Leachate Treatment Options For Sanitary Landfills

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Abstract: At the dawn of the new millennium, sanitary landfill remains an environmentally sound and cost effective option for disposing of the debris of modern civilization. It is a technology that can be successfully utilized by both developed and developing countries. Improvements in sanitary landfill design and operation parameters over the last decade have concentrated on lining systems and residuals management (gas, liquids). Improved lining systems have minimized the threat of groundwater contamination while simultaneously resulting in higher leachate recovery. Environmental protection demands that these liquids, typically high in organic content, be treated before discharge. The cost of managing these liquids is substantial in both the active and post-closure period. Numerous schemes have been developed to treat leachate. Most are based on traditional sanitary wastewater treatment schemes, but numerous innovative or new applications of existing technologies, are now available for leachate treatment.

Several treatment options (biological, physical, chemical, thermal) are described along with associated advantages and disadvantages. Incentives for exploring alternative leachate treatment technologies include:

- Reduced cost of managing leachate and other landfill liquids,
- Utilizing processes that can meet more stringent effluent quality,
- Utilizing processes that are more amenable to changes in leachate quality over time,
- Utilizing processes with the ability to remove difficult contaminants such as total dissolved solids (TDS) and,
- Utilizing processes that can effectively reduce the elevated ammonia concentrations that are associated with recirculation and bioreactor modes of landfill operation.

This paper addresses the emerging issue of leachate composition changes as a function of recirculation and bioreactor operation techniques. One of the most promising of the advanced landfill operating models is bioreactor, which uses moisture control (via recirculation and other methods) to optimize the degradation of organic compounds in a landfill. One potential concern is the increasing concentration of ammonia in recirculated leachate. Cost effective and efficient ammonia control is one of the key requirements for successful bioreactor operations. The control of ammonia has not historically been addressed at on-site leachate treatment systems in the U.S. This is an area where concentrated research effort is required.

A case history of an U.S. East Coast landfill is presented to illustrate one method of on-site ammonia control. This landfill has recirculated leachate for several years. Concentrations of NH_3-N range from 300 to 550 mg/L. An enhanced biological process for the elimination of nitrogen from the landfilled waste and leachate was tested. Preliminary data suggests that the nitrification process was successful during the field trial and would be successful on a full-scale application.

Key Words: ammonia, biological treatment, bioreactor, evaporation, filtration, landfill, leachate, membrane treatment, nitrification, recirculation, reverse osmosis, thermal, treatment.

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1.0 Introduction: Several options for leachate treatment (physical, chemical, biological, thermal) are described along with the associated advantages, disadvantages, relative ease of operation, and relative cost. Incentives for exploring alternative leachate treatment technologies include:

- Reduced cost of managing leachate and other landfill liquids,
- Utilizing processes that can meet more stringent effluent quality,
- Utilizing processes that are more amenable to changes in leachate quality over time,
- Utilizing processes with the ability to remove difficult contaminants such as total dissolved solids (TDS) and,
- Utilizing processes that can effectively reduce the elevated ammonia concentrations that are associated with recirculation and bioreactor modes of landfill operation.

This paper also addresses the issue of leachate composition changes as a function of recirculation and bioreactor operation techniques. A potential negative of recirculation is the increasing concentration of ammonia. Cost effective and efficient ex situ ammonia control is one of the key requirements for future leachate treatment schemes. The ammonia control phenomenon is discussed along with a case history.

2.0 Traditional schemes for leachate treatment: The leachate treatment alternative of choice for many landfills is off-site treatment at a Wastewater Treatment Plant (WWTP). This is often the most economical solution, but leachate is not always welcomed by the WWTP. Off-site treatment carries the additional liabilities of over-the-road transportation and cost. It offers the benefit of transferring wastewater treatment to the experts, elimination of duplicating costly treatment plants and offering the landfill owner a turn key disposal option.

On-site leachate treatment schemes (either pre- or full treat) often mimic the traditional wastewater treatment industry. Most leachate treatment schemes to date have been biological systems, including sequential batch reactors and fixed film reactors. These on-site biological-based systems generally do not have the capability to deal effectively with ammonia or TDS.

3.0 Innovative leachate treatment technologies: Numerous treatment technologies have been developed, refined or adapted for use in leachate treatment service over the past few years. One obstacle to developmental work in the field of leachate treatment is current market conditions in the solid waste industry. Due to industry consolidation in world markets, there are few major waste companies. This equates to relatively few dollars spent annually on leachate treatment equipment. Regulatory interest in the U.S. has largely moved to air-related issues, the market for expensive treatment schemes is minimal and so it does not drive the investment by equipment manufacturers and inventors. It is, however, often possible to find technologies of interest to leachate treatment in other non-related fields, such as food and the petrochemical industry.

