Original Article

WMIR

Waste Management & Research
1-8

DOI: 10.1 177/ 0734242X2093 1937
journals.s agep ub.com/home /wmr

(i) SAGE

Sustainable landfill leachate treatment

Yudi Wu, Boya Wang and Gang Chen@

Abstract

Landfilling is one of the most widely used forms of solid waste disposal, yet the management of landfill leachate is challenging because of the complex composition and high contaminant concentration. This study provides an on-site treatment system to treat 500 m^3 day• of the leachate gene rated from the Perdido Landfill in Escambia County, Florida. The main concerns of the landfill leachate are ammonium-nitrogen, total dissolved solids (f DS) and biological oxygen demand (BOD) from the long-term monitoring (from September 1999 to May 2015). To targett hese major contaminants as well as other pollutants, we designed a wetland treatment system by fully utilizing the existing facilities at the Perdido Landfill site. The modified wetland treatmentsystem consists offive components in series: leachate collection/aeration ponds, anaerobic ponds, aerobic ponds, wetlands and limestone filter ponds. The leachate collection/aeration ponds provide functions of nitrification as well as ammonia and CO_2 stripping. The following anaerobic ponds focus on nitrogen removal by denitrification. The BOD is removed in the aerobic ponds. The ID S are removed in the wetlands and limestone filter ponds. In the wetlands, 60% of chloride and 40% of other contaminants are absorbed by *Parthenium sp.* In the limestone filter ponds, bicarbonate, calcium, magnesium and iron are removed.

Keyw ord s

On-site treatment, landfill leachate, wetlands, nitrogen, TDS, limestone

Received 15th April 2020, accepted 13th May 2020 by Senior Editor-in-Chief P. Agamuthu.

Introduction

As the most cost-effectivemethod of solid waste disposal, landfilling iscurrently commonly practiced all over the world (fownsend et al., 2015). However, this is a great challenge for the management of the landfill leachate owing to its complex composition and high contaminant concentration. Landfill leachate is generated from the moisture associated with the solid waste deposited in the landfills as weU as precipitation, which infiltrates the leachate collection system from the bottom of the landfills (Wiszniowski et al., 2006). Landfill leachate is usually transported to municipal wastewater treatmentplants for further treatment. Because of its complex composition and high organic concentration, municipal wastewater treatment plants are becoming reluctant to accept landfill leachate (Yang and Tsai, 2011). Currently, there is an urgent need to find alternativeways to treat landfill leachate.

Perdido Landfill, located in Escambia County, is currently discharging landfill leachate to a local wastewater treatment utility. Rising costs have led the County to seek on-site options for landfill leachate treatment. It is estimated the current (as of July 2015) daily leachate generation is 250 m^3 day·[1] The leachate is collected in two lined aeration ponds. According to the leachate characteristics provided by the Escambia County Department of Solid Waste, the major conta minan ts of the leacha te are ammonia-N (205.9 mg L"} and total dissolved solids (TDS) (2923 mg L"} (fable 1). The County is planning to implement a composting facility at the Perdido Landfill site. It will be constructed on the 7-acre yard waste pad with room to manage 270,000 metric tonnes peryear of organic waste (for composting duration up to 8 weeks). Because Florida Department of Environmental Protection requires compost leachate to be captured and disposed properly, oneof the County's options is to discharge the compost leachate to the landfill leachate collection ponds. Another option for compost leachate disposal is to bypass the landfill leachate facility and discharge directly to the local wastewater treatment utility.

Taking into consideration the potential compost leachate introduction and/or future landfill expansion, a leachate treatment system of 500 m^3 day• is considered in the design. Based on the evaluation ofthe feasibility analysis report provided bythe Escambia County (fownsend, 2015), a modified wetland treatment system (i.e. anaerobic ponds, aerobic ponds, wetlands and limestone filter ponds) is recommended.

The Perdido Landfill at Escambia, like many other landfills that serve small to medium communities, accepts various wastes including residential, commercial and industrial waste. Thus, the nitrogen content inthe leachate is not as high as typicalmunicipal

Department of Civil and Environmental Engineering, FAMU - FSU College of Enginee ring, Florida State Univers ity, Tallahassee, FL,USA

Corre sponding author:
Gang Chen, De pa rt m e n t of Civil and Environmental Enginee r ing, FAMU - FS U College of Engineering, Florida State Un ive rs ity, Tallahassee, FL 32310, USA.
Ema il: gche n@eng.fa mu. fs u.edu

Table 1. Leacha te ch a racte ris tics (ave rage from Se pte mbe r 1999 to May 2015).

Pa ra meter	Va lu es	Pa ra mete r	Va l ues
pH	7.73	Te mpe ra ture (° C)	23.3
Spec ific Conduct ivity (µS cm 1)	5 1 64	BOD (mg -L 1)	> 166
Dissol ved Oxygen (mg -L 11	2.62	COD (mg-L 11	1 3 1 1
Oxida t ion / Reduc t ion Pote ntial (mV)	- 24 .1	Bica rbonate Hardness (mg-L 1 as CaC0 3)	1917
Tur bid ity INTU)	92.1	Am monia- N [mg -L 1)	205.9
Chlor ide (mg -L 1)	626	Nit rate 1mg -L 11	7 .64
Sod i um 1mg -L 11	631	Iro n 1mg -L 11	42 .6
TDS 1mg -L 11	2923	Magnesium (mg-L 11	1 63 .7

