WHAT SHALL WE DO WITH GARBAGE-DUMP AND LANDFILL LEACHATE?

Tzenge-Huey Shih
Civil Engineering Department
University of Alabama

Introduction

Current and future regulations will require the land disposal of garbage and other solid wastes in lined structures that will minimize the creation of leachate and will provide for its control (roofs may even be required for such structures). A major problem that we will have to care for that may not have been considered sufficiently is that the garbage dumps and sanitary landfills upon which we have depended for solid-waste disposal in the past represent a lurking liability with which we must deal over the next two or three decades. Those waste deposits include large amounts of organics that have been generating large volumes of organic-laden leachate and will continue to do so. As our growing populations encroach upon those areas that bear the wastes, we are finding that the leachates are contaminating the groundwaters that we need for drinking water and other uses. If we are to be able to use the waters, we must remedy the affected aquifers through the extraction and treatment of those leachates.

The objectives of the research reported in this paper were to study the regulations pertinent to solid-waste leachate, to consider the feasibility of leachate treatment at existing publicly owned treatment works (POTWs), and to simulate, through a program written in BASIC language, the oil-fired incineration of such leachate.

Regulations Review

Solid-Waste-Landfill Management and RCRA

With the passage of the Resource Conservation and Recovery Act (RCRA) of 1976, Subtitle C of RCRA required the Environmental Protection Agency (EPA) to establish a comprehensive regulatory program to ensure proper management of hazardous waste. Subtitle D of RCRA required EPA to provide technical assistance to the states and to develop federal criteria for controlling solid-waste management practices, and it authorized federal financial assistance to the states to accomplish this.

In 1978, EPA began implementing the provisions of Subtitle D. The guidelines for state plans were completed in 1979. The criteria for classifying solid-waste disposal facilities were finished in 1979, and minor modifications were issued in 1981. The criteria are entitled the "Criteria for the Classification of Solid Waste Disposal Facilities and Practices".

They appear in Part 257 of Title 40 of the Code of Federal Regulations (40 CFR Part 257). If a facility meets these criteria it is classified as a "sanitary landfill", otherwise it is an "open dump" and must be upgraded or closed.

The Development of 40 CFR Part 258

On November 8, 1984, the Hazardous and Solid Waste Amendments (HSWA) were passed which required EPA to promulgate revised RCRA Subtitle D criteria for facilities that receive hazardous household waste or hazardous waste from small-quantity generators. In response to HSWA, in August 1988, Part 258 was added to 40 CFR. Groundwater monitoring and appropriate corrective actions were included in 40 CFR Part 258 as being necessary to detect and correct contamination. The requirement is applicable to the acceptable location of new facilities and for existing facilities. For hazardous waste management, the HSWA strategy required each state to establish a permit program or other system of prior approval for facilities receiving small amounts of hazardous waste before November 8, 1987. Therefore, state governments have the responsibility of proving the existence and tracing the flows of hazardous-waste leachates.

After continuing development during the last decade, the rules for solid-waste management finally are defined clearly. To those owners and operators of new and existing municipal solid-waste landfills, 40 CFR Part 258 is the guide to be applied for such operations. All other solid waste disposal facilities and practices that are not regulated under Subtitle C of RCRA are subject to the criteria contained in 40 CFR Part 257. Open dumps are prohibited absolutely by RCRA.

Comparison of State and Territory Regulations

In a recent report prepared for EPA, the correspondences among existing local regulations of the 55 states and territories and the proposed federal regulations were studied (1). This review was based upon consideration of the three regulations aspects of facility design, groundwater monitoring (GWM), and corrective action (CA). Included within facility design were the provisions for liners, leachate collection systems (LCS), and final cover. A summary of the review is presented in table 1.

According to this review, only 27 percent of the state and territorial regulations required liners through design standards. About 52 percent of the jurisdictions did not have leachate collection standards. However, most of them required that all landfill have a final cover. Approximately 68 percent of states and territories recognized the importance of ground water monitoring. At least 73 percent of them did not in their regulations mandate corrective action if contamination by leachate happened at a landfill.