Table 1 summarizes several leachate treatment technologies that have been successfully used in U.S. markets. Table 2 compares the relative capital and operation costs for several leachate treatment systems as applied to a 114 m^3/day (30,000 gpd) plant. Tables 1 and 2 appear at the end of this paper. Selected leachate treatment methods are discussed in more detail below.

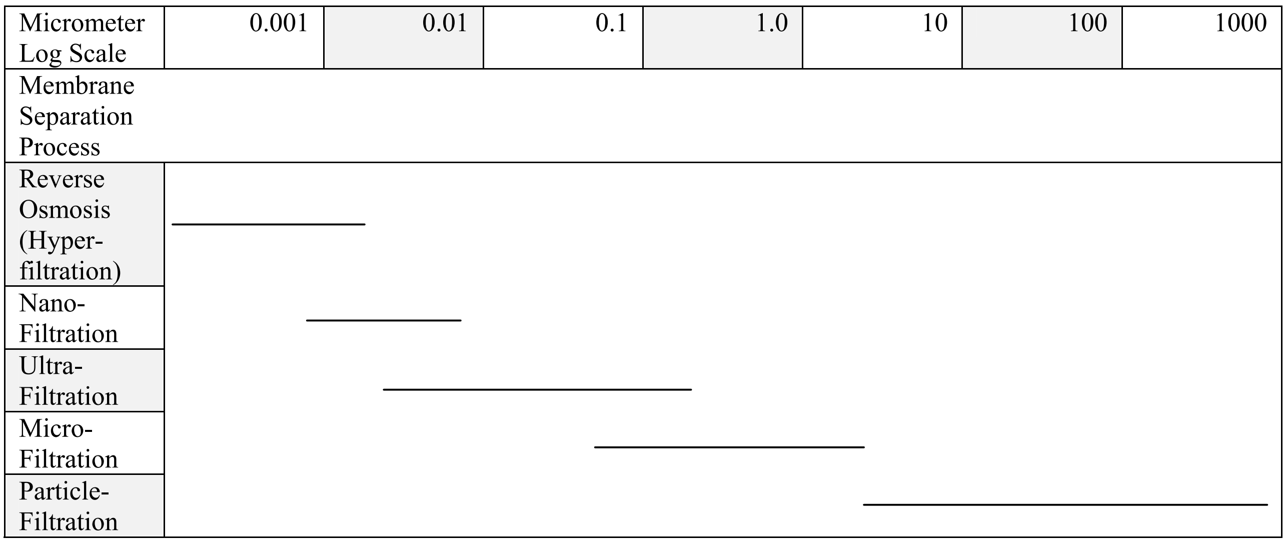
3.1 Clay-based products

Clay-based treatment products are available, typically bentonite clay modified with various polymers and chemicals. These clays are modified with various components that provide treatment of oils, sulfate, phosphate, and metals. The resulting mass is a complex mixture of encapsulated contaminants and clay solids held together by Van der Waals and electrostatic forces. Once the pozzolanic reactions begin between the lime and the bentonite, the process of microencapsulation is complete. The contaminants are microencapsulated and are surrounded by a barrier of clay particles making it nonreactive to external leaching. The process generally only takes one minute and can be done in one treatment tank plus one solids tank.

3.2 Membrane separation

Membrane separation uses selective semi-permeable membranes to remove concentrations of organic and inorganic compounds from water. These compounds typically consist of high-molecular weight species including dissolved (soluble) solids such as complexed metals and salts, oil emulsions, colloidal dispersions (clay, micro-organisms), macromolecules (proteins, polymers), and suspended solids. The semi-permeable membrane allows the passage of water, but rejects the passage of the other compounds. Three types of systems are described: reverse osmosis, direct osmosis concentration, and conventional membrane separation. Figure 1 illustrates the range of particle sizes that can be removed by several types of separation processes.

Figure 1, Range of Particle Size Applicability for Various Separation Processes



3.2.1 Reverse osmosis

Reverse Osmosis (RO) is a membrane process that separates soluble components on the basis of molecular size and shape. It is capable of removing TDS. A high-pressure pump forces leachate through a membrane, overcoming the natural osmotic pressure and dividing the leachate into a water stream (permeate or product) and a concentrated (brine) stream. Molecules of water pass through the membrane while contaminants are flushed along the surface of the membrane and exit as brine. Typical recovery rates (percentage of the feed that becomes permeate or clean water) range from 75 to 90%. Adequate throughput for a leachate membrane separation system requires that the system must operate at pressures of 2,000 to 2,800 kPa (300 to 400 psi) above the osmotic pressure of the solution. At a concentration of 10,000 mg/L (ppm) of TDS, the osmotic pressure of leachate is approximately 700 kPa (100 psi). Typical RO systems operate at pressures between 2,800 and 5,500 kPa (400 and 800 psi). Pretreatment (typically filtration and/or pH adjustments) may be required before RO to avoid unacceptably high cleaning and reduced membrane life.