Table 2. Calculat ed TDS based on cat io n and anion com pos it io n.
Diffe re nce between sum of ca tion and anion = 32.9 me q-L 1 = 22 .7% of to ta l a moun t of io ns

Va lue s	Mo le c ula r Weigh t lg/ moll	Charge	Molar Concent ra tion lmmol-L 11	Mass Conce ntratio n 1mg -L 11	Nor mal Conce ntra t ion lmeq -L 11
Chloride (Cl-J	35.5	- 1	17.6	626.0	17.6
Nit rate [N0-3 J	62 .0	- 1	0 .1 2	7 .6	0 .1 2
Bica rb o na te (HC0-3)	61.0	-2	38.3	2338.1	38.3
Sodi um [Na +]	23.0	+1	27.4	631.0	27.4
Ammo nia IN H4+]	18.0	+1	13.9	250.0	13.9
Magnesium **[M g2+]**	24.3	+ 2	6.7	163.7	13.5
Calc ium 1Ca2+]	40.1	+ 2	16.3	654.7	32.7
Ferrous 1Fe 2 +]	55.8	+2	0.73	42.6	1.5
		TDS in mg -L 1 = 4713.7		Anion sum in meq -L 1 = 58 . 0	
				Cat io n sum in meq -L 1 = 88.9	

solid waste (MSW) landfills. As there are a lot of landfills operating in this way, especially those serve small to medium communities, this design will be helpful for these landfills.

Leachate character istics

Major concerns of the landfill leachate are high arnmonia-N content, TDS and biological oxygen demand (BOD) content. Conventional wetlands are capable of removing ammonia and BOD. However, TDS are a significant challenge for wetland systems. TDS include all inorganic and organic substances fuat can pass through a 2-micrometer filter (Rhoades, 1996). In practice, TDS are commonly the sum of cations and anions, including carbonate, bicarbonate, chloride, fluoride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, potassium, herl>icides and hydrocarbons, etc. The United States Environmental Protection Agency Secondary Regulations advise a maximum co ntamina- t ion level of500 mgL"1for TDS, whichis consistentwith Florida Groundwater Cleanup Target Levels. The targeted concentration threshold for total ammonia-N is 10 mg L"1 (Shippen, 1994). As shown in Table 1, the leachate had a TDS value of2923 mg L"1 TheTDS value was furfuer evaluated in two differentways based on the cation and anion composition and fue leachate conductivity using the methods of TDS Calculator (Walton, 1989) and Water Quality Field Guide (Shippen, 1994). For fue first method, the bicarbonate, calcium and magnesium concentrations were calculated to be 2338.1 mg L 1, 654.6 mg L 1 and 163.6 mg L '

Table 3. TDS calculatio n based on conductivity*.

Type of Water	TDS (mg-L 11	Conversion Factor
Fres hwate r	0-2200	0.7
Brack is h water	2200-8300	0.6
Sa line wate r	> 8300	0.5

* TDS (mg L"1) = Conductivity (µS cm"1) x Conversion Factor

(estimated from the Perdido Landfill leachate characteristics report). Accordingly, the calculated TDS were 4713.7 mg L ' (Table 2). It should be noted fuat several cation data were not available, thus the difference between fue sum of cations and anions was larger fuan 10%. For the second mefuod, fue TDS were calculated by leachate specific conductivity (5164 µS cm ' from Table 1) multiplied by a conversion factor (Table 3), i.e. TDS = 5164 x 0.6 = 3098.4 mg L"1 The TDS value from feasibility analysis report was 4400 mg L"1 We therefore used 4700 mg L"1 for TDS for fuis design.

As there is a possibility of the compost leachate to be introduced to the landfill leachate treatment facility, compost leachate characteristics are taken into considera tion for this desig n (Romero et al., 2013). At the composting facility, the organic fraction of MSW is composted. Subsequently, the chemical and physical nature of the compost leachate affects the landfill leachate treatment when mixed togefuer. Compost leachate carries bofu dissolved species and particulate materials suspended in fue liquid. Compost leachate is also rich in soluble organics. Typical

Table 4. Typical characteristics of compost leachate of a large-scale enclosed static pile composting facility.

	pH	Conductivity (µS cm^{-1})	BOD5	COD	BOD5/COD	TKN	NH4 +	Cl-	VFA
			(mg O2 L^{-1})			(mg L^{-1})			
Minimum	7.1	9.3	8	2434	0	250	98	1514	118
Maximum	8.2	27.9	11,571	31,812	0.7	1602	558	5254	9535
Geometric Mean		17.6	1368	9121	0.1	636	224	2949	1125
Lower 95% Confidence Limit (Geometric)		14.1	431	5832	0.09	458	157	2254	529
Upper 95% Confidence Limit (Geometric)		21.9	4341	14266	0.3	884	319	3857	2394

Source : Adapted from Krogmann and Woyczechowski (2000).
TKN: Total Kjeldahl N; VFA: Volatile Fatty Acid.

