study for operating bioreactor landfills.

Keywords: landfill, bioreactor, recirculation, leachate, field capacity, permeability

INTRODUCTION

The Yolo County Department of Public Works is conducting a project to demonstrate landfill bioreactor technology at its Central Landfill located near Davis, California. This technology has the potential to provide accelerated landfill gas generation rates as well as significant environmental and solid waste management benefits. Landfill decomposition is accelerated through controlled additions of liquid, both water and leachate.

Two cells have been constructed, each containing approximately 9,000 tons (8,182 metric tons) of municipal solid waste. One cell serves as a control cell while the other cell receives controlled liquid additions and is called the "enhanced cell". The base liner leachate collection systems for both cells were constructed in conformance with Subtitle D. Each of the two cells has a base area of 100 by 100 feet (30.5 meters) and a depth of about 45 feet (13.7 meters). The waste was placed in 5 foot lifts (1.5 meters) and covered with shredded greenwaste as daily cover rather than soil. Cells are covered with impermeable membranes and surrounded by compacted clay levees to contain landfill gas and to assure that all liquid additions are added in a controlled manner. The cells are instrumented to measure temperature and moisture movement, and to some degree moisture content. Cell filling occurred from April to October, 1995, and liquid addition to the enhanced cell began on October 23, 1996. Details concerning the construction, operation and monitoring, an initial results of the project have previously been published (SWANA, 1997).