Regardless of the type of RO system used, a concentrated brine residual will result. Options for managing the brine include transportation to off-site treatment/disposal site, recirculation into the waste mass, evaporation, and solidification. Solidification can be accomplished by using a bulking agent such as sawdust, flyash, or lime, followed by landfill disposal (if the solidified product meets disposal criteria.)

3.2.2 Direct osmosis

Direct Osmosis Concentration (DOC) is a cold temperature membrane process that separates waste streams in a low-pressure environment (Osmotek, Corvallis, OR). Originally designed for food processing, DOC has been adapted to treat leachate. The system operates by placing a semi-permeable membrane between the leachate and an osmotic agent (OA), typically salt brine with a concentration of approximately 10%. The semi-permeable membrane allows water to pass from the leachate (without outside pressure) into the salt brine, and rejects contaminants found in the leachate. As the process continues, the OA becomes dilute. This process is called osmosis; it continues until the water concentrations on both sides of the membrane are equivalent. DOC is an equilibrium process, while RO is a high-pressure process. Osmotic pressure selectively draws molecules through the membrane and avoids membrane fouling. The system can reject metals and organics and operates at a pressure of about 35 kPa (5 psi). In a typical leachate treatment system, the DOC technology removes over 93% of the water from the leachate. Water is driven out of the leachate by osmotic pressure generated by the high salt concentration gradient across the membrane. The salt brine (used as the OA) has a concentration of 10.5 %, which produces an osmotic driving force equal to 8,300 kPa (1,200 psi). In the process, the OA is diluted to a concentration of about 5%. The OA then is reconcentrated by conventional RO and reused to extract water from more leachate.

3.2.3 Filtration

Other forms of membrane separation are ultrafiltration and microfiltration. Ultrafiltration removes large organic molecules, but allows all dissolved salts and most small organics to pass. Microfiltration systems remove all particulate matter such as silt and bacteria, but will not remove dissolved salts and most organic molecules. (See Figure 1) These filtration systems can be found in some metals removal processes for landfill leachate with membranes specifically designed to remove hydroxide and sulfide forms of metals precipitates. As with the RO and DOC units described earlier, these membrane filtration units produce a concentrate that must be managed and disposed.

3.3 Thermal processes

Thermal processes, particularly evaporation, are the only “treatment” technologies available today that disposes of the water component of water-based waste streams, such as leachate. This technology can reduce the total volume of leachate to less than five percent of the original volume. Leachate evaporation systems generally are economically feasible at sites with an adequate supply of landfill gas (LFG) to evaporate the volume of leachate generated. The energy required to evaporate one kg of water is 2,675 kJ. Approximately 350 kJ are required to heat 1kg of leachate to its boiling point. An additional 2,325 kJ are required to vaporize 1 kg of water at the boiling point.

To be cost effective, evaporators should be fueled by landfill gas. Evaporation is a technology that effectively integrates the control of landfill gas and landfill leachate. Evaporative systems typically require an air permit for the flare and modification to the landfill solid waste permit to address leachate management practices.

Unlike conventional treatment systems, evaporative systems are insensitive to changes in leachate characteristics, including concentrations of BOD, COD, suspended and dissolved solids, and variations in feed temperature. Generally, pH is the only factor to which the evaporative systems are sensitive; this is because of the corrosive potential of acidic leachate against alloys used in constructing the evaporators. To insure that pH is not a problem, a pH adjustment system is provided where pH might drop below 7.0.

The byproduct of these systems is a residual material that usually can be returned to the landfill for disposal. Depending on the evaporative system, the residual material is a solid, grit-like material that can be buried with the solid waste, or it is in a semi-solid form that can be recirculated into the buried waste, if permitted by regulatory agencies. The residual can also be solidified by adding a bulking agent and then be disposed with the waste.

The air quality of combusted gases exhausted from an enclosed flare connected to an evaporator should not change significantly from that of the exhaust emitted when the flare is operating alone. Within the thermal oxidation zone of the flare, the destruction rate efficiency (DRE) for organic contaminants introduced by evaporator exhaust vapor remains the same as that for organic contaminants in LFG treated in the flare. This stability in DRE is true because operating temperatures within the flare remain the same and residence time actually increases slightly when the evaporator is operating. In some systems, exhaust vapor from the evaporator simply replaces some of the quench air used in the flare. In other evaporative systems, the thermal oxidation process is designed to meet site-specific DRE requirements.