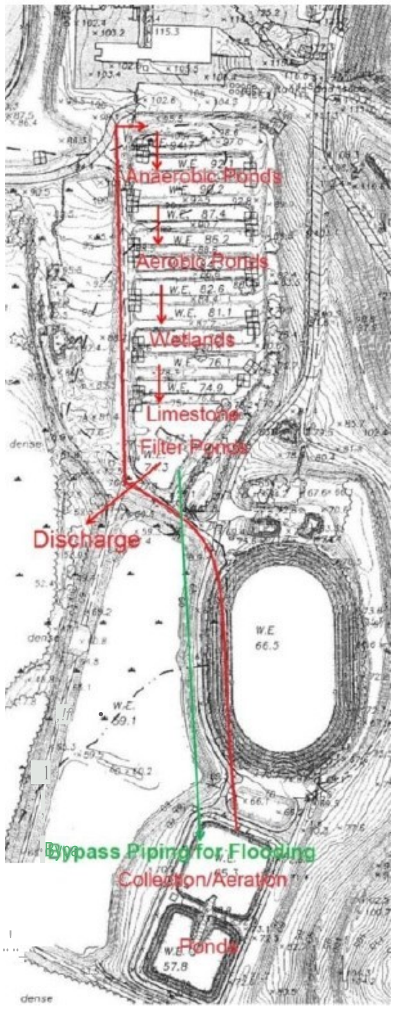

Figure 1. Wetland treatment system for landfill leachate.

characteristics of compost leachate from the composting of a mixed feedstock (w/w, 55% source-separated MSW, 30% yard waste and 15% foliage residue from tobacco cultivation) are summarized in Table 4 (Krogmann and Woyczechowski, 2000). The compost leachate usually has high BOD, TDS (especially in terms of chloride) and ammonia-N. The existence of compost leachate absolutely interferes with the landfill leachate treatment. The following designs are based on the landfill leachate characteristics with the options of compost leachate being introduced to the landfill leachate.

Wetland treatment system for landfill leachate

Overview

The wetland treatment system is composed of leachate collection/aeration ponds, anaerobic ponds, aerobic ponds, wetlands and limestone filter ponds (Figure 1). The major targeted contaminants are TDS, nitrogen and BOD. The effluent should meet the following criteria: TDS < 500 mg L^{-1}, total N < 10 mg L^{-1} and BOD < 20 mg L^{-1}.

The major components of TDS are bicarbonate, chloride, calcium, magnesium and iron. This design fully utilizes the footprint of the existing leachate collection ponds, wetlands and sand filter ponds at the Perdido Landfill site (Figure 2). Pumping is required from collection/aeration ponds to surged ponds, from where the conveying of the leachate is by gravity. Aeration is required in the leachate collection ponds; therefore, the existing ponds will be renamed leachate collection/aeration ponds. The wetland system includes 10 treatment cells, a surge pond and a modified limestone filter pond The leachate is to be introduced to the treatment cells through the surge pond. The first three cells are anaerobic ponds with increased depth, the next three ponds are aerobic ponds and the last four cells are wetlands with planted *Parthenium sp.* The limestone filter ponds are designed for further TDS removal. The collection/aeration ponds achieve nitrification and CO_2 stripping. In these ponds, ammonia-N is converted to nitrate-N and bicarbonate is reduced (by CO_2 stripping). In the anaerobic ponds, nitrate-N is removed (i.e., converted to N_2 through denitrification). The aerobic ponds are for BOD removal and leachate stabilization. Some 60% of chloride is to be removed in the wetlands by *Partheniwn sp.* The limestone filter ponds further reduce bicarbonate and precipitate calcium, magnesium and iron. To ensure TDS and chloride removal, the pH needs to be adjusted, and alum needs to be added in the limestone filter ponds. In the case of flooding, leachate not properly treated is to be recirculated to the collection/aeration ponds through the bypass piping system.

Leachate collection/aeration ponds

The leachate collection/aeration uses the existing leachate collection ponds, which is noted as (1) in Figure 2. There are two collection ponds with equipped surface aerators. The volume

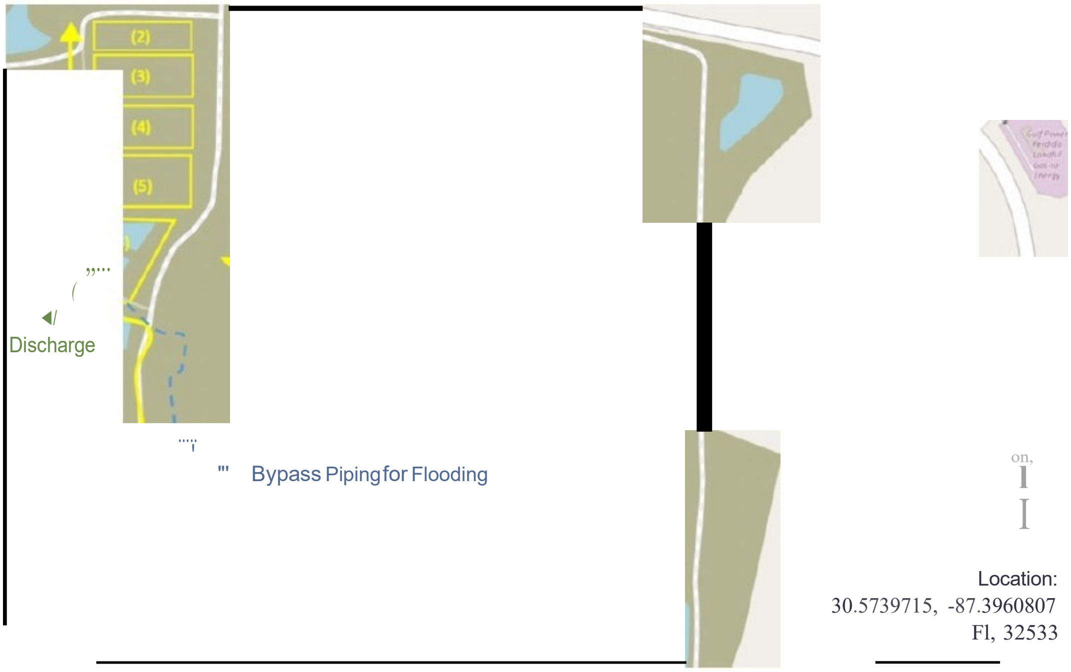

Figure 2. Wetland treatment system components and location. Source: OpenStreetMap (2020).

