Algal Bioremedmiation of Landfill Leachate Pretreated by Reverse Osmosis

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Abstract

Landfills are a pervasive by-product of human society, representing the final repository for the majority of anthropogenic wastes. Landfills and the environmental discharges produced from the decomposing wastes must be managed even after closure of the landfill. Current waste treatment strategies for landfill leachates use considerable natural resources and energy capital, but are essential for the preservation of clean water, air, soil and health for future generations. An emerging method for landfill leachate remediation is membrane filtration or reverse osmosis (RO). An experimental two-stage RO system at the closed Alachua County Southwest Landfill reduced electrical conductivity from 16,100 to 1,195 µS/cm and total ammoniacal nitrogen (TAN) from 1,110 to 80 ppm in the first stage and to 73.2 µS/cm and 5.5 ppm, respectively, in the second stage. Reverse osmosis failed to reduce TAN in landfill leachate to meet groundwater cleanup target levels (GCTL) of 2.8 ppm. Algae cultivation was explored as a biological means of TAN reduction. Pairing RO with algal bioremediation may reduce the cost of a two-stage system, by eliminating the second stage. Algal cultivation systems were developed on-site at the landfill and reduced TAN levels of the RO pretreated leachate to below detectable limits (0.1 ppm) within eight days of operation. Growth of algae was modest and reduction in TAN is hypothesized to be mainly from atmospheric volatilization. Elemental analysis of the RO treated landfill leachate revealed phosphorus as a potentially limiting nutrient for algal growth and therefore ammoniacal nitrogen biological assimilation.

Introduction

Landfilling is currently the most common method for the disposal of anthropogenic solid waste. Landfills must be lined with impermeable membranes, consequently forcing landfill operators to deal with large volumes of liquids percolating through the accumulated waste within a landfill. These liquids, termed landfill leachate, must be managed for a minimum of 30 years post closure of the landfill. Current methods in leachate remediation involve transfer to publically-owned water treatment facilities or on-site wastewater treatment to meet Groundwater Cleanup Target Levels (GCTLs) (FDEP 2005). Leachates are generally considered toxic and must be diluted or pretreated prior to bioremediation. Emerging methods involve chemical, physical oxidation processes, but use large chemical and energy inputs and are not yet economical. Membrane filtration is a promising technology with the capacity to remediate landfill leachate (Renou *et al.* 2008).

In the presented research, we explore the combination of membrane filtration (RO) and algal photosynthetic biological oxidation in the remediation of landfill leachate from the Alachua County South West Landfill (ACSWL) in Archer, Florida. Combining both RO and algal bioremediation techniques may help alleviate the economic burden of landfill leachate remediation. We evaluate the cost of remediation through different methods as well as the biological capacity for algal bioremediation. We focus specifically on TAN as our primary criteria of remediation. The conventional leachate transfer processes (Figure 1) is compared with the 2-stage RO treatment of landfill leachate (Figure 2), and additionally 1-stage RO treatment combined with algal bioremediation (Figure 3).

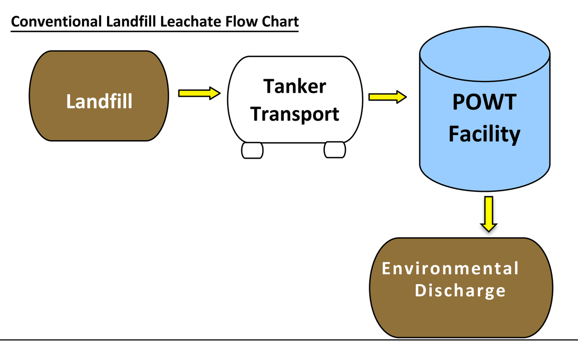


Figure 1. Conventional landfill leachate treatment the transfer of leachate by tanker truck to Publically-owned Water Treatment Facility (POWT)

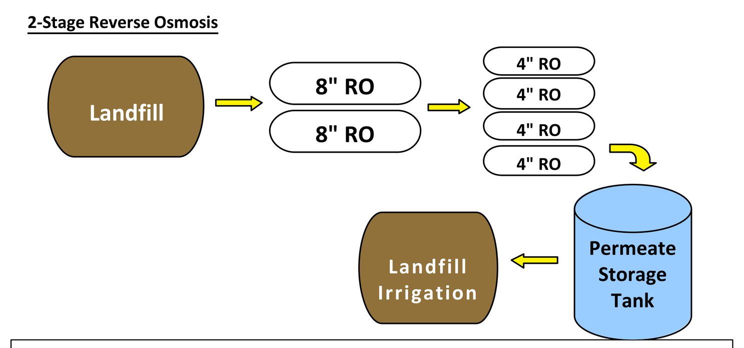


Figure 2. The experimental 2-stage reverse osmosis system for remediating landfill leachate at the ACSWL, 8" RO is the primary treatment, 4" RO is the secondary treatment.