3.3.1 Direct injection

Another form of leachate evaporation is the direct injection of leachate into an enclosed flare that has been modified to accept liquids. Some flare manufacturers have built enclosed flares to allow injection of liquid directly into the flame (Callidus Technologies, Inc., John Zink Company). Most of these systems were sized for flows around 4 litres/min (1 gpm). The flare unit is the same as that used to combust the LFG; however, the flares are modified with the addition of "injection guns" that atomize the leachate inside the flare. Either a high pressure pump or compressed air is used for atomizing the liquids. The flare can operate as a typical flare when leachate is not added.

The injection system uses the heat and turbulence in the lower flame zone of the flare to ensure that emission levels are not impaired. The point of leachate injection is crucial in providing even evaporation and destruction without impacting the flare's thermal destruction efficiency, flame stability or temperature control.

3.3.2 Vapor compression distillation

A vapor compression distillation (VCD) process differs from an evaporation process in that a clean effluent is produced (VACOM II, L.P.). The process consists of a series of heat exchangers and a disengagement vessel. Leachate is introduced into the VCD system through a heated recirculation loop. Leachate and concentrate enter the disengagement vessel through a tangential nozzle at a velocity sufficient to create a cyclonic separation of steam from the liquid. As the leachate and concentrate rapidly recirculate, active boiling occurs inside the primary heat exchanger and within the cyclonic pool formed inside the disengagement vessel.

Steam generated from the boiling leachate is recycled back into the primary heat exchanger to transfer heat to the recirculating leachate. As the steam gives up its latent heat to incoming leachate, it cools to slightly below the boiling point and condenses. Pressurized by a steam blower, the condensate exits the primary heat exchanger and flows into a secondary heat exchanger. This secondary heat exchanger recovers heat from the condensate and preheats the incoming leachate. The condensate (effluent) exits this heat exchanger at approximately 49° C (120 °F).

Because heat is required for initial startup of the system, as well as make-up heat during the operation of the system, a separate boiler system is provided to produce a low-pressure 100 kPa (15-psig) steam that is used for heat. This boiler can use LFG, natural gas, or propane as its primary fuel source.

Approximately 90 to 98% of the leachate typically is evaporated and recovered as condensate producing an effluent that requires disposal. Depending on the site, the volume of product, and permitting requirements by state and local regulators, the effluent could be used in daily operation of the landfill for dust control and irrigation. For larger volumes, or where regulators will not allow the use of effluent on site, methods of disposal include discharge to surface waters via an NPDES permit or discharge to a POTW. The concentrate produced by the system could be recirculated into the landfill or solidified and disposed of in the landfill.

There are no air emissions from the VCD distillation system itself, since the system is heated with the steam. However, since the make-up steam boiler system can be fueled by LFG, natural gas, or propane, there is an air emission source.

3.3.3 Mechanical vapor recompression (fixed film distillation)

The Mechanical Vapor Recompression (MVR) process is similar to the VCD process in that a clean effluent requiring disposal is produced. The MVR process uses the "falling film" principle, which occurs in a vacuum (Hadwaco). The core of the process is a polymeric evaporation surface (heat transfer element) on which water can boil at 50 to 60° C (120° to 140°F). The process functions similar to a heat pump. Raw leachate is pumped through two parallel heat exchangers into the bottom of an evaporation vessel. From there, a circulation pump transfers a small volume of the leachate into the top of the vessel where it is distributed evenly on the heat transfer element.

During its downward flow over the heat transfer element, leachate boils on the outer surface of the element. This boiling action evaporates a portion of the leachate, while the remaining portion collects beneath the element in the bottom of the vessel as a concentrated leachate. The resulting water vapor is drawn through a high-efficiency fan compressor to increase the pressure and temperature to a point slightly higher than the temperature of the evaporating liquid. Vapor then is forced to the inner surface of the heat transfer element, where it condenses. Latent heat is transferred to the wastewater side of the heat transfer element; clean condensate is collected at the base of the heat transfer element. Heat released by condensation is reused in the heat transfer element to evaporate more leachate. Once the process has started, besides the power used by the fan and various pumps, no external heat or energy is required. The condensate can be returned to the process. Heat from the condensate also is recovered by preheating the incoming leachate through one of the two heat exchangers. The condensate exits the unit as an effluent.

Some of the concentrated waste in the bottom of the evaporation vessel periodically is removed for disposal by a concentrate pump, then routed through the second of the two influent heat exchangers before leaving the system. This concentrate is similar to the concentrate produced by a reverse osmosis process. Concentrate disposal is via recirculation into the solid waste (if allowed by local regulators), or solidified and buried with incoming solid waste. The volume of concentrate can be ~5 to 10 % of the incoming waste stream flow.

