MBR Pretreatment of Landfill Leachate for the Removal of Ammonia and Potential Future Removal of Total Dissolved Solids

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ABSTRACT

The Pollution Control Financing Authority of Warren County (PCFAWC or Authority) New Jersey operates a solid waste landfill. Leachate collected in the landfill cell underdrain system drains to a lined basin, from which it had historically been pumped via an adjoining wastewater collection system to a 0.5 MGD regional Publicly Owned Treatment Plant (POTW). Significant increases in leachate flow volumes and ammonia loads resulted in the suspension of pumping to the POTW, requiring the PCFAWC to evaluate alternative leachate disposal options. Bench scale treatability analyses followed by a process evaluations, which considered potential future regulatory requirements, resulted in the selection of on-site leachate pretreatment using the membrane bioreactor process (MBR). The MBR plant has been successfully operating for several months, meeting its design requirements. Full nitrification and significant denitrification is being achieved while requiring minimal cleaning of the ultrafiltration membranes.

KEYWORDS: MBR, landfill leachate, ammonia, TDS

INTRODUCTION

In response to the increasing production of leachate from the solid waste landfill owned and operated by PCFAWC, the Authority investigated the most appropriate means to dispose of the leachate in an environmentally responsible manner. The raw leachate had historically been pumped to a local 0.5 MGD POTW for treatment and disposal. The POTW was a conventional, nitrifying, single-stage activated sludge treatment plant with primary clarification. As the production of leachate increased, as well as the ammonia concentration in the leachate, the raw leachate could no longer be discharged to the WWTP without pretreatment or a reduction of the raw leachate flow rate to control the quantity of ammonia to the POTW.

GOALS AND OBJECTIVES

The primary goal of the project was to investigate and implement the most cost effective means to dispose of the leachate in an environmentally responsible manner. Accordingly, the Authority identified four potential means to dispose of the leachate:

1. Upgrade the local POTW to be of sufficient capacity to treat the raw leachate,
2. Truck the raw leachate to one or more local wastewater treatment plants (WWTP) for disposal,
3. Convey (pump) the raw leachate to a nearby resource recovery facility to allow the raw leachate to be used as process water,
4. Pre-treat the leachate on site and discharge the pretreated leachate to the local POTW.

The landfill was approaching its permitted solid waste volume capacity and the Authority was in the process of filing for a permit to be allowed to increase the volume of the landfill sufficient to accept solid waste for another decade or more. Due to the current volume of the landfill's solid waste and the expected future volume of solid waste, the Authority was faced with three issues related to leachate:

1. Disposing of increased volumes of raw leachate with varying concentrations of constituents, with a particular concern for ammonia,
2. A large variance of leachate production resulting from precipitation,
3. The potential by the State regulators to require the removal of total dissolved solids (TDS).

EVALUATION OF ALTERNATIVE LEACHATE DISPOSAL METHODS

The evaluation of the alternatives for leachate disposal resulted in the following determinations:

1. Upgrading the local POTW to treat the additional ammonia load and to provide the capability to remove TDS in the future was not cost-effective and its implementation would be administratively difficult due to split jurisdictions,
2. Trucking the raw leachate to one or more local WWTPs for disposal was costly and was not deemed to be a long-term solution,
3. Conveying the leachate to the resource recovery facility was not cost-effective and was not deemed to be a long-term solution,
4. Pre-treating the leachate on site was determined to be the most cost effective and feasible long-term solution.

Consequently, the subsequent evaluations focused on selecting the most appropriate on-site pretreatment system.

PILOT STUDY

As biological treatment with nitrifying activated sludge is a method of choice for ammonia removal from wastewater, a bench-top treatability test was conducted as a part of technology evaluations. The test objective was to evaluate if biological treatment of raw leachate, and nitrification in particular, would be possible without pretreatment for metals removal. The biological reactor was seeded with nitrifying activated sludge from the municipal treatment plant receiving the Authority's raw leachate. The reactor was operated at room temperature for four weeks, with pH adjusted with caustic as needed.

Fresh samples of raw leachate were collected weekly and used for feeding the reactor on subsequent days. The aeration was interrupted once per day and 1/3 of the reactor volume (supernatant) was discarded and replaced with fresh leachate. Consequently, the operations simulated the performance of an activated sludge system in a semi-Sequencing Batch Reactor (SBR) mode with an HRT of three (3) days. During the last week of operation, the reactor was fed twice daily with 4.5 liters of leachate, which simulated operation with an HRT of only one (1) day.