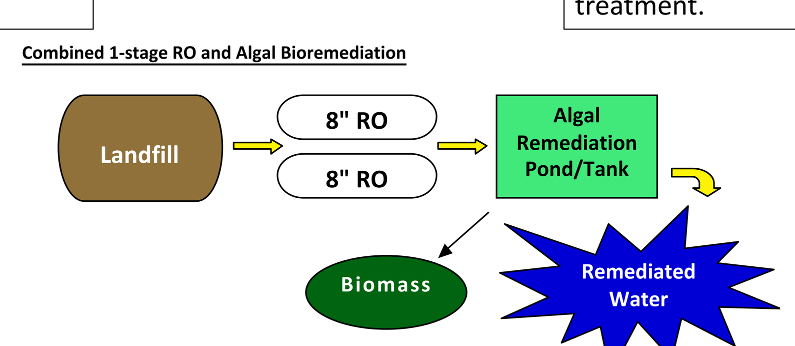


Figure 3. The integration of algal bioremediation with the first stage reverse osmosis treatment system, 8" RO is the primary treatment. Algal biomass is a potential co-product.

Objectives

- Determine TAN remediation capacity of combined algal bioremediation system.
- Evaluate growth of algae in reverse osmosis treated landfill leachate.
- Compare remediation cost between the conventional treatment, 2-stage reverse osmosis, and 1-stage reverse osmosis combined with algal bioremediation

Methodology

- *Algal Cultivation*: Native algae, collected on-site, were cultivated in 800L concrete tanks. The suspension of microalgal cells were mixed by submersed impeller pump. An inoculation density of 50% by volume was used to initiate the algal culture.
- *Algal Growth*: Culture growth was monitored by optical density at 545nm using a thermo-fisher Genesys 10UV-Vis spectrophotometer.
- *Total Ammoniacal Nitrogen (TAN)*: TAN was measured using an ammonia selective electrode (Orion 95-12) according to APHA standard methods 4500-NH3.
- *Electrical conductivity (EC):* EC measured using (Hach) following APHA (1998) methods 2510
- *Culture pH*: pH was measured in accordance with APHA standard method 4500-H$^+$.
- *Elemental Analysis*: Elemental analyses for N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, and Co were performed by an external certified laboratory.
- *Cost Evaluation:* An economic comparison was made between the 2-stage RO, 1-stage RO with algal bioremediation and Algal bioremediation alone, using cost estimates for running the 2-stage reverse osmosis treatment system and the cost of electricity required for algal cultivation.

Results

- *Algal Cultivation*: Native algae tolerated permeate without dilution (Fig. 6 and 7).
- *Algal Growth*: Culture growth was moderate, reaching a maximum by day 8 (Fig. 4).
- *Total Ammoniacal Nitrogen (TAN)*: TAN was reduced below detection levels within 8 days (Fig. 4).
- *Electrical conductivity (EC):* EC was reduced by 28.5% in 8 days (Fig. 5).
- *Culture pH*: The pH of the algal culture rose rapidly by 2 units and remained around pH 8.5 (Fig. 5).
- *Elemental Analysis*: The elemental analysis indicated low levels of essential nutrients in the RO treated landfill leachate, as an example phosphorus is reduced by two orders of magnitude from ~10mg/L to 0.1mg/L (Table 1).
- *Cost Evaluation:* The economic comparison between conventional landfill leachate treatment, 2-stage RO, 1-stage RO with algal bioremediation, shows significant potential savings in the application of algal bioremediation (Fig. 8-10).