Table 5. DO concentration and nitrification achieved.

DO Concentration	Nitrification Achieved
< 0.5 mg L-1	Little, if any, nitrification occurs
0.5 to 1.9 mg L-1	Nitrification occurs, but inefficiently
2.0 to 2.9 mg L-1	Significantly nitrification occurs
3.0 mg L-1	Maximum nitrification

capacity of each pond is 18,500 m^3. For two ponds to receive 500 m^3 of leachate per day, the retention time is 74 days. The current landfill leachate from the collection ponds maintains a dissolved oxygen level of 2.62 mg L^{-1}, which can fulfill the nitrification requirements (Table 5).

For typical nitrification (f_e = 0.9 and f_s = 0.1), the general equation can be expressed as:

$$0.13NH_4^+ + 0.225O_2 + 0.02CO_2 + 0.005HCO_3^- \rightarrow 0.005C_5H_7O_2N + 0.125NO_3^- + 0.25H^+ + 0.12H_2O \quad (1)$$

From reaction (1), for each 1.82 g of NH_4^+-N, 7.2 g O_2 and 0.305 g HCO_3^- are consumed. On the daily basis, input NH_4^+-N is 205.9 mg L^{-1} x 500 m^3/day = 101 kg, oxygen O_2 requirements are 101 kg (7.2/1.82) = 400 kg, and HCO_3^- consumed is 101 kg (0.305/1.82) = 16.9 kg.

Through aeration, there is a chance for gaseous ammonia to be stripped to the atmosphere. Using the model of nitrogen removal in facultative lagoons (based on the depth of the collection/aeration ponds), the net ammonia can be calculated as (Middlebrooks et al., 1999):

$$N_e = \frac{N_o}{1 + t \times (0.000576T - 0.00028) \times e^{(1.080 - 0.042T) \times (pH - 6.6)}} \quad (2)$$

Table 6. Typical performance data for selected aeration devices.

Aeration Device	Oxygen Transfer Rate, kgO2/kWh
Fine Bubble Diffusers	2.0-2.5
Coarse Bubble Diffusers	0.8-1.2
Vertical Shaft Aerators	Up to 2.0
Horizontal Shaft Aerators	Up to 2.0

Source: Adapted from Roman and Muresan (2014).

Where N_e is the effluent nitrogen (mg L^{-1}), N_0 is the influent nitrogen (mg L^{-1}), T is the temperature of the pond (°C) and t is the detention time (days). For this case, N_e is 159.4 mg L^{-1} if temperature is assumed to be 25°C and the detention time is 20 days (although the capacity retention time of the collection/aeration ponds is 75 days, a retention time of 20 days is recommended). Effluent NO_3^--N is 153.3 mg L^{-1}.

Based on the typical performance data of aeration devices (Table 6), the required horsepower for the two-leachate collection/aeration ponds by surface aerators is calculated as follows:

$$P = \frac{400\ kg\ O_2}{(0.9\ kg\ O_2/745\ Wh/hr) \times (24\ hrs)} = 14\ kWh \quad (3)$$

Therefore, each pond needs a minimal 7 kWh surface aerator. Based on the average industrial electricity rate in Pensacola of 8.14¢/kWh, energy costs for the aeration are: 8.14¢/kWh x 14 kWh x 24 h = $27 per day. It should be noted that above calculation is based on the leachate pH of 7.73 from Table 1.

Anaerobic ponds

The leachate is to be introduced to the surge pond with a retention time of 2 days. The leachate is then discharged to the

Table 7 . Anae robic pond design criteria.

Sou rce	Optima l De pth (ml	Su rface Load ing (kg m^2 di	De tention Time (di	BOD Re moval (%1	TSS Re moval (%1	Optima l Temperat ure (Kl
(Me tca lf et a l., 1 9791	2.4- 4.9	0.02- 0.05	20-50	50-85	20-60	303.2
(WHO,19871	2.4- 4.9	> 0.1	5	50-70	NA	298 .2- 303 .2
(Mara et al., 19921	2.0- 4.9	> 0.3	1- 2	75	NA	298 .2
(Arthu r, 19831	4.0	0.4- 1.6	2	NA	NA	300 .2- 303 .2

Table 8 . Ae robic pond design cr it e ria .

Source	Optima l De pth (ml	Su rface Load ing (kg m^2 di	De tention Time (di	BOD Re moval (%1	TSS Remov al (%1	Optima l Temperat ure (Kl
(Metca lf et a l., 19791	0.9- 1.5	0.0017	5-20	60-80	NA	293 .2
(WHO, 19871	0.9- 1.5	NA	5-10	50-60	NA	NA
(Mara et al., 19921	0.9- 1.5	NA	NA	NA	NA	NA
(Arthur, 19831	1.2- 1.5	NA	5	NA	NA	NA

anaerobic ponds (the first three cells of the existing wetlands system). The depth of the anaerobic ponds is 3.3 m and the retention time of the anaerobic ponds is 30 days (i.e. 10 days for each pond). This is consistent with typical anaerobic pond design criteria (Table 7). The surge pond and anaerobic ponds need to be lined with a double liner in order to meet surface impoundment requirements (Arthur, 1983).