A summary of the results is provided in Table 1. The test reactor achieved almost full nitrification from the beginning of operation, with an average ammonia reduction of more than 95% during the three (3) day HRT operating mode. When the reactor was stressed during the last week of operation (HRT of one day), nitrification failed. The treatability test indicated that raw leachate is amenable to biological treatment, including nitrification.

Table 1. Summary of Leachate Biotreatability Test

Day from Start-up	Raw Leachate Parameters, mg/L						Supernatant Parameters, mg/L					
	TKN	NO_3-N	NH_3-N	COD	BOD$_5$	TSS	TKN	NO_3-N	NH_3-N	COD	BOD$_5$	TSS
	Reactor Hydraulic Retention Time of 3 Days											
0	157	<0.080		834	211							
3	151	0.094	137	864	211		9.7	106	6	313	38	
6	152	<0.040	138	981	155		7.8	129	2.1	329	22.4	
10	158	<0.040	120	948	151		7.1	145	1	474	60	34
13	149	<0.040	134	887	153		6.9	142	1.7	334	13.8	
16	154	<0.200	132	892	140		7.3	140	1.5	373	60.1	
20	200	<0.400	144	1000	83	201	18.2	149	19.5	446	84.1	60
	Reactor Hydraulic Retention Time of 1 Day											
28	198	1.5	187	932	79.7	164	76.8	108	88.8	741	67.3	
30	203	0.62	186	1170	65.6	131	121	74.6	115	793	72.5	

Other observations from the treatability test are as follows:

- Reactor effluent (supernatant) was very turbid, most likely as a result of high leachate TDS, which averaged 7,500 mg/L. This solids loss with the effluent prevented MLSS build-up during the test (MLSS averaged 800 mg/L). A positive control of effluent TSS (polymer, filtration) would be needed to allow control of system's MLSS.
- Caustic addition would be necessary to supplement alkalinity and maintain system pH.
- Addition of phosphorus source might be required to prevent nutrient deficiencies in the raw leachate.

SELECTION OF TECHNOLOGY FOR LEACHATE PRETREATMENT

As the main pretreatment objective was reduction of ammonia, the major alternative technologies were nitrifying activated sludge (SBR was initially considered) and ammonia stripping. Evaluations based on the literature review and inspection of several East Coast US leachate treatment facilities yielded the following conclusions:

1. Activated sludge system is the technology of choice and could reliably nitrify ammonia in leachate, particularly if the leachate is pretreated by high pH precipitation for heavy metals removal to prevent nitrification inhibition. Since the concentration of organics and ammonia in the leachate are several times higher than in domestic wastewater, an HRT of several days would be required for achieving a low enough F/M (high enough sludge age) to effect winter nitrification. A major concern in operating an extended aeration system with HRT of several days in cold climates is the possibility of nitrification inhibition or freezing during periods of low ambient temperatures. Additionally, the HRT during winter months could be much higher due to the typical seasonal decrease in leachate generation rate, thereby exacerbating low temperature concerns.
2. A once-through ammonia stripping tower would require an air to water volumetric ratio on the order of several thousand with pH in the tower maintained at 9.5 or higher. Due to evaporative losses, such an installation acts as a cooling tower and operation at low ambient temperatures could lead to freezing. Consequently, ammonia stripping utilizing once-through air stream is an appropriate technology for applications in warm climates or where adequate waste heat is available. An additional complicating factor is that ammonia release to air on a large scale would require significant permitting efforts, including plume modeling, with attendant uncertainties and/or additional air treatment installations required. An alternative is a closed loop ammonia air stripping system consisting of an alkaline ammonia stripper and acid scrubber for ammonia recovery, generating ammonium sulfate brine for off-site disposal. However, the technology provider was not able to demonstrate a track record of a full-scale operating facility.

As a result of the foregoing evaluation, the project team decided to pursue the activated sludge treatment option. Initially, an SBR reactor was contemplated. However, due to the above discussed temperature considerations, and, more critically, concerns about future TDS controls discussed below, a membrane bioreactor (MBR) was eventually selected.

TDS AND OTHER DESIGN CONSIDERATIONS

In addition to the need to significantly remove the ammonia load discharged to the receiving POTW, additional concerns regarding potential TDS limits were identified during the process evaluation. The POTW discharges to the Delaware River Basin, and, as such, is subject to the Deleware River Basin Commission (DRBC) jurisdiction, in addition to the NJDEP water quality regulations. One of the DRBC policies was to limit TDS in the wastewater treatment discharges to end-of-the-pipe concentration of 1,000 mg/L. Such a limit would be impossible for the POTW to comply with due to the percentage of leachate in the influent wastewater tributary to the POTW.