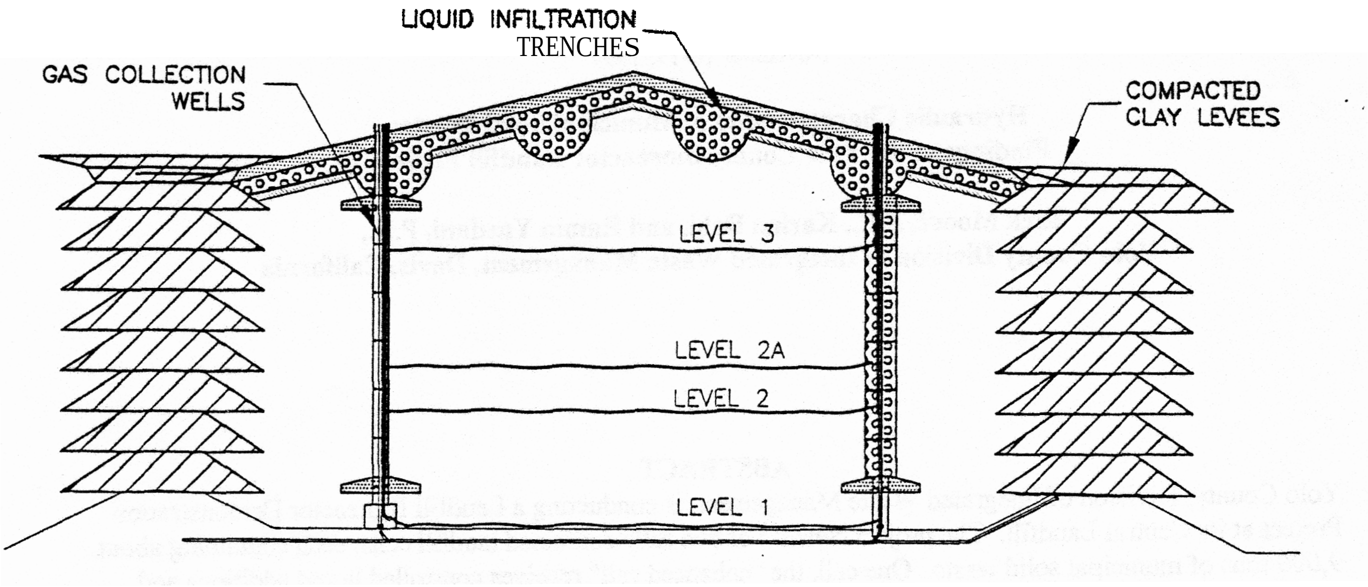

FIGURE 1. EAST-WEST SECTION OF ENHANCED CELL

EXPERIMENTAL SETUP

Liquid is added to the enhanced cell through 14 individual infiltration trenches placed on 20 foot centers *(6* meters) in the surface of the enhanced cell. These trenches are about 10 feet long, 5 feet deep, 3 feet wide *(3* by 1.5 by 1 meter), and filled with shredded tires. The total flowrate pumped to all of the infiltration trenches is about 10 gallons per minute (gpm) **(38** liters per minute) and distributed evenly throughout the infiltration trenches. Supplemental liquid (clean water) was added to the cells to increase the moisture content of the waste; as leachate is generated it is recirculated back into the cell. The supplemental liquid is added to the same manhole to which leachate from the enhanced cell drains. The mixture of leachate and clean water is then pumped to the infiltration trenches on the enhanced cell. In this paper, the term "supplemental liquid" is used for the clean water that is added to the cell, and "total liquid input" is used for the mixture of clean water and leachate that is pumped into the infiltration trenches.

Four levels of instrumentation were placed in the enhanced cell during waste filling; these are shown in Figure 1 and summarized in Table 1. Two types of moisture sensors are used; gypsum block moisture sensors and perforated 2 inch (5.1 cm) diameter polyvinyl chloride (PVC) pipes filled with gravel with two electrodes spaced 8 inches (20.3 cm) apart. To increase their life, each gypsum block was embedded in a quart (0.9 liter) sized block of plaster-of-paris.

Level	Distance from Bottom of Cell	Number of Gypsum Block Sensors	Number of PVC Sensors
3	35 feet (10 7 meters)	9	4
2A	20 feet (6.1 meters)	4	4
2	15 feet (4.6 meters)	9	4
1	0	3	0

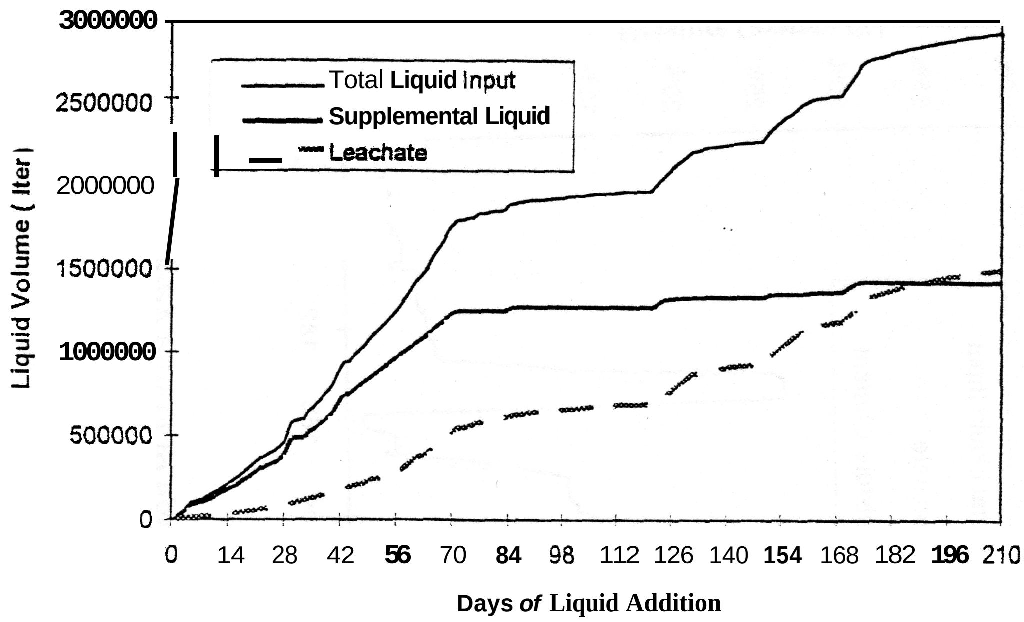

FIGURE 2. CUMULATIVE LIQUID VOLUMES VERSUS TIME

A PVC moisture sensor was calibrated prior to placement in the waste and the range of responses indicating three moisture conditions was observed; these moisture conditions are 1) below field capacity (no free liquid), 2) between field capacity and saturation (some free liquid), and 3) saturation. The gypsum block moisture sensors provide qualitative data only; quantitative evaluation of moisture content cannot be made from either type of moisture sensor data, however, when combined with a water balance the moisture sensors help in evaluating the distribution of stored liquid throughout the waste mass.