For denitrification (f., = 0.733 and fs = 0.267), the gene ral equation can be expressed as:

(a) Heterotrophic with methanol

$$0.1667CH_3OH + 0.1561NO_3^- + 0.1561H^+ \rightarrow 0.0733N_2 + 0.00954C_5H_7O_2N + 0.119CO_2 + 0.3781H_2O \quad (4)$$

(b) Heterotrophic with acetate

$$0.125CH_3COO^- + 0.1438NO_3^- + 0.1438H^+ \rightarrow 0.0658N_2 + 0.0122C_5H_7O_2N + 0.0639CO_2 + 0.1542H_2O + 0.125HCO_3^- \quad (5)$$

To remove 1 g of NO_3^-, 0.55 g methanol is required. Similarly, if acetate is used, 0.82 g acetate is required.

Aerobic ponds

After anaerobic pond treatment, the leachate is introduced to the aerobic ponds (the fourth to the sixth cells). The depth of the aerobic ponds is 1.3 m and the retention time of the aerobic ponds is 12 days (i.e. 4 days for each pond). This is consistent with typical aerobic pond design criteria (Table 8) (Chagnon, 1999). The aerobic ponds need to be lined with a double liner in order to mee t surface impoundment requirements (Shippen, 1994).

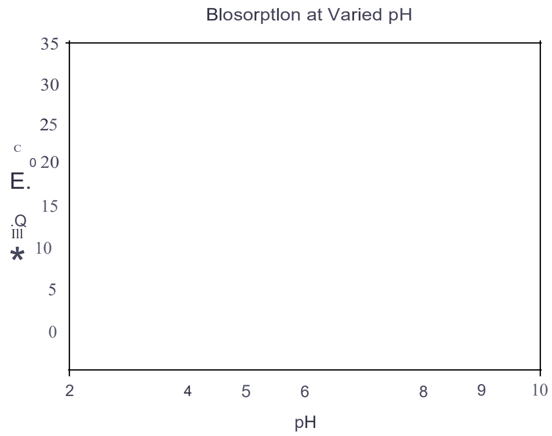

Figure 3. Chloride bioso rption by *Parthenium sp.* as a funct io n of pH.

Wetlands

The wetlands are implemented using the seventh to tenth cells. The depth of the wetlands is 0.3 m and the retention time of the wetlands is 4 days(i.e. 1 day for each wetlands cell). The depth of wetlands is consistent with the typical design criteria (Crites, 1988; Hammer, 1989). In order to assure that the plants are not subjected to incompatible amounts of water depth, the design water depth is 0.3 m for the emergent vegetation. The bottom of the wetlands needs to be either impermeable layers of clays or lined with a double liner in order to meet surface impoundment requirements (Ship pen, 1994).

Parthenium sp., which is an herbaceous annual or ephemeral member of the family *Asteraceae,* is to be planted within the wetlands as a sorbent for chloride removal. It can reach heights of up to 2 m in good soil and attain flowering in less than 4-6 weeks of germination. It is well known that the process of biosorption is governed by the solution pH. Research has demonstrated that chloride sorption can reach the optimum level at pH 7.0(Figure 3) (Apte et al., 2011). Biosorption of chloride by *Parthenium sp.* can

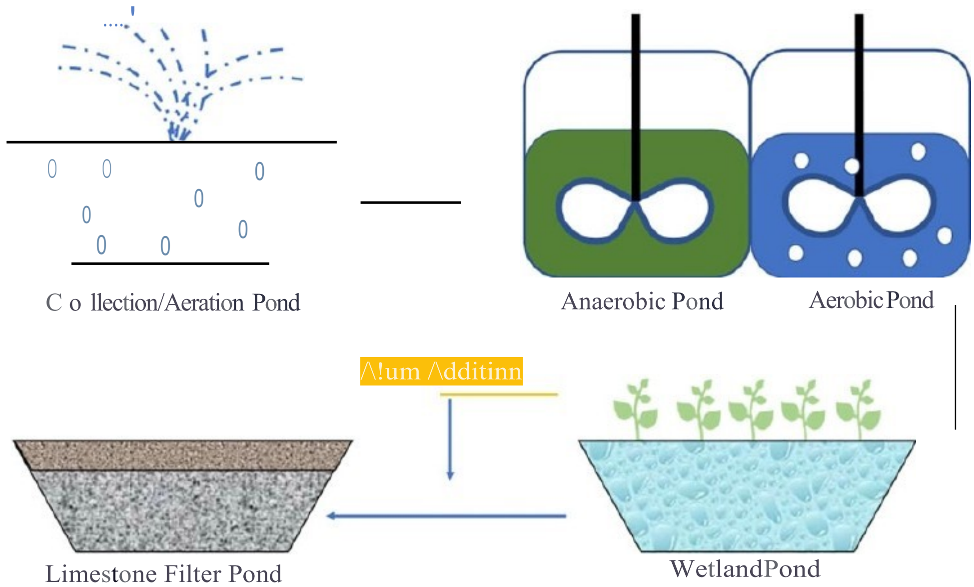

Figure 4. Wetland treatment system for landfill leachate with alum addition.

become stable after 2 h. Annual harvest is recommended for *Parthenium sp.* The landfill leachate is first treated in the collection/aeration ponds for nitrification, followed by anaerobic and aerobic treatment for denitrification and organic removal before being introduced to the wetland ponds. Before reaching the wetland ponds, the aeration, anaerobic and aerobic treatment stabilizes the leachate and reduces the toxicity for the plants in the wetlands.