Properties of Landfill Leachate

The properties of landfill leachate depend upon many factors. They include amount of precipitation, type of leachate-collection system, type of wastes, time and location of waste placement, and operational methods. In general, leachate properties are very difficult to predict, and they may vary considerably from site to site and among different locations in the same facility. Methods for sampling and analysis of landfill leachate were discussed in detail in Chian and DeWalle (5).

Properties of landfill leachate were studied intensively in order to provide the background of 40 CFR Part 258 (2). The data sources were six independent studies (executed by Wisconsin, NUS, Trade Assoc., Sobotka, Texas A&M, and WMI) on leachates from 83 municipal-solid-waste landfills (MSWLFs). They included 60 landfills which yielded both organic and inorganic leachate analyses, 16 landfills which yielded only inorganic analyses, and 7 landfills which yielded only organic analyses.

The information on leachate from 11 hazardous waste landfills was studied and reported by TRW so that it could be used as the basis for the comparison with and evaluation of MSWLF leachate. Nine out of 11 landfills were analyzed for both inorganics and organics. Of the two remaining, one was analyzed only for inorganic and the other one was analyzed for organics alone.

Despite the magnitudes of the costs and the efforts that were expended to obtain leachate data representative of about 6,000 landfills nationwide, the collected data were proclaimed to have several weakness (2). The weaknesses were attributed to limited sample size, inconsistent sampling and analytical methods, and ambiguous sample-background information (such as insufficient description of landfill ages and types of wastes disposed).

However, until it is possible to collect more suitable and more complete long-term data, the existing data are still very valuable. The analytical data (2) indicated that organic and inorganic concentrations in leachates from pre-1980 MSWLFs were much lower than those for post-1980 MSWLFs. Therefore, post-1980 data are more pertinent to the problems that we will face than are data from pre-1980's facilities. Summaries of median inorganic and organic data respectively from hazardous waste landfills and post-1980 MSWLFs are presented in Tables 2 and 3.

Estimation of Leachate Generation

The quantity of leachate generated at a facility is determined by the water (or liquid) balance at the site (4). Methods used to simulate the leaching processes have been reported by Lowenbach (6).

Over time at a landfill, the water sources sum to equal the quantity of water losses and leachate produced. Sources include precipitation and water that is present in the deposited wastes. Groundwater flow also may contribute to leachate quantity in facilities constructed in the saturated zone (depending on liner design).

In addition to the water that is sorbed among the deposited wastes, aerobic decomposition of the organic wastes can provide a water source. The moisture content of solid waste may vary as widely as from 10 to 30 percent depending upon its sources. Large proportions of kitchen wastes may cause high water contents.

In organic waste that is decomposed aerobically, hydrogen is oxidized to produce water which increases the quantity of leachate. Under anaerobic conditions, hydrogen and carbon sources will be converted into methane. In addition to other factors, the volumetric extent within which aerobic conditions prevail in a landfill depends upon the depth and nature of the material used to cover the wastes. The decomposition of landfill solid wastes is believed to occur first under aerobic and then under anaerobic conditions (7). Ehrig reported leachate generation attained its maximum rate after a year of waste burial and gradually decreased after the end of the fifth year (8).

Precipitation contribution can be estimated by empirical equations based on field observation and the mechanics of saturated flow in porous media (9-11). The rate at which water is transmitted through the surface layer is highly dependent upon the condition of the surface. For landfills that receive snow, one should consider the increasing of leachate quantity at the time of snow melting. Leachate generated from precipitation may be 3 to 4 times or even higher than that from moisture derived from the landfill waste (12). Roofing principles are proposed for avoiding leachate created by precipitation.

Liquid discharges include evaporation, transpiration, and seepage out of the facility. The evaporation and transpiration phenomena decrease the volume of waste discharged as leachate and thus indirectly increase the pollutant concentrations within the leachate. The contaminants remain in the leachates. Most of the water from the landfill-liquid sources that is discharged from the landfill leaves as leachate.

Leachate Treatment

The required degree of landfill-leachate treatment is described in 40 CFR Part 258.27. The discharge of leachate should not violate any requirements of the Clean Water Act, including, but not limited to, the National Pollutant Discharge Elimination System (NPDES) requirements.

