Smart Storage: Stabilization of Stored and Landfilled Waste using Aerobic and Anaerobic Biotreatment Technology

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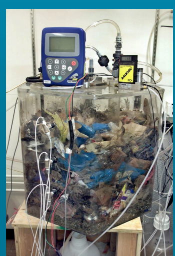
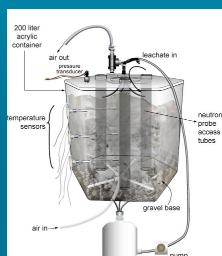
http://esd.lbl.gov/CEB/landfill/

ABSTRACT

In order to increase the lifetime of landfills and to lower leachate treatment costs, an increasing number of Municipal Solid Waste (MSW) landfills are being managed as either aerobic or anaerobic bioreactors. We have carried out a laboratory study using three 200-liter tanks filled with fresh waste materials to evaluate different treatment strategies of MSW. Landfill gas composition, respiration rates, and subsidence were measured to compare the relative effectiveness of the two treatments and were designed to develop bioreactors systems for studying the biotreatment of stored waste. The tanks were prepared to provide the following conditions: (a) aerobic (air injection with leachate recirculation), (b) anaerobic (leachate recirculation), and (c) a dry anaerobic landfill (no air injection, no water addition and no leachate recirculation). Leachate from the aerobic tank had significantly lower concentrations of potential contaminants, and dissolved organic carbon and ammonia. Respiration tests on the aerobic tank showed a steady decrease in oxygen consumption rates from 1.3 mol/day at 20 days to 0.1 mol/day at 400 days. Over the test period, the aerobic tank settled 35%, the anaerobic tank 21.7%, and the dry tank 7.5%. Mass loss calculations were also well correlated with the settling rates. The aerobic tank produced negligible odor compared to the anaerobic tanks, as indicated by the ammonia levels that were 2 orders of magnitude higher in the leachate of the anaerobic tank. These results suggest that aerobic management of MSW landfills could increase the rate of stabilization, reduce odor, and reduce the need for leachate and air emissions treatment systems and elaborate containment strategies. Though anaerobic treatment is an attractive option because it produces methane as a post-waste product, the long-term cost advantages of aerobic strategies may be more practical.

BIOREACTOR DESIGN





Three bioreactors consisting of 200-liter clear, hexagonal Lucite tanks were instrumented to monitor pressure, temperature, moisture, humidity, gas and leachate composition, and flow rates. All tanks contained 9 cm of gravel at the bottom, overlain by 30 kg of typical MSW. Air was injected into the bottom of the tanks for aerobic treatment, and gas was vented out the top. Leachate could be collected at the bottom of the tanks, recirculated, and sprinkled over the top of the MSW. The tanks were insulated on the sides and top with 2-inch solid foam and covered with vinyl fabric to block light. The aerobic tanks had a continuous flow of humidified air through the tanks.
Two experimental runs of 400 days were completed. In the first experiment, one aerobic and one anaerobic bioreactor tank were tested, and the third tank was used to simulate conversion of a conventional dry, anaerobic landfill to a wet, aerobic landfill. The second experiment consisted of two aerobic and one anaerobic bioreactor.

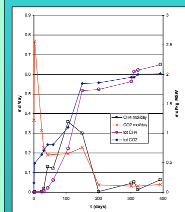
Tank Description	Duration (Days)	Treatment Description	Recirculation Rate (mL/min)	Air Flow Rate (L/min)
Experiment 1				
Aerobic, wet	400	1. Air injection 2. Leachate recirculation	20	1.9
Anaerobic, dry	0 to 197	3. No air injection 4. No leachate recirculation	None	None
Converted to				
Aerobic, wet	197 to 400	5. Air injection 6. Leachate recirculation	20	1.9
Anaerobic, wet	400	7. No air injection 8. Leachate recirculation	20	None
Experiment 2				
Aerobic, wet	400	9. Air injection 10. Leachate recirculation	20	1.9
Aerobic, wet	400	11. Air injection 12. Leachate recirculation	20	1.9
Anaerobic, wet	400	13. No air injection 14. Leachate recirculation	20	None