The MVR system operates most efficiently in waste streams where TDS content is relatively low, with a maximum practical influent TDS concentration of about 5% (50,000 mg/L). The unit should have a sand filter to reduce the total suspended solids (TSS) in the influent and a chemical feed system for pH control. For leachate with high ammonia concentrations, pH control is needed. Lowering the pH of the influent reduces the ammonia concentration of the condensate. Sulfuric acid commonly is used for the pH adjustment step.

3.4 Biological, land based treatment options

Several land treatment systems are available to treat leachate. These systems usually are sized for small leachate flows, since a significant amount of land may be needed to handle larger flows. The three most common land treatment systems found at MSW landfills are:

- Constructed Wetlands
- Windrow Composting
- Phytoremediation

<u>3.4.1 Constructed wetlands</u>

Constructed wetlands systems have successfully treated contaminated stormwater and domestic and industrial wastewater treatment (PBS&J, Inc.). Wetlands have also been tested for treatment of MSW leachate. To date, most of the work focused on dilute leachate, where the leachate is mixed with stormwater or is derived from an unlined landfill where the leachate is influenced by groundwater. It may be feasible to incorporate a constructed wetlands system into an overall leachate management plan to treat weak leachate, or for use as a downstream polishing step before discharge to surface water, groundwater, or POTW. Types of wetlands systems and key design considerations are discussed here.

Four types of wetland systems have been used to treat industrial and municipal wastewaters, including:

- natural wetlands
- aquatic plant systems
- subsurface-flow constructed wetlands
- surface-flow constructed wetlands.

Subsurface-flow constructed and surface-flow-constructed wetlands are the most common types of wetlands used to treat landfill leachate. Subsurface-flow wetlands are lined basins containing rock or gravel beds planted with one or more species of wetland plants. Wastewater flows through the gravel bed at or just below the surface of the bed. Treatment is by pollutant assimilation and transformation by the microflora attached to the gravel, plants, and detrital material within the bed, and wetland vegetation growing in the bed. The function of a subsurface-flow wetlands is analogous to a large trickling filter. Of the two types of constructed wetlands, subsurface-flow wetlands generally operate less effectively than surface-flow wetlands because the gravel bed becomes clogged. In some cases, clogged subsurface-flow wetlands continue to operate as surface-flow wetlands.

Surface-flow wetlands function as some natural wetland systems except that the hydrology and plant community of treatment wetlands are designed and managed to optimize pollutant removal. Plant species are selected for compatibility with the design operating depth and hydroperiod, with high rates of vegetative growth, and to establish a wetland community with high pollutant removal capabilities.

The following key issues should be incorporated into the design of a constructed wetlands system:

- selection of plant communities
- nutrients
- temperature effects on nutrient removal rates
- metals — concentration and type
- organic pollutants — concentration and type.

3.4.2 Windrow composting

In a pilot study conducted in 1992 by the Iowa Metro Waste Authority, leachate was used in the yard waste composting process to add moisture to the process (Biocycle 1996). Results of the test indicated that leachate maintained moisture at optimum levels and significantly enhanced biological activities in the windrows, reducing organic constituents and immobilizing metals and other inorganics. Collected leachate is pumped to a truck and transported to the composting site. Leachate is introduced into the center of the windrow as the truck travels down its length. Windrow piles are turned periodically as in normal windrow operations. Testing is done for various metals, nutrient content, bulk density, moisture content, organic matter content, and particle size to ensure a quality product. Finished compost is used as landfill final cover.

3.4.3 Phytoremediation (via poplar trees)

Another approach to leachate management is to plant hybrid poplar trees in the final cap of a landfill (Magnuson 1998). This method of leachate management uses spray irrigation and the tree's ability to uptake leachate via the roots. The concept replaces geomembrane caps with dense poplar plantings. As of 1998, 13 states allowed pilot demonstrations at landfills and/or Superfund sites. A few of the sites are implementing full-scale operations.

Collected leachate is spray irrigated on poplar trees planted in rows that are 4 m apart; trees are spaced every 1 m. The trees are planted in a minimum of 0.6 m of intermediate soil cover. The soil cover consists of a mixture of clay, ground wood, and organics. Because the trees are planted so close together, they must be thinned after a few years. At many of the sites, the amount of leachate that is applied is more than the trees evaporate and transpire. Therefore, some of the leachate percolates down through the solid waste (recirculates). After about 10 years, the trees are harvested, the wood is ground as fertilizer, and the fertilizer is used in the soil cover. The trees are replanted and the cycle continues.