Two main concerns pertinent to leachate contamination are those for heavy metals and organic matters. Concentrations of heavy metals, such as copper, lead, and zinc, generally are low in leachate (19). Organic material, due to high BOD and strong odors, usually raise different concerns from those for heavy metals.

Heavy Metals Removal

The removal of heavy metals, together with solids, are mainly executed by adding coagulants and then settling the coagulum in a precipitation tank (11). Another function of precipitation tanks is to moderate the leachate flow rate so that shock loading conditions may be avoided.

Organic Materials Removal

Most of the readily decomposable organic materials in deposited wastes may be decomposed within the first 5 years after burial. Therefore, the ratio of BOD to COD is lowered for leachate from wastes buried for longer periods. However, due to the destruction of solid-waste structure, suspended solids and heavy metals still may be found in the leachate from older deposits.

The considerations for the treatment of the organic constituents of sanitary-landfill leachate should include that of the biological decomposition of organic waste within a landfill. Four phases have been proposed to describe the solid-waste biological decomposition processes (13,14,18).

The first phase is characterized by the decomposition of high-molecular-weight, humic, carbohydrate material to form volatile fatty acids. The second phase is the biological decomposition of free volatile fatty acids to compounds containing the carbonyl group and amino acids. During the third phase, the compounds containing the carbonyl group and amino acids are converted to high-molecular-weight compounds. In the fourth phase, slow decomposition of the compounds produced in the third phase occurs.

The organic material present in leachate from landfills in the first and second phase, volatile fatty acids, and amino acids are readily treated by biological processes. Leachates produced by landfills in the third and fourth phases generally require both biological and physical-chemical treatment, if relatively low effluent organic concentrations are required.

The strength of a leachate produced by a sanitary landfill, evaluated in terms of gross organic parameters, will decrease with time, with the leachates from landfills in phase one and two being the strongest. These materials are characterized by CODs ranging about 20,000 mg/l, and have acetic and propionic acids as their major constituents, although amino acids and compounds containing the carbonyl group also usually are present. Leachate from landfills operating in phases three or four usually are significantly lower in organic content, with typical CODs ranging from 1,500 to 4,000 mg/l. Chian (15) studied the leachate treatment processes and concluded the most recommended processes as being those presented in Table 4.

The biological treatment methods seem suitable for treatment of leachate from young landfills which have high COD/TOC and BOD/COD values. The aerobic methods may function with difficulty for the treatment of high-concentration leachates. The popular strategy of using aerobic methods for organic removal from such leachates is extended aeration. Even this generally produces less efficient removal ratios than do the anaerobic methods. In order to remove high concentrations of organic matters from the leachate, aerobic reactors require a proportional oxygen supply which may contribute to the operation and maintenance costs.

The anaerobic digestion method, which provides higher organics-removal efficiency, requires long hydraulic detention times. The two-stage anaerobic filter-bed method worked much better than other methods. Recent research showed that leachate treated by up-flow anaerobic sludge bed (UASB) and multi-stage anaerobic fluidized bed have the benefits of short hydraulic detention time and high organic removal efficiency (12,16,17).

Treatment of Landfill Leachate at POTWs

The background document of 40 CFR Subpart D indicated that the most common method of leachate disposal was treatment at municipal treatment plants (23). But, what is the ability of POTWs to accept landfill leachate? Decker et al. [24] surveyed the performance of wastewater treatment plants to identify significant technical-information needs at the existing plants. The surveyed population included the 100 largest plants among the Association of Metropolitan Sewerage Agencies (AMSA) members and 40 small treatment plants in Wisconsin. The survey findings showed that 64 percent of the plants surveyed had designed capacity smaller than 5.0 mgd and half of them had capacity smaller than 1.0 mgd. Only 15 percent of surveyed plants were less than 5 years of age, and 49 percent of them were older than 20 years. The survey showed that 48 percent of the plants experienced flow rates smaller than their hydraulic capacities. Theoretically, most of the POTWs may accept some landfill leachate based upon their designed hydraulic loading.