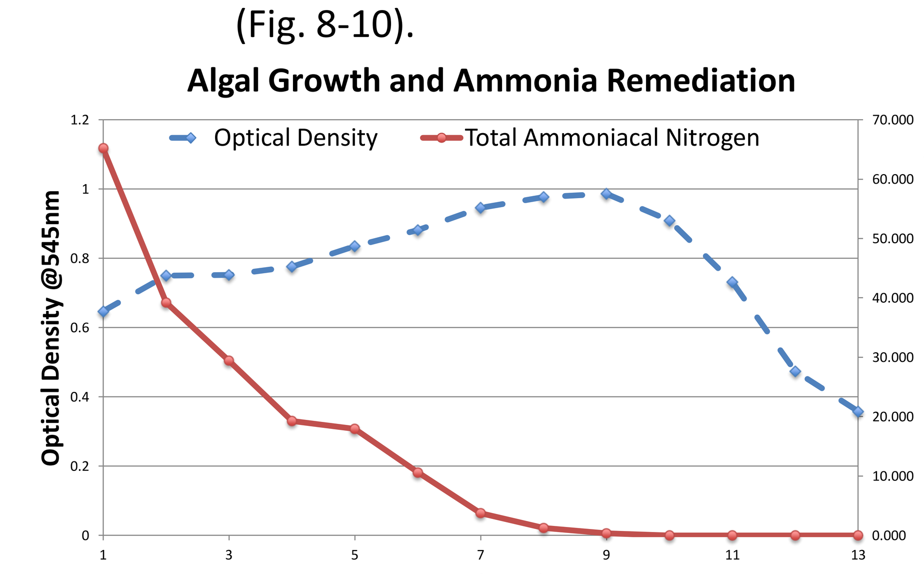


Figure 4. Time series monitoring algal growth and the removal of total ammoniacal nitrogen within the algal bioremediation system.

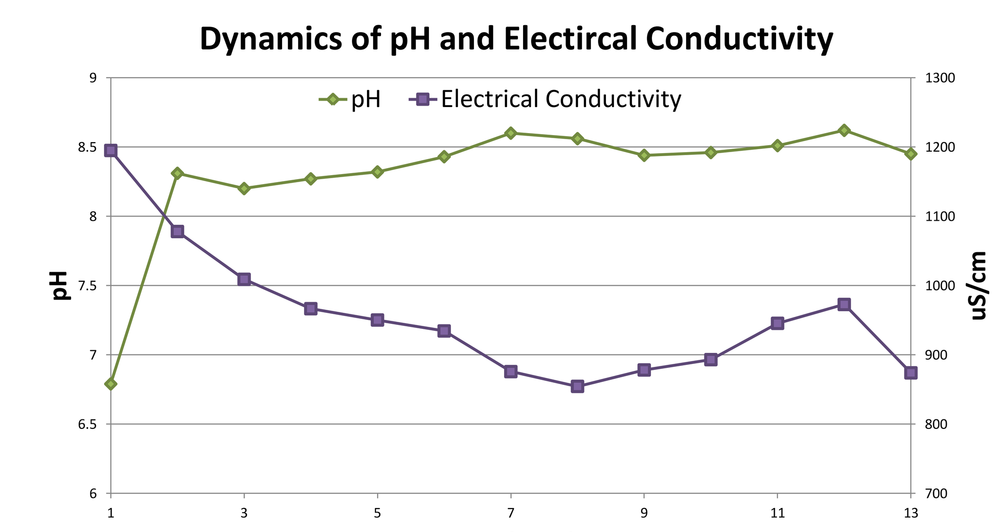


Figure 5. Time series showing the changes in pH and electrical conductivity within the algal bioremediation system.

Table 1. Elemental Analysis of Landfill Leachate, Reverse Osmosis treated Landfill leachate, and a common algal medium (Bold's Basal Medium).

Component (mg/L)	SW Archer Landfill Leachate	RO treated Landfill Leachate	Bolds Basal Medium
Macronutrients			
Nitrogen	1,119.60	120	41.20
__Ammonia-N*	1,110.00	120	_
__Nitrate-N	9.60	0.35	41.20
Phosphorus (PO_4)	9.98	0.09	163.10
Potassium	980.00	41	170.30
Magnesium	88.00	0.43	7.39
Calcium	110.00	0.5	6.82
Iron	16.00	0.141	1.00
Micronutrients			
Manganese	0.11	0.00024	0.50
Copper	0.27	<0.0022	0.02
Zinc	0.06	<.016	0.50
Cobalt	0.07	<0.0021	0.01

*Target for remediation is 2.8 mg/L

Figure 6. Algae growing in the 800L bioremediation tank on-site at the Alachua County South West Landfill. The closed municipal solid waste landfill is visible in the background.