4.0 On-site Nitrification/Denitrification of recirculated landfill leachate: A case study.

As an alternative to costly off-site or on-site leachate treatment options, or as a means of effecting enhanced biological degradation of the waste mass, more landfills are utilizing leachate recirculation. A privately owned landfill located on the U.S. East Coast has recirculated leachate (via an in-waste piping distribution system) for several years. Recirculating leachate through the waste mass over multiple passes appears to concentrate the ammonia to levels that could be inhibitory or toxic to the bacteria. The anaerobic digestion of municipal solid waste (MSW) results in an increase in ammonia nitrogen as the landfill ages. The absence of aerobic conditions prevents the reduction of ammonia to nitrates. The incomplete cycling of nitrogen is responsible for the ammonia buildup in what could be considered a closed system. Ammonia nitrogen will be consumed by heterotrophic demand to the extent possible based upon the digestible organic fraction of the waste. Simultaneously, ammonia nitrogen is produced by the anaerobic decomposition of nitrogen-containing organic material in the MSW. Excess ammonia is then lost in the leachate.

Traditional methods of reducing ammonia (e.g. air/steam stripping, breakpoint chlorination, high pH stripping, etc) tend to be expensive and labor intensive. This has led to the consideration of the complete elimination of nitrogen by capitalizing upon the anaerobic and aerobic transformations that occur naturally as part of the nitrogen cycle. A field test of an enhanced biological process for the removal of ammonia from the landfill MSW and leachate was proposed. The anaerobic leachate collected from the landfill is stored in a 1892 m^3 bolted steel tank equipped with a submerged turbine aerator. The turbine aerator was originally installed to allow mixing and aeration for odor control. The capacity of the storage tank allows a long hydraulic retention time (HRT), typically in excess of 16 days. Nitrification occurs in the tank.

Design parameters include:

Daily Leachate Flow (Q)	= 113. 5 m^3/day	(30,000 U.S. gallons/day)
Storage (Nitrification) Tank Volume (V)	= 1,892 m^3	(500,000 U.S. gallons)
Hydraulic Retention Time (V/Q)	= 16.7 days	
Leachate Temperature (T)	>10° C	>(50° F)

The hydraulic retention time is sufficient to allow the growth of nitrifying bacteria. However, a heterotrophic biomass must first be developed (2-4 weeks) to lower the COD of the leachate. The introduction of nitrifying bacteria to the nitrification tank (as pure culture produced on-site or from an activated biosolids plant) will allow the development of a mixed nitrifying culture. The tank essentially operates as a continuous flow aerobic reactor.

The nitrified effluent from the tank will contain nitrate and will be applied on the working face as allowed by permit. Once anoxic conditions are attained in the MSW, denitrification will occur and the nitrate nitrogen will be lost to the atmosphere as nitrogen gas (Onay and Pohland, 1998).

Alternatively, the nitrification tank may be operated as a Sequencing Batch Reactor (SBR). The daily batch feed concept would remain the same, but the operation of the aeration equipment would be 2 hours on and 2 hours off. This would allow denitrification to be achieved in the liquid and would result in a 50 percent reduction in electrical cost. Any residual nitrate would be consumed in the MSW as previously discussed.

4.1 Basic reactions

Nitrification is a biological process that converts ammonia nitrogen to nitrate nitrogen. The group of bacteria that perform this conversion is known as nitrifiers. The conversion occurs according to the overall equation:

$$\mathbf{NH_4^+ + 2O_2 \text{ -----> } NO_3^- + 2H^+ + H_2O}$$

The process takes place in two steps and each step is carried out by a distinct group of nitrifying organisms. These organisms are *Nitrosomonas* and *Nitrobacter*. The reactions are as follows (Benefield and Randall, 1980).

$$\mathbf{2NH_4^+ + 3O_2 \text{ -----> } 2NO_2^- + 4H^+ + 2H_2O}$$

Nitrosomonas

$$2NO_2^- + O_2 \text{ -----> } 2NO_3^-$$

Nitrobacter

Nitrosomonas performs the first step of the conversion by oxidizing ammonium to nitrite. *Nitrobacter* completes the oxidation by converting the nitrite to nitrate. The required environmental conditions for nitrification/denitrification to occur include:

- The pH must be maintained between 7.0-8.2 in the liquid.
- Water temperature should be maintained at a minimum of 18-29° C (65-85° F) for optimum activity. Functionality ceases below 7 °C (45°F).
- Aeration should be sufficient to maintain a minimum of 2mg/L (2ppm) dissolved oxygen.
- The hydraulic retention time in a complete mix chemostatic system must be greater than the doubling time for the nitrifying bacteria. A retention time of 15-20 days will most likely be necessary.
- COD - must be at levels that do not consume all available oxygen or otherwise create inhibitory conditions.
- Metals - should be examined on a case by case basis. Metals normally shown to inhibit biological activity should be analyzed initially.