However, the relatively out-of-date design, even before considering leachate, and the organic loading of the POTWs already had caused administrative problems and relatively high facility operations and maintenance costs [24]. In the mixing of leachate and wastewater, one should consider carefully the increasing organic-loading problem, the problem which caused operational problems of many POTWs studied. An interesting revelation of their survey is that some of the sludge from the POTWs was disposed back to the landfills. The leaching of sludge in the landfill may accumulate heavy metals and organic matters. Solidification and stabilization processes usually were not used to dispose POTW sludge because such sludge is not classified as hazardous waste under RCRA.

The discharge of landfill leachate into a municipal wastewater collection system with subsequent treatment at the municipal treatment plant was investigated by Schuk and James (25). Due to the unavailability of leachate from a landfill site, Schuk and James prepared synthetic wastewater to simulate its likely effect on a conventional activated sludge process.

After appropriate dilution, the inflow leachate was mixed with the primary effluent of the POTW. The secondary effluent from the pilot experiment showed that TSS and COD were 90 percent and 80 percent removed, respectively. Total nitrogen was decreased to 50 percent of its influent concentration. However, the suitable dilution of the leachate may involve the recycle of secondary effluent so that an enlargement of the plant would be necessary. Therefore, such treatment would increase the capital investment and operation and maintenance costs of the POTW.

Schuk and James also found that the phosphorous concentration in the mixed wastewater significantly affected the treatment efficiency. They recommended adequate phosphorous addition.

Few landfills are located immediately adjacent to POTWs, and no existing regulations require that landfill leachate be treated at the site of leachate generation. In some cases where piping to the POTW was not available, open-channel flow in unlined conduits has been used. Exfiltration from some of these has caused groundwater contamination. In other cases, leachate is stored in tanks until tank trucks can transport the leachate to POTWs. That solution is satisfactory only for facilities at which the amounts of leachate are small. For many future facilities, treatment at the site will be the only economical solution.

Landfill Isolation

The trends in landfill designs have been affected by current and anticipated regulations with the result that landfills are being built with single liners and even double liners (22). Low-permeability soil and flexible synthetic membranes have been used as landfill liners. The potentials of various lining materials for controlling the movement of leachate from municipal solid-waste landfills was studied extensively by Haxo et al. (20). They tested 65 materials which were subjected to at least one of seven different tests under the exposure to MSW leachate. Among the tested materials, asphaltic materials exhibited the poorest performance after 56 months of simulation. Some materials were found to be swelled and softened. The low-density-polyethylene (LDPE) film best maintained original properties during the exposure period, and it also absorbed the least leachate. However, it has low puncture resistance for use in lining a landfill.

Synthetic material, such as high density polyethylene (HDPE), polyvinyl chloride (PVC), ethylene propylene diene Jerpolymer (EPDM), and chloro-sulfonated polyethylene (CSPE) were used in Fu-Der-Ken Sanitary Landfill of Taipei (21(. Upon the basis of the test results obtained by Haxo et al., polyethylene is the material highly recommended to be used as landfill lining. To avoid the problem of liner puncture by sharp disposed solid waste, HDPE is recommended.

High leachate levels increase the potential for seepage through a liner system. Gravitational collection systems are used to drain leachate from the liner and thereby reduce the potential for trans-liner leachate migration. The system is intended to function effectively through the facility's active life and closure period and until leachate generation has ceased (3).

Leachate Incineration

Leachate treatment by an oil-aided combustion method was studied by a simulation program (MSWLLIC). MSWLLIC is an algorithm implemented in the BASIC programming language. MSWLLIC is the acronymic name for Municipal Solid Waste Landfill Leachate Incineration Calculation. This program calculates the oil requirement for the leachate combustion to decompose the organic materials into harmless carbon dioxide and water vapor. The algorithm of MSWLLIC was adapted from Taidou (26).

Program Structure

MSWLLIC consists of one main program and four subroutines. The main program calls the subroutines. Of its four subroutines, INFOR accepts data to allow the beginning of the computations. OIL performs a mass and heat balance for the leachate incinerator and oil requirements for combustion execution. HEXE calculates the heat recovery to raise the leachate temperature. PFILE prints out the results of the whole computation.

