State of Landfill Leachate Management: Challenges and Opportunities

Shrawan Singh, Ph.D., PE

Rainwater percolating through the waste in landfills results in most of the liquid that makes up landfill leachate. A smaller portion of landfill leachate is also generated by the waste liquids released during the waste decomposition process. There are other landfill derived liquids, but this article addresses landfill leachate specifically. Leachate must be removed from the landfill to protect the landfill slopes from failure, avoid seepage, improve gas collection, and keep the landfill compliant. Removed leachate needs to be managed and either disposed of offsite or treated before discharging from the landfill as it usually contains a multitude of chemicals that can adversely impact human health and the environment. Most landfills manage/treat their leachate offsite at wastewater treatment plants (WWTP); however, WWTPs are getting increasingly hesitant to accept leachate due to its dynamic characteristics, high concentration of a few specific compounds, emerging contaminants, and stringent regulations. Proactive landfill operators are aware of existing and upcoming challenge of leachate management and are looking for opportunities and options for leachate management and treatment.

Leachate Chemical Makeup

To identify an appropriate leachate treatment process, we need to know what the leachate contains. Leachate broadly contains organic matter, nutrients, inorganic ions, and some trace chemicals. General leachate chemical makeup is shown in Table 1. The organic matter cumulatively measured as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) is primarily made up of volatile fatty acids (VFA), and humic and fulvic acid type compounds, which are the primary reason for the darker color in leachate. These humic and fulvic acid-type compounds are refractory and harder to degrade biologically. During initial waste degradation, leachate typically contains high BOD and COD but as the waste degrades more, during the methane forming phase, most of the organic matter is in the form of non-biodegradable COD. Ammonia nitrogen is the primary nutrient in the leachate that can be removed biologically using phased aerobic and anaerobic treatments. Leachate also typically contains common inorganic ions such as chloride, bicarbonates, and heavy metals (arsenic, antimony, chromium, and vanadium), which have several removal options available and are normally managed through dilution, evaporation, or membrane separation. Emerging contaminants such as per and polyfluoroalkyl substances (PFAS) are also an upcoming challenge for landfill leachate operators.

Parameters	Young Leachate (0-5 years)	Intermediate (5-10 years)	Stabilized (10-20 years)	Old (>20 years)
pH	<6.5	6.5-7.5	>7.5	
BOD_5 (mg/L)	10,000-25,000	1,000-4,000	50-100	<50
COD (mg/L)	>10,000	4,000-20,000	<5,000	<1,000
BOD_5/COD	0.5-1.0	0.1-0.5	<0.1	<0.05
Organic matter	80% VFA	30% VFA	Humic and fulvic acids	
TDS (mg/L)	10,000-25,000	5,000-10,000	2,000-5,000	<1,000
Ammonia-N (mg/L)	<400 to 1,500	300-500	50-200	<30

Reference: Mukherjee et al. (2015) DOI: 10.1080/10643389.2013.876524

Table 1 - Typical leachate concentration variation with waste age.

Leachate Treatment Processes

In most cases, the leachate treatment processes are designed to remove nutrients, such as ammonia, and organic matter; however, the major challenge with organic-matter specific treatment processes is the dynamic nature of leachate over time. About 70% of Florida landfills send leachate (hauling or through forcemain) offsite to WWTP; however, WWTPs primarily have biological treatment processes and in most cases, these WWTPs are not designed to treat high non-biodegradable organic matter concentrations in the leachate and leachate treatment at WWTPs is mostly achieved through dilution. The dynamic nature and high concentration of leachate organic matter and ammonia can disrupt a WWTP's treatment efficiency as well. Leachate color and/or the presence of humic and fulvic acids also can negatively affect the UV disinfection process of WWTPs. In several cases, WWTPs have surcharges for BOD, COD, ammonia, and/or total suspended solids, or stop accepting the leachate. WWTPs increasing resistance to

Treatment Method Category	Treatment Processes
Natural Methods	Constructed wetlands, Phytoremediation, Land application
Biological Methods	Aerated ponds, Sequencing batch reactor, Membrane bioreactor , Activated sludge process, Anaerobic digester
Physical Methods	Thermal and climatic evaporation, Reverse osmosis
Physicochemical Methods	Activated carbon, Chemical oxidation
Other Management Methods	Deep well injection, Recirculation

Table 2 - Onsite leachate treatment categories and processes.

accepting leachate and expected regulatory challenges related to PFAS treatment has landfill operators looking to onsite treatment processes to manage their leachate.

Several types of onsite treatment and management methods are being used at landfills as shown in Table 2. Considering leachate contains a variety of chemicals, these processes target specific contaminants. Some are natural and biological processes and others are physical and chemical processes. Natural and biological processes are targeted to reduce the organic matter and ammonia leachate load. A larger footprint requirement can be a major limitation of natural and biological processes; for example, a constructed wetland of 65,000 gallons per day (GPD) capacity may cover up to a 3-acre area or larger. The capital cost for such a system can be up to or more than $2.5 million. Membrane bioreactor (MBR) and similar smaller footprint biological processes can remove organic matter as well as ammonia, but the capital and operating cost can be high and require experienced operators. Other biological processes such as Sequencing Batch Reactor produces a higher amount of sludge as compared to an MBR, which needs to be managed separately. Multiple vendors have been providing onsite leachate treatment solutions using such natural and biological processes.

Physical and physicochemical processes have shown treatment effectiveness for leachate containing a significant portion of refractory organic matter. Thermal and climatic evaporation are being used at various landfills, but a concentrated leachate residual is created that is usually recirculated back into the landfill. The major challenges for leachate evaporation include a heat requirement, odor, and if applicable, exhaust vapor treatment.

Membrane treatment such as reverse osmosis (RO) has shown significant promise in removing, through a separation process, many types of contaminants including chlorides and PFAS. The major advantage of membrane processes is relative simplicity of operation; however, it needs significant energy to operate, and a concentrated leachate residual is also created. Again, vendors have supplied RO membrane leachate treatment systems for landfills. Typical RO membrane systems designed for leachate treatment operate at 600 psi to 1,500 psi operating pressure and the capital cost can be significant. An RO system of 65,000 GPD capacity can cost up to $4.5 million or more based on leachate chemical characteristics and treatment level requirements. Lower operating pressure (200 to 250 psi) RO membranes have also shown promise for cost-effective leachate treatment. Disposing of concentrate and or residual is an additional challenge with membrane systems.

Promising Solutions

As discussed above, leachate characteristics are dynamic and can be site-specific. All these treatment processes have shown promise to treat leachate to various permitted discharge criteria; however, site-specific evaluations are needed. Several options are available with varying levels of cost and treatment and leachate operators might consider evaluating alternatives for their leachate management as a Plan B or Plan C to disposing of their leachate in WWTPs to prepare for the possibility of upcoming challenges.

Shrawan Singh, Ph.D., PE, is a Senior Project Professional with SCS Engineers. He can be reached at (470) 386-6010 or e-mail SSingh@scsengineers.com.