4.2 Nitrate removal (denitrification)

The most desirable nitrate removal mechanism for a leachate recirculation or landfill bioreactor is biological denitrification. Residual organics in the subsurface anaerobic environment of the landfill should provide complete conversion of the nitrate to nitrogen gas as the nitrate is utilized as an alternate electron acceptor. The completeness of this conversion may be quantified with air testing to satisfy concerns that nitrogen oxides are not being formed. The general unbalanced reaction is given.

$$NO_3^- + \text{organics} + H^+ \text{ -> } C_5H_7O_2N \text{ (Biomass)} + N_2 + CO_2 + H_2O$$

Table 3: Laboratory results for the nitrification of leachate at various leachate water dilutions

Sample ID	Time (days)	COD (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)
Cell 3	0	1618	450	0
(100:0 Leachate:Water)	5	1258		
	8	1088	350	
	17	1040	350	50
	23	1054	250	150
	29	1022	60	375
Cell 3	0	1078	550	0
(75:25 Leachate:Water)	9	868		0
	14			7.5
	15	738	250	7.5
	21	772	200	15
Cell 3	0	718	300	0
(50:50 Leachate:Water)	9	582	250	0
	14			15
	15	520	200	20
	21	616	80	125

A typical nitrification curve was exhibited with the undiluted leachate as shown in Figure 2. The total COD (particulates included) is reduced over time and became relatively stable from day 8 to the end of the study. As the ammonia concentration began to drop the nitrate levels began to increase. Nitrification was essentially completed in the second two weeks of the study after COD reduction had been achieved.

5.0 Conclusions and research needs:

- There are numerous traditional and innovative technologies currently available for treating MSW leachate. Site specific choices should be made based on treatment efficiency, capital cost, operation and maintenance cost, operator complexity, regulatory permits and other issues. There is no single best choice for all leachate. *Research Need: Develop software that allows a user to input raw influent quality and desired effluent quality, energy cost and other variables, to help operators select an optimal technology for treatment of a specific leachate. Note that pilot testing to verify the choice is always prudent.*
- In most cases, leachate can also be efficiently treated at a WWTP. This may be the best and least expensive option and should be compared to other alternatives.
- The solid waste industry may have to invest R&D monies to further develop specific leachate treatment technologies, since there is minimal motivation for vendors due to the relatively limited volume of the market. In the interim, applications from other industries (food processing, petrochemical, etc) should be considered.
- Ammonia is a significant issue that has not been addressed in previous years. The ammonia issue becomes even more critical with the move toward leachate recirculation and bioreactor landfills.
- Cross media pollution, especially air emissions from treatment schemes is becoming increasingly important. *Research need: Quantify air emissions and control technologies from various leachate treatment technologies including air emissions from landfills operated as recirculation or bioreactor sites.*

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Table 1: Summary of Selected Treatment Technologies with Application for Leachate Service

Treatment Technology	Advantages	Disadvantages	Residuals
Equalization	• Low Cost • Oper. Flexibility • Reduced Shock Load	• Large Land Area • or Tankage • Odor Potential • Air Emissions	• Sludge
Physical Treatment			
Sedimentation	• Low Cost • Lowers Downstream Loading • Generally combined with chemical precipitation	• Solids residual	• Sludge, incl. chemical/metal sludge
Flotation	• Removes hard to settle solids • Removes fats, oil and grease	• High Energy Req. • Odor Potential	• Sludge/Floatable
Filtration	• Obtains low suspended solids	• Higher Cost • Backwash Required	• Filtrate
Adsorption-Carbon, Powdered or Granular	• Removal of most organic compounds • Powdered carbon can supplement activated sludge systems • Generally used for polishing in leachate application	• Cost • Handling of Carbon • Breakthrough • Non-selective • Generally requires pre-filtration	• Spent Carbon • Sludge (PAC only)
Adsorption-Clays	• One stage treatment • Manual or Automatic • Removes FOG, heavy metals	• Clay handling • Cost • Sludge handling	• Sludge
Membrane Processes			
Reverse Osmosis (RO)	• Removes TDS • Automated, ease of operation • High quality effluent	• Scaling • Bio-fouling • Brine Disposal • Membrane Replacement • High Energy Req'd	• Concentrated Brine
Filtration	• High Quality Effluent • Lower energy than RO	• Cost • Backwash requirement • Does not remove TDS	• Back-wash/concentrate
Chemical			
pH Adjustment	• Easy to operate • Precursor to metals removal • Neutralize to meet discharge criteria	• Chemical handling • Odor potential	• None (See Sedimentation)
Coagulation	• Colloidal solids removal • Easy to operate • Improves effluent quality	• Chemical handling • Overdose could impact downstream unit processes • Cost of chemicals	• None (See Sedimentation)
Ion Exchange	• Selective removal of anions/cations	• Media regeneration required • Fouling/Binding • Chemical handling	• Spent Regenerant • Backwash
Oxidation	• Non-selective • Can use Cl, O_3, $KMnO_4$,	• Cost • Worker Safety	• Sludge