LIQUID ADDITION

Liquid addition to the enhanced cell began on October 23, 1996. A *summary* of the supplemental liquid additions is provided in Table 2. In addition to the supplemental liquid (clean water) added to the enhanced cell, all of the resulting leachate was recirculated back into the cell. Therefore, the total liquid input to the enhanced cell is the sum of supplemental liquid and leachate. A graph of the cumulative supplemental liquid, leachate generated, and total liquid input is shown in Figure 2.

Supplemental liquid was added fairly continuously between October 23, 1996 and January 2, 1997. Following this penod of addition, the supplemental liquid was turned off and only leachate was recirculated Supplemental liquid was added on other dates as shown in Table 2 when leachate flowrates decreased due to liquid absorption by the waste and on some occasions when nighttime temperatures were below freezing. Since the last date of supplemental liquid addition on Apnl 15, 1997, leachate in recirculation has all been absorbed by the waste with the exception of about 260 gallons per day (gpd) (984 liters per day) which remains in circulation through the waste. Therefore, virtually all of the 377,690 gallons (1430 m^3) of supplemental liquid added has been absorbed by the waste mass.

LEACHATE GENERATION

Daily volumes of supplemental liquid addition and leachate generation, and the corresponding average moisture content of the waste, is shown in Figure 3. The moisture content of the as-placed waste was assumed to be 25% based on a *dry* waste weight (20% on a wet waste weight). The moisture contents in Figure 3 are calculated on a *dry* waste weight basis.