Limestone filter ponds

The limestone filter ponds have four ponds in series. The depth of the four limestone filter ponds is 3.3 m and the retention time will be 2.8, 7.5, 8 and 2.8 days, respectively. The bottom of limestone filter ponds needs to be either impermeable layers of clays or lined with a double liner in order to meet surface impoundment requirements. Limestone is a naturally occurring rock that can be crushed and processed to produce a uniform granular material, which, when used in a properly designed limestone contactor, allows the water pH in the range of 7.2-8.3. It is expected that this pH range reduces bicarbonate content and precipitates heavy metals. The limestone used for the limestone filter ponds has a grading of 11 to 14 mm. For further removal of chloride, alum (aluminum sulfate) is to be added in the limestone filter ponds (Figure 4). Chloride, the major contributor to TDS, is removed by the ultra-high lime with aluminum process.

The high pH and calcium content in the limestone filter ponds together with the added aluminum make it possible for chloride to be removed in terms of calcium chloroaluminate [$Ca_4Al_2Cl_2(OH)_{12}$] precipitation. A chemical mixing tank is needed for alum addition. With alum addition, chloride removal by calcium chloroaluminate precipitation is achieved according to the following reaction,

$$4Ca^{2+} + 2Al(OH)_4^- + 2Cl^- + 4OH^- \rightarrow Ca_4Al_2Cl_2(OH)_{12}(s) \quad (6)$$

Water quality

The methanol addition requirements for denitrification and cost estimates are calculated as follows: To remove 90% or 617.6 mg L^{-1} NO_3-N, 339.6 mg L^{-1} methanol is required. The density of methanol is 792 kg m^{-3}. Therefore, for the treatment of 500 m^3 of leachate per day, 214 L of methanol is required. The methanol costs are $0.18 to $0.8 per liter. Therefore, $38 to $171 is required for methanol costs every day. The leachate characteristics after each treatment step for the landfill leachate are summarized in Figure 5.

Limestone is an alkaline agent and the limestone filter ponds are subsequently rich in HCO_3^-. Under these conditions, calcium and magnesium are removed by precipitation through the following reactions:

$$HCO_3^- \rightarrow H^+ + CO_3^{2-} \quad (7)$$

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \quad (8)$$

$$H_2O \rightarrow H^+ + OH^- \quad (9)$$

$$Mg^{2+} + 2OH^- \rightarrow Mg(OH)_2 \quad (10)$$

As an alkaline agent, the produced protons by above reactions can be easily consumed by the limestone.

With this design, the effluent from the wetland treatment system that is composed of leachate collection/aeration ponds, anaerobic ponds, aerobic ponds, wetlands and limestone filter ponds meets the following criteria: TDS < 500 mg L^{-1}, total N < 10 mg L^{-1} and BOD < 20 mg L^{-1}. The leachate collection/aeration ponds mainly remove ammonia by ammonia stripping, and convert ammonium to nitrate. The anaerobic ponds remove nitrate by denitrification. At the same time, BOD is removed BOD is further removed in the aerobic ponds. Nitrate and chloride are further removed in the wetlands. Finally, bicarbonate, magnesium, calcium, iron and chloride, the major contributors to TDS, are removed in the limestone filter ponds.