	H_2O_2 • Can be used for ammonia removal	• May be pH and catalyst dependent	
Biological			
Sequencing Batch Reactor	• Minimal Tankage • Fully Automated • Adaptable to flow and quality fluctuations • Good Ammonia Removal	• High Energy for aeration	• Biological Sludge
Activated Sludge (continuous)	• Easy to operate • Widely used • Good Effluent Quality	• More tankage (as compared to SBR) • High Energy for aeration • Odor potential	• Biological Sludge
Oxidation Ponds/Lagoons	• Low capital cost • Easy to operate • Takes advantage of stormwater dilution • Low skills required for successful operation	• Large Land Requirement • Odor potential • Air emissions • Safety-humans/wildlife	• Sediment/Sludge (infrequently)
Fixed Film (e.g. Rotating Biological Contactors (RBC), packed tower)	• Small footprint • Can be operated aerobically or anaerobically	• High Energy Cost for Aeration • Poor nitrification (generally design related)	• Biomass/Sludge
Thermal			
Evaporator	• No liquid effluent • Small footprint • Easy to operate	• Dependent on landfill gas supply for economical operation • Material Compatibility	• Solids (minimal) • Flare Emissions
Distillation	• Good VOC and Ammonia Removal • Energy Efficient • Small Footprint • High Quality Effluent	• Operational Complexity	• VOC-laden liquid sidestream • Concentrate • Air Emission from Boiler
Biological Land Based			
Constructed Wetlands	• Simple to operate • Good weak leachate or for final polishing • “Green” solution	• Can’t handle high strength leachate • Climate considerations • Large land requirement	• Plant harvestings
Phytoremediation	• Simple to operate • “Green” solution • Market value for harvested timber	• Periodic thinning and harvesting • Irrigation system maintenance • Odor potential • Climate considerations	• Harvested Timber

Table 2: Selected Leachate Treatment Unit Process for Q = 114 m^3/day

System Description	Major Unit Processes	Relative Ease of Operation* (Scale 1-5, 1 = Easiest)	Relative Capital Cost	Relative O&M Cost
Conventional	• Equalization • pH adjust/Chemical Precipitation/Sedimentation • Biological, SBR • Residual Mgmt	3	1	1
Conventional	• Equalization • pH adjust/Chemical Precipitation/Sedimentation • Biological, Fixed Film (Packed Towers, Trickling Filter, RBC) • Residual Mgmt	3.5-4	2	1.5
Conventional	• Lagoon • Residuals Mgmt	1.0-1.5	0.5	0.25
Membrane	• Equalization • pH adjust • Pre-Filtration • Reverse Osmosis • Residuals Mgmt	2.0-2.5	1.5-1.8	0.75
Thermal	• Equalization • Evaporation • Thermal Oxidation • Residuals Mgmt	2.0-2.5	0.8-0.9	0.5
Thermal	• Equalization • pH adjustment • Distillation • Residuals Mgmt	2.5-3.0	1.0	0.5-0.75
Biological-In Situ (Bioreactor)	• Equalization • Recirculation-moisture content control • LF Gas Control	1.5-2.0	0.5	0.25
Biological-In Situ (Facultative Bioreactor)	• Equalization • Nitrification • Recirculation-moisture content control • LF Gas Control	2.0-2.5	0.6	0.3-0.4
Biological-Land Based	• Equalization • pH Adjust • Constructed Wetlands	1.5-2.0	0.4	0.1-0.2
Biological-Land Based	• Equalization • pH Adjust • Phytoremediation (poplar trees)	3.0-3.5	0.5	0.4-0.5

*Scale 1-5, with 1 = lowest operation and maintenance requirements
**Relative to conventional biological SBR unit with a capacity of 114 m^3/day (30,000 gpd). Benchmark for capital cost of 1.0 equals approximately = $1 million USD. Benchmark for O&M relative to 1.0 for cost of operating and maintaining an SBR system.

Figure 2: Nitrification of Cell 3 leachate in a shake flask study.