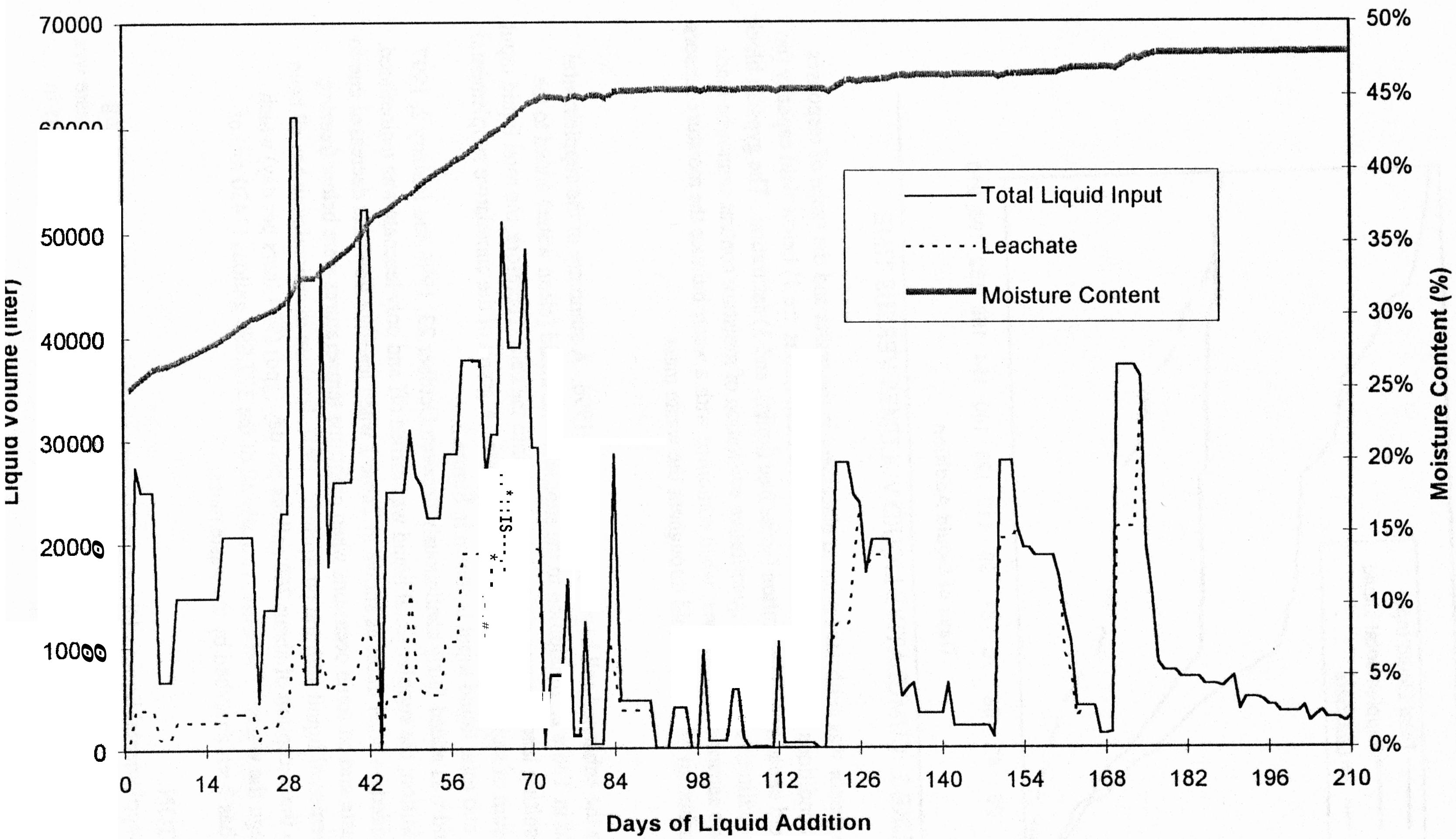

Figure 3. Moisture Content and Daily Liquid Volumes Versus Days of Liquid Addition

at least not over the short term. A spike input of liquid to the landfill results in a spike of leachate generation. Equalization of leachate flowrates from leachate recirculation is not evident from this *study.*

MOISTURE DISTRIBUTION

Moisture distribution through the waste is ascertained by increases in the waste moisture content as indicated by observations of the moisture sensor data. The ability to uniformly distribute moisture through surface infiltration was a concern due to the potential effects of channeling. **As** a general observation, moisture is well distributed throughout the waste mass. The upper layers of waste, closer to the infiltration trenches, achieved a higher moisture content **than** the lower levels, **as** would be expected, but moisture distribution appears fairly uniform within the horizontal levels. However, moisture sensors at the south side of the cell were the first to detect increases in moisture at all levels, significantly sooner than the corresponding sensors on the north side. The two vertical gas recovery wells are located near the south side of the cell, approximately 20 feet from the clay levee. It is hypothesized that the application of a vacuum to the gas recovery wells to extract the landfill gas may have promoted the migration of moisture towards the wells or that channeling may have occurred down the wells. Additionally, significantly more settlement is observed around the vertical wells than the rest of the surface of the enhanced cell. The flow to the two southernmost infiltration trenches was shut off on November 27,1996, and only the remaining 12 infiltration trenches have been used since that date.

WASTE PERMEABILITY ESTIMATE

The unsaturated permeability of waste in the enhanced cell is estimated using Darcy's law and assuming a hydraulic gradient of unity. The permeability calculated is that corresponding to the superficial or macroscopic velocity, the movement of the wetting front through the waste rather than the channeling velocity. The following equation presented by Zeiss, et al (1992), and modified slightly here is used to calculate the unsaturated permeability, K_{us}.