Simulation Example

In order to demonstrate the utility of the simulation, a data set of typical landfill leachate and reasonable operational parameters were submitted to the simulation program. Leachate was assumed to be collected and settled in a storage tank until the total solid concentration attained 5,000 mg/l. The flue gas from the leachate incinerator was set to be 300 degrees C. A gas-liquid heat exchanger was followed by an incinerator to raise the temperature of influent leachate. The combustion flue gas was cooled from 300 degrees C to 100 degrees C through the heat exchange with the influent leachate. The exchanged flue gas temperature of 100 degrees C is a little bit higher than its dew point under the atmospheric pressure. The white vapor caused by water vapor partial pressure below the dew point of the flue gas might be misunderstood to be a nonhydrous pollutant. The odors of the flue gas would be absorbed by a catalytic absorption tower which was not considered in the simulation program.

Simulation Results

The leachate temperature was raised from 10 degrees C to 85 degrees C by recovering heat from the leachate combustion flue gas. About 60 kg (or 75 l) of oil needs to be used to burn one ton of leachate. The latent heat of water vaporization took about 82 percent of the total energy input. If the leachate could be centrifuged or dried to increase its solids concentration, the efficiency of leachate incineration could be improved.

Conclusions

The new regulation, 40 CFR Part 258, has been added as the guidance for solid-waste landfill operation. Together with RCRA Subtitle C & D and 40 CFR Part 257, the operations of municipal solid-waste and hazardous-waste landfill are covered by more complete regulations than before. Garbage dumps no longer will be legal. Groundwater monitoring will be part of the landfill operation.

The separation of run off and leachate are important for wastewater-volume minimization. The roofing principle, an ideal for the separation of precipitation and leachates is to protect the top of the landfill. A dependable lining system, an ideal to prevent the contamination of groundwater, is to isolate the bottom of the landfill from its surroundings.

If aerobic processes are to be used for leachate treatment, effluent recycle with the lowered concentrations and extended detention times in the system may be a useful option. Anaerobic methods may be considered for landfill-leachate treatment due to the high efficiency and short hydraulic retention time they allow. Leachate incineration may be considered if its organic concentration and operational temperature can be raised sufficiently.

Recommendations

It will be necessary that all future landfills be constructed with liners so as to minimize the leachate quantity and its infiltration of aquifers. HDPE may be considered as the most recommended landfill lining. The authors urge the separate collection of run off and leachate so as to minimize the volume of leachate to be treated.

References

1. NUS Corp., "Criteria for Municipal Solid Waste Landfills (40 CFR Part 258), Subtitle D of Resource Conservation and Recovery Act(RCRA), Update Review of Selected Provisions of State Waste Regulations; Draft Report," EPA/530/SW-88/039, 1988.

2. "Criteria for Municipal Solid Waste Landfills (40 CFR Part 258), Subtitle D of Resource Conservation and Recovery Act (RCRA), Summary of Data on Municipal Solid Waste Landfill Leachate Characteristics; Draft Report," EPA/530/SW-88/039, 1988.

3. Bass, Jeffrey, "Avoiding Failure of Leachate Collection and Cap Drainage Systems," Noyes Data Corporation, New Jersey, 1986, p. 2.

4. Fenn, D. G., et al., "Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites," EPA/SW-168, 1975.

5. Chian, Edward S. K. and DeWalle, Foppe B., "Compilation of Methodology for Measuring Pollution Parameters of Landfill Leachate," EPA-600/3-75-011, 1975.

6. Lowenbach, William, "Compilation and Evaluation of Leaching Test Methods," EPA-600/2-78-095, 1978.

7. Vesilind, P. Aarne and Rimer, Alan E., "Unit Operation in Resource Recovery Engineering," Prentice-Hall, New Jersey, 1981, p. 394.

8. Ehrig, H. J., "Quality and Quantity of Sanitary Landfill Leachate," Waste Management & Research, Vol. 1, 1983, pp. 53-68.