While DRBC regulations allowed a procedure to petition for an increase in the default limit of 1,000 mg/L, up to the full assimilative capacity of the receiving stream (based on a Water Quality Standard of 500 mg/L), the outcome of such process was uncertain both in terms of timing and adequacy of the numerical relief granted, if any. As the Authority wanted to proceed with the design and construction of the pretreatment plant without delay, it was decided to base the pretreatment process on an MBR technology. While construction of an MBR facility was recognized to be more expensive than conventional variants of an activated sludge system, it offered significant, if sometimes intangible, advantages to the owner:

- effluent from an MBR will undergo a tight membrane filtration (ultrafiltration), which is an ideal pretreatment for a Reverse Osmosis (RO) process, should control of TDS be required at some point in the future,
- MBR reactors with a relatively small volume could be constructed in a building, eliminating freezing concerns,
- as identified during the treatability test, supernatant from the aeration vessel was very turbid, indicating concerns about control of biomass loss with the effluent. Use of an MBR provides a positive means of solids retention, eliminating such concerns.

MBR DESIGN

Based on the most recent leachate characterization data, design conditions for the leachate pretreatment process were established as shown in Table 2. The design of the leachate pretreatment plant was integrated with existing raw leachate holding facilities on the landfill site. These facilities consisted of a 900,000 gallon leachate equalization basin with two downstream, one (1) million gallon raw leachate emergency overflow basins. These facilities were retained to provide critical flow equalization ahead of the MBR facility, increase flexibility in operation of the MBR facility, and increase operational flexibility in leachate management options.

Table 2. Leachate Characteristics and Design Basis

Parameter	Units	Raw Leachate - Design Basis		Effluent Limits for Discharge to POTW (2)	
		Average or Range	Maximum or Range	Monthly Average or Range	Daily Maximum or Range
Flow	GPD	50,000	60,000	50,000	60,000
pH	S.U.	7.4	6.8 - 7.9	5.5 - 9.0	5.5 - 9.0
Temp.	deg. F	65	54 - 77	NA	NA
TSS	mg/L	100	350	300	300
TDS	mg/L	7,500 (prelim.)	15,000	No Limit	
NH_3-N	mg/L	300	600	40	40
COD	mg/L	1,600	3,000	900	1,350
BOD_5	mg/L	139 (1)	960 (1)	300	300

(1) BOD_5 data may be artificially low; treatability study seed sludge may not have been acclimated to wastewater

(2) Limits for TSS, COD, BOD_5 and NH_3-N are calculated from the actual mass loading limits

In selection of the MBR system provider, a key element was vendor responsiveness to this fast-track project and experience with similar installations. The provider of choice was Dynatec Systems, Inc. of Burlington, NJ, which has a successful track record of providing landfill leachate MBR installations in a timely manner.

The process flow schematic of the pretreatment system is shown in Figure 1. The MBR is housed entirely in a new treatment building and consists of three main treatment tanks (one anoxic and two aerobic tanks), where ammonia and other pollutants are oxidized by beneficial bacteria (Figure 2). The anoxic zone was added in consideration of potential future denitrification requirements at the POTW, as well as to minimize supplemental caustic addition. Provisions for the addition of caustic, supplemental carbon source, and phosphoric acid were included to provide operational control for treatment optimization.