$$K_{us} = \text{waste depth/time to breakthrough}$$

The waste depth is the total vertical distance traversed by liquid infiltrating into the cell and collected as leachate. The time to breakthrough is the time required for leachate traveling at the macroscopic veiocity to traverse the entire depth of the cell. Waste depth is approximately 38 feet (11.6 meters) from the bottom of the infiltration trenches to the top of the gravel operations layer. The time to breakthrough is a somewhat more elusive parameter and is determined here through changes in leachate volume, appearance, and chemistry. As previously mentioned, liquid addition began on October 23, 1996. Leachate generation from the onset of liquid addition until November 26, 1996 had been approximately 17% of the total liquid input: it is assumed that this leachate generation was due to channeling. On November 27, the leachate volume as a percentage of total liquid input nearly doubled, to **3** 1%, and the leachate appearance changed from a light orange color to dark black with a very strong odor. Chemical analysis showed dramatic increases occurred in nearly all analytes as well as a drop in pH. It is surmised that this change in leachate volume is due to the addition of macroscopic leachate flow to the channeled flow that had been occurring and that the change in appearance was due to the production of leachate that had percolated through the waste more slowly than the previous channeled flow. Therefore, the time to breakthrough used here is 35 days. The unsaturated permeability is calculated below.

$$K = 38 \text{ ft}/35 \text{ days} = 1.1 \text{ ft/day} = 3.9 \times 10^{-4} \text{ cm/s}$$

The volume of supplemental liquid that had been added to the enhanced cell as of November 27 is 141,200 gallons (534 m^3). The total weight of municipal solid waste placed in the cell plus shredded greenwaste used as daily cover was 8,568 tons (7,789 metric tons). Assuming that the moisture content at the time of placement was 20% of the wet weight, the moisture content of the fill on November 27 was

TABLE 2. **HISTORY** OF LIQUID ADDITIONS

Dates of Supplemental Liquid Addition dates, (day since starting liquid addition)	Average Daily Supplemental Liquid Flowrate* gallons/ day, (cubic meters/day)	Total Supplemental Liquid Added gallons, (cubic meters)
10/23/96 to ½/97, (0 to 71)	4,640 (17.6)	329,500 (1247)
1/14/97 to 1/21/97, (83 to 90)	1,020 (3.9)	7,140 (27)
2/21/97 to 2/25/97, (121 to 125)	3,510 (13.3)	14,040 (53)
2/27/97 to 3/3/97, (127 to 131)	408 (1.5)	1,630 (6)
3/21/97 to 3/24/97, (149 to 152)	1,983 (7.5)	5950 (23)
4/1/97 to 4/4/97, (160 to 163)	727 (2.8)	2,180 (8)
4/10/97 to 4/15/97, (169 to 174)	3,450 (13.1)	17,250 (65)
Total Supplemental Liquid Added		377,690 (1,430)

After the beginning of liquid addition to the enhanced cell, leachate was generated immediately. As illustrated in Figure 3, there was virtually no lag time between addition of liquid to the cell and leachate generation. The rate of total liquid input for the first 35 days ranged from 1,000 to 16,000 gallons per day (3,785 to 60,560 liters per day). This range of liquid inputs resulted in a consistent proportion of generated leachate to total liquid input of about 17% until November 27, 1996, when there was a noticeable increase in the volume of leachate generated. This increase in leachate production relative to liquid input also coincided with a dramatic change in leachate chemistry and appearance. For the next 20 days, the proportion of leachate generated averaged about 25% of the total liquid input. The volume of leachate then increased to an average of 47% of the total liquid input until the supplemental liquid addition ceased on day 71. The moisture content of the waste during the addition of the supplemental liquid steadily increased from 25% to 45% at an average rate of 0.29% per day (dry weight basis). After the addition of the supplemental liquid stopped, the volume of leachate generated dropped significantly except for intermittent periods when supplemental liquid was added (Table 2). Following day 178, after which no supplemental liquid was added, the volume of leachate gradually dropped from 2,000 to 260 gallons per day (7,570 to 984 liters per day) at an average rate of reduction in leachate generation of 12 gallons per day (45 liters per day). A *summary* of leachate generation and moisture contents are presented in Table 3.