9. Viessman, Warren Jr., et al., "Introduction to Hydrology," Harper & Row, New York, 1977, pp. 67-81.

10. Ponce, Victor M., "Engineering Hydrology: Principles and Practices," Prentice Hall, 1989, pp. 34-38.

11. National Municipal Cleaning Association of Japan, "An Explanation of the Design Guide of Landfill Leachate Treatment," Environmental Facilities No. 9, 1982, pp. 32-53.

12. Chen, C. C., "An Investigation of Landfill Leachate Treatment," Proceedings of the Symposium of Refuse Treatment, Taipei, Taiwan, The Republic of China, July 9-10, 1987.

13. Stanforth, R., Ham., R. & Anderson, M., "Development of a Synthetic Municipal Landfill Leachate," JWPCF, 51, No.7, 1979, pp.1965-1975.

14. Chian, E. S. K. & DeWalle, F. B., "Evaluation of Leachate Treatment, Vol. 1, Characterization of Leachate," EPA-600/2- 77-186a, 1977.

15. Chian, E. S. and DeWalle, F. B., "Evaluation of Leachate Treatment, Vol. 2, Biological and Physical-Chemical Processes", EPA-600/2-77-186b, 1977.

16. Kao, W. D., "A Research of Garbage Leachate Treatment by Anaerobic Filter Bed," Thesis, National Cheng-Kung University, Taiwan, The Republic of China, 1986.

17. Ran, K. D., et al., "The Recent Research of Anaerobic Techniques Applied on Wastewater Treatment in Netherlands," Journal of Industrial Pollution Prevention, The Economic Affairs of the Republic of China, Vol. 7, No. 3, 1989, pp. 101-104.

18. Barlaz, M. A., et al.," Mass-Balance Analysis of Anaerobically Decomposed Refuse," Journal of Environmental Engineering, Vol. 115, No. 6, December, 1989, pp. 1009-1011.

19. Bagchi, Amalendu, "Design of Natural Attenuation Landfills," Journal of Environmental Engineers, Vol. 109, No. 4, August, 1983, pp. 800-811.

20. Haxo, H. E., et al., "Liner Materials Exposed to Municipal Solid Waste Leachate,", Vol. 3, 1985, pp. 41-54.

21. Yang, R. C., "The History of Fu-Der-Kan Sanitary Landfill Development", Proceedings of the Symposium of Refuse Treatment, Taipei, Taiwan, July 9-10, 1987, p. 13-14.

22. Tchobanoglous, George, et al., "Solid Wastes: Engineering Principles and Management Issues," Mcgraw-Hill, 1977, pp. 339-344.

23. "Criteria for Municipal Solid Waste Landfills (40 CFR part 258), Subtitle D of Resource Conservation and Recovery Act (RCRA), Design Criteria; Draft Report," EPA/530/SW-88/042, 1988.

24. Decker, Karen, et al., "Technology and Design Deficiencies at Publicly Owned Treatment Works," Water Environment & Technology, Vol. 1, No. 4, December, 1989, pp. 515-519.

25. Schuk, Walter W. and James, Stephen C., "Treatment of Landfill Leachate at Publicly Owned Treatment Works," Waste Management & Research, Vol 4, 1986, pp. 265-277.26. Taidou, Takahuzi, "Wastes Incinerators - Planning and Design," Environmental Planning and Preparing Research Association, Tokyo, 1982, pp.142-148.

Table 1. A Review of Solid-Waste Regulations

Facility Design														
Liners			Leachate Collection System			Final Cover			Groundwater Monitoring			Corrective Actions		
NS	PS	DS	NS	PS	DS	NS	PS	DS	NS	PS	DS	NS	PS	
32	9	15	29	21	6	6	3	46	17	34	4	41	14	
19*			15*			3*			9*			18*		

Source: (1)

Note: (1) NS: no standard (2) PS: performance standard (3) DS: design standard (4) *: possibly in guidance based on 1984 RCRA Subtitle D State Census

Table 2: Median Inorganic Constituent Concentrations Summary (milligram per liter except as noted)