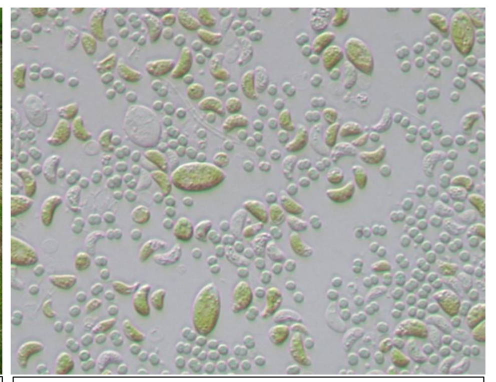
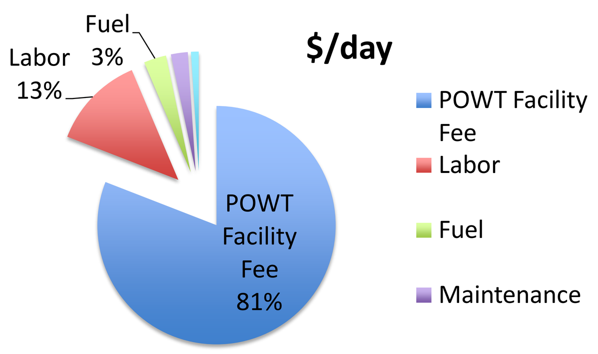


Figure 7. Photomicrograph of native algal diversity showing multiple species including the *Scenedesmus*, *Bumilleriopsis*, *Scenechocystis*, and *Chlorella*, 500x magnification.

Cost Evaluation

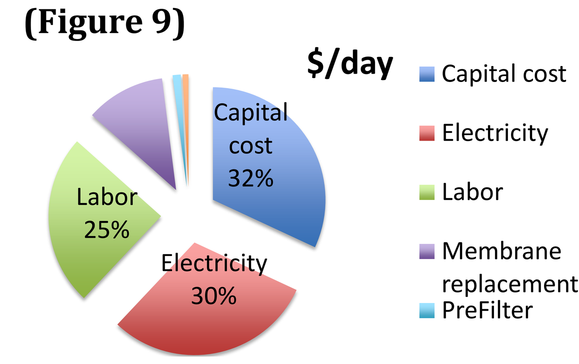
- **Conventional Treatment by Leachate Transport to Publically-owned Water Treatment Facility (Figure 8)**



Max. daily treatment	24,000
Est. total volume	5,000,000
Days to remediate	208

Cost Category	$/total volume
POWT Facility Fee	265,000
Transport	65,958.90
Total Estimated Cost	**$330,959**

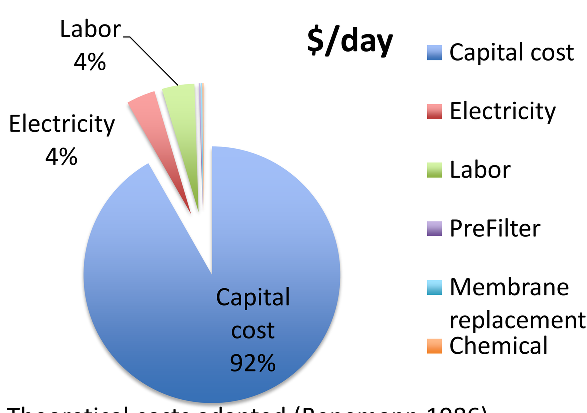
- **2-Stage On-site Reverse Osmosis Landfill Leachate Treatment (Figure 9)**



Max. daily treatment	4,500
Est. total volume	5,000,000
Days to remediate	1,111

Cost Category	*$/total volume*
Capital cost	42,788
Labor	33,330.00
Electricity	40,851.50
Membrane	18,220
Total Estimated Cost	**$135,190**

- **Theoretical cost for a 1 hectare algae pond 20cm deep (Figure 10)**



Max. daily treatment	28,800
Est. total volume	5,000,000
Days to remediate	173.6

Cost Category	*$/total volume*
Capital cost*	50,950
Labor	5,208.00
Electricity	4,631.60
Membrane	659.68
Total Estimated Cost	**61,449**

* Theoretical costs adapted (Benemann 1986).

Conclusions

- Algal Bioremediation reduced TAN levels below the GTCL required levels of 2.8mg/L.
- Algal biomass was limited primarily due to limited elemental nutrients. Supplementing these could improve growth responses and decrease remediation time.
- An elevated pH suggests that a percentage of TAN was lost due to atmospheric volatilization.
- Combined 1-stage RO and Algal Bioremediation have a significant potential for reducing the cost of leachate treatment.

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