One of the benefits that one might expect from leachate recirculation is an equalization of leachate flowrates. For instance, widely varying leachate flowrates might be equalized through recirculation. However, as can be seen in Figure 3, equalization of leachate flows was not achieved through recirculation,

Period of Liquid Addition (start to end day)	Average Daily Volume of Leachate gallons (liters)	Average Daily Volume of Liquid Input gallons (liters)	Ratio of Leachate Generated to Volume of Liquid Input (%)	Time Averaged Waste Moisture Content (%)
1 to 34	902 (3,414)	5,352 (20,257)	17%	29%
35 to 54	1,796 (6,798)	7,212 (27,297)	25%	37%
55 to71	4,423 (16,741)	9,318 (35,269)	47%	42%

33.5% on a *dry* weight basis. Using the density of waste achieved in the cell of 1027 lbs. per yd^3 (608 kg/m^3), a volumetric moisture content of 16% is calculated.

WASTE FIELD CAPACITY

Waste field capacity as used in this paper means the maximum moisture content that a solid waste sample can hold without draining, disregarding the effects of channeling. The objective of liquid addition in this project is to add enough liquid to accelerate the waste decomposition rate while not exceeding the field capacity of the waste. This poses the difficulty of knowing when field capacity has been reached. It was decided that liquid addition would cease when the volume of leachate generated was 50% of the liquid input, and then leachate would be recirculated until absorbed by the waste mass. If leachate continued to be absorbed, it would be assumed that field capacity had not yet been reached, and more liquid could be added.

The total amount of supplemental liquid added to the enhanced cell is 377,690 gallons (1,430 m^3). After stopping the addition of Supplemental liquid the leachate generated was recirculated and continued to be absorbed by the waste. Virtually all of the supplemental liquid has been absorbed by the waste, with exception of 260 gallons per day (984 liters per day) still in recirculation. Using the same waste mass and initial moisture content assumptions cited previously, the moisture content of the waste after absorption of the supplemental liquid is 48% on a dry weight basis. Because all of the supplemental liquid added has been absorbed, it is surmised that the moisture content has not yet exceeded field capacity. Using the method for calculating field capacity presented by Tchobanoglous, et al, (1993), the enhanced cell attained field capacity on November 18,1996, day 26 of liquid addition. This is contradicted by PVC sensor readings in sensor Level 2, which did not indicate the presence of free liquid, although moisture content increases in this level were evident from gypsum block moisture sensor readings.

CONCLUSIONS

The conciusions listed below are based on observations made under the specific conditions of this project, particularly the range of landfill infiltration rates (liquid input rates), the use of shredded greenwaste as daily cover, and the vertical length of the leachate flowpath. These conditions will vary from site to site and with liquid management practices. Additionally, these results are based on a relatively short period of liquid infiltration into the landfill; the liquid input schedule in this project was such that 87% of the liquid added to the landfill occurred from October 23, 1996, to January 2, 1997. Therefore, the conclusions cited below are general in nature and should be applied with local conditions in mind and in combination with other study results.

1. Leachate flow can be divided into two portions, channeled flow and macroscopic flow. The volume of channeled flow can be estimated as a constant percentage of landfill infiltration which allows more accurate leachate generation projections prior to breakthrough of the macroscopic leachate flow. The "channeling factor" observed in this *study* is 17% of the total volume infiltrating the landfill.

2. The amount of landfill liquid infiltration absorbed by the waste, and conversely the amount of leachate generated, can be modeled as a percentage of the liquid infiltrating into the landfill. The percentage of landfill liquid infiltration absorbed by the waste decreases with increasing moisture content, and leachate generation as a percentage of infiltration increases until the absorptive capacity of the waste is exceeded.

3. The application of a vacuum to landfill gas collection points may have an affect on moisture distribution in landfills.

4. Liquid infiltration through the surface of the landfill using shredded tires resulted in uniform moisture distribution in this study.

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