Water Quality Parameter	HWLFs	Post 1980 MSWLFs
Alkalinity	540	3,900
Ammonia	870	299
Biological Oxygen Demand	13,400	185
Calcium	72	747
Chemical Oxygen Demand	12,600	4,300
Chloride	2,028	820
Conductivity (umho/cm)	20,000	8,800
Hardness	2,930	2,900
Iron	17.2	230
Nitrogen (Organic)	22.8	45
pH (units)	6.9	6.91
Potassium	34	462
Sulfate	399	260
Sodium	377	817
Total Dissolved Solids	10,562	7,976
Total Suspended Solids	1,470	554
Total Organic Carbon	4,624	2,860
Aluminum	2.2	2.6
Arsenic	2.78	0.011
Barium	0.84	1.0
Cadmium	0.6	0.0065
Chromium (Total)	0.110	0.008
Copper	0.215	0.031
Lead	0.48	0.046
Manganese	7.65	12.38
Magnesium	25.4	412
Nickel	0.272	0.185
Selenium	6.53	0.002
Silver	0.02	0.036
Vanadium	0.150	0.0185
Zinc	0.536	0.335

Source: (2)

Table 3: Median Organic Constituent Concentrations Summary (micrograms per liter)

Water Quality Parameter	HWLFs	Post 1980 MSWLFs
Acetone		60,0004,000
Chloromethane	340	400
1,1-Dichlorethane	594	4
Trans-1,2-Dichlorethylene	2,350	14
Diethyl Phthalate	83	32
Isophorone	208	25
Methylene Chloride	7,715	120
Phenol	1.09	1,700
Toluene	880	590

Source: (2)

Table 4. Leachate Quality Parameters and Proper Treatment Processes

COD/TOC	BOD/COD	Age of Fill (years)	COD (mg/l)	Biological Treatment	Chemical Oxidation	Ozonation
>2.8	>0.5	<5	>10,000	Good	Poor	Poor
2.0-2.8	0.1-0.5	5-10	500-10,000	Fair	Fair	Fair
<2.0	<0.1	>10	<500	Poor	Fair	Fair
		Reverse Osmosis	Activated Carbon	Ion Exchange Resin	Chemical Precipitation	
		Fair	Poor	Poor	Poor	
		Good	Fair	Fair	Fair	
		Good	Good	Fair	Poor	

Source: (15) Other biological treatment methods were summarized by Kao (16) as in table 5.

Table 5. A Summary of Biological Methods for Leachate Treatment

Methods	Proposer	Inflow COD (mg/l)	BOD/COD	Hydraulic Detention Time (days)	COD Removal Rate (%)	System Used	Organic Loading (kg/m^3-d)
	Boyle & Ham	8800	0.8	5	74	Lagoon	1.76
	Cook & Foree	290-8450	0.45	5-10	46.5-98.1	Activated Sludge	0.85
	Uloth & Marinic	44000-52000	0.69-0.82	>20	97	Extended Aeration	2.60
Aerobics	Robinson & Moxis	4805	0.59	1-20	62-97	(Same)	.24-4.81
	Chain & DeWalle	30000	0.65	7	99	(Same)	4.29
	Pohland Kahm	500	0.52	0.3	58	(Same)	1.67
	Polit & Qasim	360	x	0.5	86	(Same)	0.72
	Karr	3550	0.64	0.6	77	(Same)	5.92
	Coulter	1350	.61-.63	x	83-86	R.B.C.	x
	Boyle & Ham	8960-22400	0.82	5-20	90-96	Recycle	1.42-1.79 Digestion
	Forree & Reed	12900	0.45	10	92	Digestion	1.29
Anaerobics	Karr	16500	0.62	15	99	(Same)	1.10
		5500	0.78	10	93	(Same)	0.55
	Chian & Dewalle	30000	0.65	27	97	Filter B.	1.11
	Rogers	1300	0.81	1.2	87	(Same)	1.08
	Wu & Kennedy	10117-21868	.09-.64	1.75-8	68.6-96	Two-Stage Filter B.	2.73-5.78
Combination Methods	Boyle & Ham	740	0.17	5	40.5	Aerobic	0.15
	Forree & Reed	510	x	1	22	Lagoon +	0.51
	Chian & Dewalle	1000	x	1	17	Anaerobic D.	0.14

Source: (16)