Garbage Composition in Bioreactors

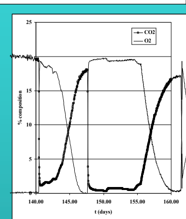
Component	Weight (kg)	Weight (%) with soil	Weight % without soil	Average Weight % from Literature
Paper (mixed, cardboard)	5.7 (dry)	19.0 (dry)	25.7 (dry)	42.2 (wet)
Food Waste	3.6	12.0	16.2	12.1
Metal (aluminum, steel)	2.1	7.1	9.6	7.8
Glass	2.5	8.4	11.4	9.4
Plastic (bottles, bags)	2.4	8	10.8	6.4
Garden Waste	2.7	9	12.2	12.8
Other Waste (wood, rubble, textiles, rubber, leather, soil)	11.0	10.5	14.2	8.2
Soil	7.8	26.0	--	--

RESULTS

This study demonstrated that maintaining the MSW landfill as an aerobic bioreactor increased the rates of settling and stabilization and produced more environmentally benign leachate and gas. The aerobic landfill bioreactors showed significantly more settling than the anaerobic reactor and maintained a neutral pH and low levels of all measured parameters (BOD, COD, and metals) compared to the wet, anaerobic bioreactor leachate. The reduction in noxious odors was a significant advantage of the aerobic system.



Landfill gas composition from the anaerobic, wet tanks

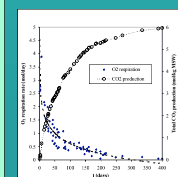


Typical gas composition for the wet, aerobic tanks over a 20-day period. This figure shows aerobic tank A from day 140 to day 160. The dip in the O_2 concentration and increase in CO_2 concentration is caused by respiration tests. CH_4 was not detected.

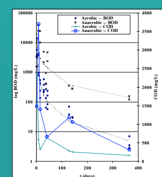
Average Metal Concentrations in the Leachate

Element	Aerobic A (ppb)	Aerobic B (ppb)	Aerobic C (ppb)
Mg	7180	8360	37200
Mn	48.2	27.9	2290
Fe	63.3	48.7	1530
Si	1780	1590	6440
Sn	657	883	2410
Ca	22900	26800	219000
Na	79700	73200	855000
K	ND	31900	129000
B	426	360	199
Al	<PQL	26.5	<PQL
Sb	2.5	12.2	6
Ba	40.9	41.2	56.9
Cr	<PQL	<PQL	18.5
Co	<PQL	1	4.4
Cu	10.1	14.9	8.5
Pb	<PQL	<PQL	31.4
Ni	34.5	7.8	18.7
Zn	12.2	10	27.8
Sr	130	136	639
Cd	1.1	0.5	2.1

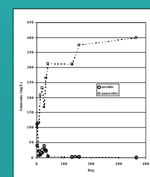
Average Values for measured parameters in the leachate of the MSW bioreactors



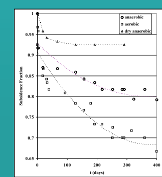
Decline in oxygen consumption rates as the MSW aged in the aerobic, wet tanks. The dashed line on the O_2 respiration curve represents a log fit



BOD and COD measurements from the aerobic, wet and anaerobic, wetbioreactors.

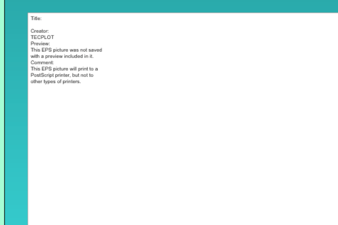


Ammonia concentrations in the aerobic and anaerobic bioreactor leachate.

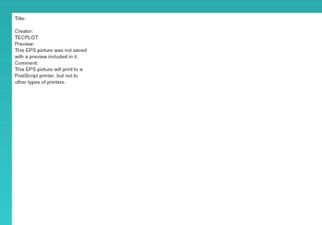


Cumulative settlement of the MSW from 0 to 400 days. Settlement from have been combined and grouped according to treatment.