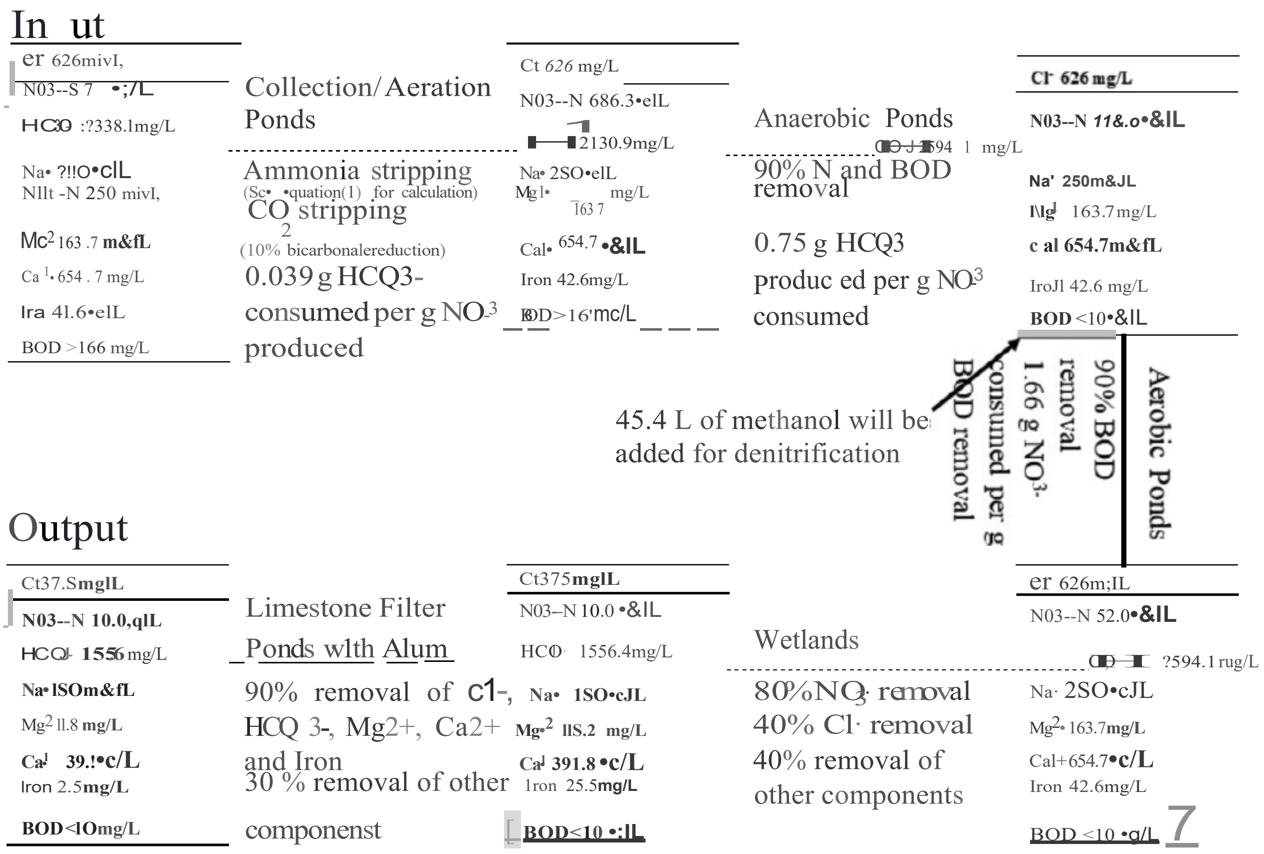

Figure 5. Leachate characteristics after each treatment step for landfill leachate.

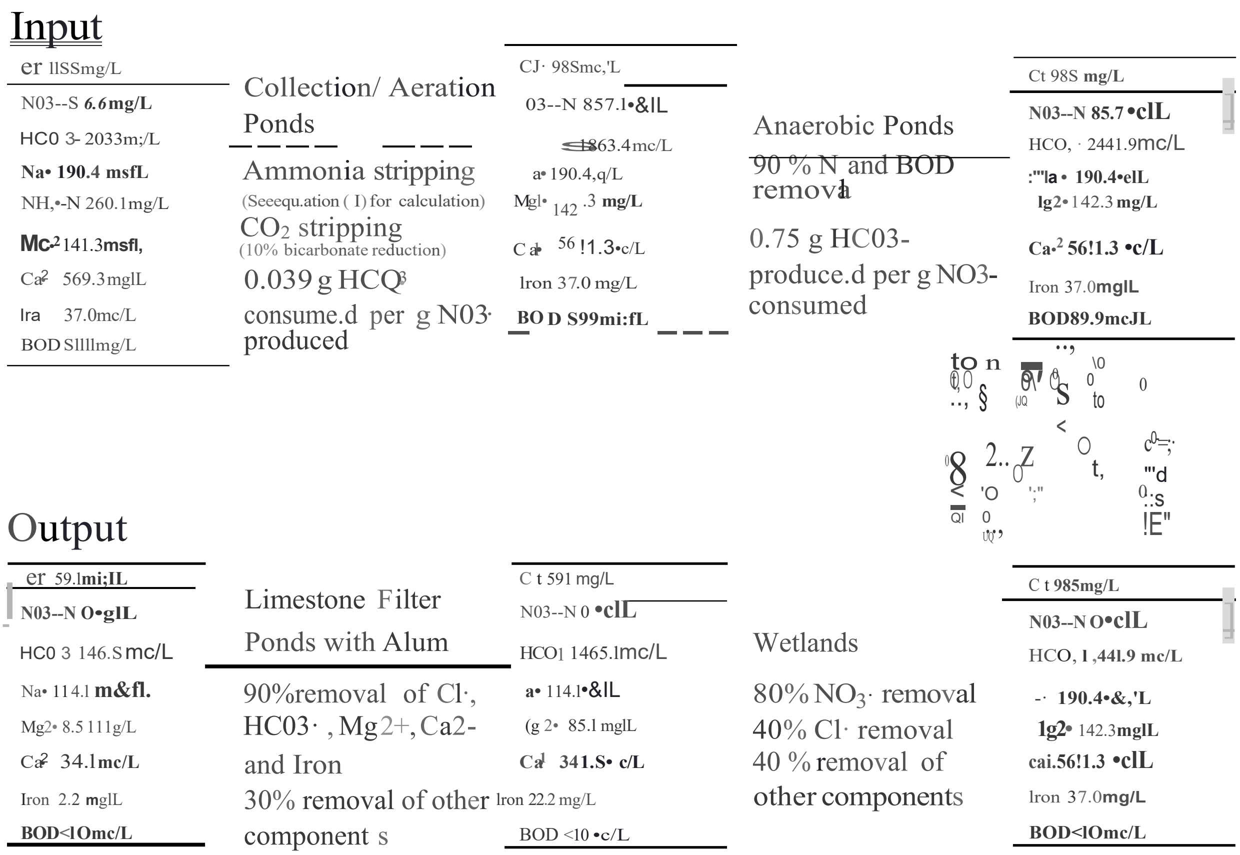

Figure 6. Leachate characteristics after each treatment step for combined landfill and compost leachate.

Wetland treatment system for both landfill leachate and compost leachate

For the treatment of combined landfill leachate (500 m^3 day"1) with compost leachate (75 m^3 da·y,1 10% of composted wastes), the same treatment process can meet the target goal. Based on the mass balance, the characteristics of the combined leachate are obtained The leachate characteristics after each treatment step for the combined land fill and compost leachate are summarized in Figure 6.