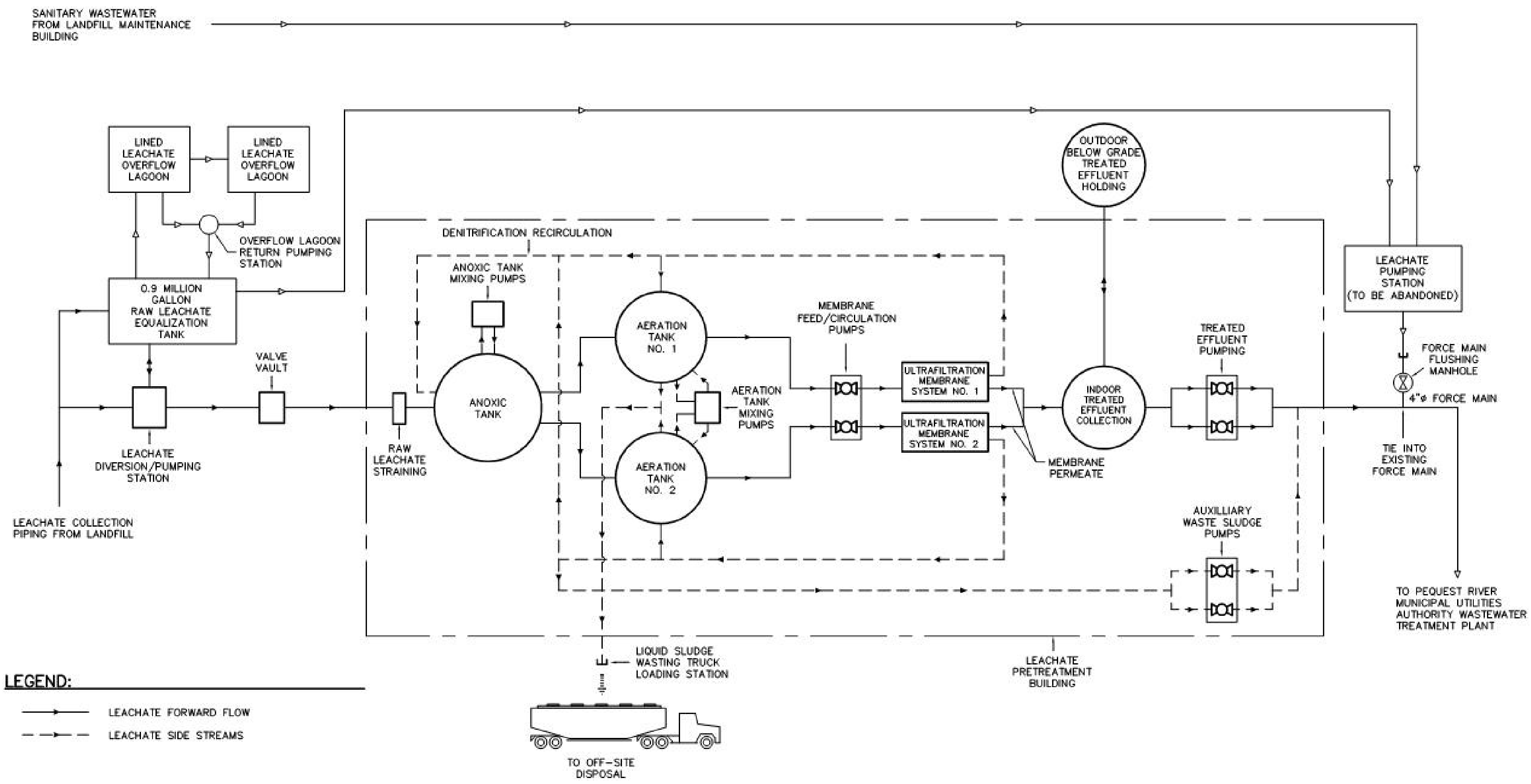

Figure 1. Process Flow Schematics

Figure 2. General View of the MBR Facility

The design MLSS concentration range was specified as 10,000 to 15,000 mg/L. The raw leachate is pumped to a single, 80,000 gallon (approximate working volume) anoxic tank mixed with a submerged jet mixing system, where it is combined with mixed liquor returned from the membrane reject (Figure 3). Partially denitrified effluent is split and flows by gravity to twin, 60,000 gallon aerobic tanks (approximate working volume) with jet aeration systems. With the overall working system volume of approximately 200,000 gallons, the design average F/M of the system at 10,000 mg/L of MLSS is 0.04 #COD/#MLSS-day (including anoxic volume).

Figure 3. Reaction Tanks and Aeration/Mixing Systems

The mixed liquor is separated from the effluent by a battery of membrane filtration (ultrafiltration) units. Two independent, pre-engineered membrane systems, each with a capacity of 50,000 gpd, were provided. Normally, only one system is expected to be on line. Each system consists of 48 tubular, cross-flow membranes, mounted in eight (8) parallel modules, each with six passes (six (6) membranes in each module) (see Figure 4). An individual membrane consists of a 3½ - inch diameter PVC pipe, in which seven (7) individual ultrafiltration tubes are housed. The mixed liquor is pumped at a high surface velocity across the membranes using a 580 gpm (16.7 times forward flow), high pressure pump. The reject stream is divided between the suction side of the membrane feed pumps with the balance returned to the aerobic and anoxic tanks. In-place membrane cleaning system with acid is provided.