LANDFILL BIOREACTOR MODEL: T2LBM



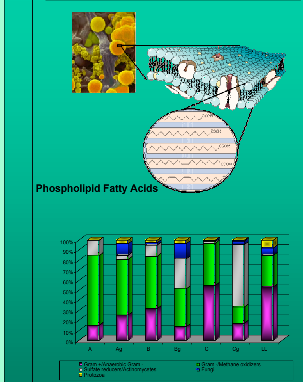
Liquid saturation and velocity vectors during leachate recirculation (left), and model heterogeneous permeability with gas velocity vectors during air injection (right).



Temperature and mass fraction of CO_2 in the gas phase during air injection. The highest temperatures are in the middle of the domain (R = 0 m) while the lowest temperature is at the bottom where the 20ºC air is injected. The lack of large temperature increase for the aerobic tank in the model result agrees well with the laboratory experiments, and results from the small size of the tanks and associated conductive cooling through the acrylic sidewalls, along with the injection of 20ºC air.

MICROBIAL COMMUNITY STRUCTURE

A. PHOSPHOLIPID FATTY ACID ANALYSIS



Microbial Community Distribution in Landfill Bioreactors and Landfill Leachate Samples

B. T-RFLP Community Analysis

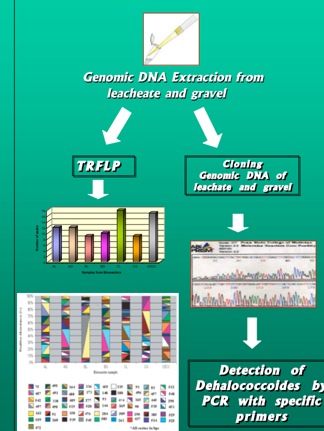


Fig 3. (A) number of terminal fragments present (richness)
(B) Relative abundance of T-RF 16S rRNA from landfill bioreactors (eveness).

Analysis of microbial community structure gives a general overview of the microbial communities present in the landfill bioreactors under different environmental conditions (oxic, anoxic), and give an understanding of what groups of microorganisms are actively involved in bioremediation and landfill stabilization. This analysis also allows for a determination of the conditions that are most favorable for the microorganisms in the landfill to degrade refuse components at optimal rate.

CONCLUSIONS

Storage of landfilled waste with both leachate recirculation and air injection accelerates the decompositions of the waste. Concentrations of metals and other constituents in the leachate of the MSW bioreactor are lower overall in the aerobic system.
- The aerobic landfill bioreactors showed significantly more settling and mass loss than the anaerobic bioreactor and maintained a neutral pH and low levels of all measured parameters, including BOD, COD, and ammonia, compared to the wet, anaerobic bioreactor leachate
- The reduction in noxious odors was also a significant esthetic advantage of the aerobic system.
- All major groups of microbial communities are present in the Bioreactor leachate and gravel sample as well as in the landfill samples, but their distribution is varied. Approximately 80% of the biomass belong mainly to bacteria. The remaining 20% accounts for fungi and other microeukaryotes.
- To explore the bacterial communities present in the landfill bioreactors the 16S rRNA of the total communities were amplified and analyzed by T-RFLP. The results showed more diversity in the leacheate samples from the anaerobic bioreactors. Dehalococcoides was present of this group in the leacheate samples from Yolo County Landfill
- The good agreement between the laboratory experiment and T2LBM simulation results for a relatively complex process involving flow, transport, biodegradation, and gas production suggests that T2LBM is modeling fundamental processes active in the mesoscale bioreactor.
- To our knowledge, T2LBM is the first simulation model capable of handling 3-D multicomponent and multiphase flow, transport, and biodegradation with landfill gas production.

White, D.C., Davis, W.M., Nickels, J.S., King, J.D., Bobbie, R.J. Determination of sedimentary microbial biomass by extractable lipid phosphate. Oecologia. 1979. 40. 51-62.
Borglin, S., Hazen, T., Oldenburg, C., and Zawislanski, P. Mesoscale laboratory experiments of aerobic and anaerobic biotreatment of municipal solid waste, March 2002. LBNL 50576 (submitted for publication)
Oldenburg, C.M., Borglin, S.E., and Hazen, T.C., Multiphase Modeling of Flow, Transport, and Biodegradation in a Mesoscale Landfill Bioreactor. LBNL 50027 (submitted for publication)

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