Figure 4. Battery of the UF Membranes

CONSTRUCTION AND INITIAL PERFORMANCE

The final construction cost was within 1% of the original public bid price.

The MBR reactor was seeded with well screened, debris-free nitrifying activated sludge from nearby municipal WWTP. Due to the high biomass inventory needed (10,000 mg/L MLSS), biomass build-up was slow, as only one to two truckloads of sludge could be accepted at the facility per day. During the start-up, the leachate flow to the reactors was kept at a proportion to the biomass inventory. At no time was a problem encountered with achieving full nitrification.

Build-up of the biomass inventory was interrupted on several occasions when a sudden foaming in the aerobic rectors occurred, resulting in a loss of biomass. At least on one occasion foaming-over was caused by a sudden process change (batch ferric addition and pH change); on others no specific cause could be identified. Addition of non-silicone based antifoaming agent at regular intervals brought the foaming under control. As the process fully acclimated and stabilized, foaming ceased to be an issue.

While one of the secondary reasons for selecting the MBR process was the concern about freezing of an alternative, outdoor, extended aeration system, temperatures in the MBR remained quite high throughout the winter (in 80’s). This is primarily due to the high energy input from the high pressure, recirculation pumps, aeration blowers as well as other equipment. As the reactors are housed in a building, heat losses are minimized. Additionally, the very high strength of the wastewater in terms of COD and ammonia could be contributing a significant heat of bio-reaction to the energy balance. During the recent summer heat wave, the temperature in the reactors reached 107^o F, but performance of the reactors did not suffer.

Following resolution of the initial mechanical and operational issues, the completed project is effectively removing ammonia and other permitted constituents with minimal operator attention and the fully automated facility meets all of the design criteria established by the Project Technical Design report. A summary of the recent MBR performance is provided in Table 3.

Table 3. Summary of Recent MBR Performance (1)

Parameter	Raw Leachate	Permeate
Flow, gpd	34,660	-
COD	3,993	1,543
BOD_5	335	13
NH_3-N	940	34
NO_3-N	< 2	247 (2)
TDS	15,000	16,633

1) As reported by the contract, outside laboratory for the period 6/16/10 - 7/8/10

2) In house laboratory reports decline in effluent NO_3-N to an average of 45 mg/L in the period 7/6/10 - 7/20/10

As a comparison with Table 1 indicates, the present leachate strength in terms of major parameters (NH_3-N, COD, TDS) is significantly higher than the design values. Nevertheless, the system provides almost complete nitrification at full design volumetric flows, the extent of which is generally limited only by the supply of oxygen (aeration DO set-point). Aeration intensity is monitored and adjusted on a regular basis in order to minimize DO input to the anoxic zone with the mixed liquor recycle stream and thus maximizes denitrification. This is being performed in order to satisfy a request from the receiving POTW, which initially experienced process difficulties reportedly related to the high nitrate concentration in the treated leachate.

An unexpected complication, which arose during process start-up, related to concerns about color impact resulting from the presence of the treated leachate in the effluent discharged from the POTW. For many years, the POTW was accepting raw, untreated leachate for treatment without color concerns. However, after several years (approximately three years) of interruption in accepting the leachate, during which time the Authority trucked their raw leachate to other municipal WWTPs, the introduction of the MBR-treated leachate to the POTW resulted in noticeable color in the POTW effluent. Following a series of jar tests, ferric chloride addition was implemented in full scale at the MBR facility. At a high enough dose, ferric proved to be an effective solution to the color concerns.

Excess biological sludge generated by the facility is periodically trucked for off-site disposal. Sludge is wasted directly from the process reactors at a concentration of approximately 15,000 mg/L (1.5% solids).

Ultrafiltration membrane performance is excellent. Only one, “demonstration” chemical cleaning was performed during the ten month start-up and operting period, and pressure losses at the membranes are stable. It is being speculated that some of the incinerator ash in the landfill material is present in the leachate, acting as a gentle liquid abrasive for the membranes.

SUMMARY

The following are observations and conclusions from the start-up and initial ten-month operation of this MBR facility pretreating raw municipal leachate:

- The selection of MBR treatment was dictated primarily due to concerns about potential future TDS limits.
- MBR is the most cost effective treatment option available.
- The leachate pretreatment facility is fully nitrifying and a significant degree of denitrification is being accomplished.
- Ultrafiltration membranes operate without a need for frequent cleaning and with a stable pressure loss.
- Sudden foaming was a major issue during the start-up and initial operting period but has subsided.