Volatile fatty acids (VFAs) from the compost leachate can reduce nitrate formation. As the compost leachate accounts for 13% of the combined leachate (75 m^3 day·1 in combination with 500 m^3 day·1 landfill leachate), the effect should be minimized by the dilution. To further avoid this issue, the aeration in the collection/aeration ponds needs to be enhanced to reduce the VFAs before further treatment. It should be noted that VFA loading can be a limiting factor for proper functioning of a constructed wetland.

With this design, the effluent from the wetland treatment system that is composed ofl each ate collection/aeration ponds, anaerobic ponds, aerobic ponds, wetlands and limestone filter ponds meets the following criteria: TDS < 500 mg L"1, total N < IO mg L"1 and BOD < 20 mg L"1. By ammonia stripping and ammonium nitrification in the leachate collection/aeration ponds, nitrate concentration reaches 857.1 mg L·1 The anaerobic ponds remove 90% of nitrate by denitrification and 90% BOD. Because enough BOD is available, no methanol addition is required. In the aerobic ponds, most of the BOD is removed. After the wetlands, chloride is 591 mg L"1 and bicarbonate is 1465.1 mg L"1 which contribute significantly to the TDS. In the limestone filter ponds with alum addition, 90% of bicarbonate and chloride are removal, meeting the treatment requirements.

Conclusions and recommendations

Based on the evaluation of the feasibility analysis study, it is feasible for Escambia County to perform an on-site leachate treatment at Perdido Landfill site. A wetland treatment system, which includes anaerobic ponds, aerobic ponds, wetlands and limestone filter ponds is recommended for either landfill leachate treatment alone or combined landfill and compost leachate treatment. High TDS (including chloride), BOD and nitrogen can be removed efficiently. Through the wetland treatment system, the effluent meets the following criteria: TDS < 500 mg L"1, total N < IO mg L "1 an d BO D < 20 mg L"1.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the researc h, authorship, and/or publication of this article: The authors acknowledge the support from the National Institute ofF ood and Agriculture through Grant No. 2018-68002-27920 to Florida A&M University and also the National Science Foundation through Grant No. 1735235, awarded as part of the National Science Foundation Research Traineeship.

ORCID iD

Gang Chen CID https://orcid.org/0000-0002-6476-7812

References

Apte S, Apte S, Kore VS, et al. (2011) Chloride removal from wastewater by biosotption with the plant biomass. *Univer.sal Jo urna l of Environmental Research & Technolcgy* I: 416-4 22.

Arthur J (1983) *Notes in the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries.* Washington: The World Bank.

Chagnon FFJ (1999) *Design and Dynamic Modeling of Waste Stabilization Ponds.* Cambridge: Massachusetts Institute of Technology.

Crites RW (1988) *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment.* Washing ton: US Environmental Protection Agency, Office of Research and Development

Hammer DA (1989) *Constructed Wetlands for Wastewater Treatment: Municipal Industrial and Agricultural.* Chelsea: Lewis Publishers.

Krogmann U and Woyczechowski H (2000) Selected characteristics of leachate, condensate and runoff released during composting of biogenic waste. *Waste Management& Research* 18: 235- 248.

Mara D, Alabaster G, Pearson H, et al. (1992) *Waste stabilization Ponds: A Design Manual for Eastern Africa* . Leeds: Lagoon Technology International.

MetcalfL, Eddy HP and Tchobanoglous G (1979) *Wastewater Engineering: Treatme,nt Dispos,al and Reuse.* New York: McGraw-Hill.

Middlebrooks BM, Reed SC, Pamp A, et al. (1999) Nitrogen Removal in Wastewa te r Stabilization Lagoons. In: 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop, Kansas City, Missouri, 2-4 August 1999.

OpenStreetMap (2020) www.openstreetmap.org (accessed 17 June 2020).

Rhoades J (1996) Salinity: Electrical Conductivity and Total Dissolved Solids. In: Bigham JM (ed.) *Methods of Soil Analysis: Part 3 Chemical Met hods* . Madison: Soil Science Society of America, pp. 417-435.

Roman MD and Mure MV (2014) Analysis of oxygen requiremen ts and transfer e fficiency in a wastewater treatme nt plant *International Journal of Latest Research in Science and Technology* 3: 30-33.

Romero C, Ramos P, Costa C, et al. (2013) Raw and digested municipal waste compost leachate as potential fertilizer: comparison with a commercial fertilizer. *Journal of Cleaner Production* 59: 73- 78.

Shippen RS (1994)*Water Qua lity Standards Handboak,*2nd ed. Washington: U.S. Environmental Protection Agency.

Townsend T (2015) *Examining On-Site Leachate Treatment Methods at the Perdido LandJtll: AFeasibility Analysis.* Gainesville: Hinkley Center for Solid and Hazardous Waste Management.

Townsend TG, Powell J, Jain P, et al. (2015) *Sustainable Practices for Landfill Design and Operation.* New York: Springer.

Walton NRG (1989) Electrical conductivity and totaldissolved solids: what is their precise relationship? *Desalination* 72: 275- 292.

WHO AE (1987) *Wastewater Stabilization Ponds: Principles of Planning and Practice, World Health Organization.* Alexandria: Regional Office for the Eastern Mediterranean.

Wiszniowski J, Robert D, Surmacz-Gorska J, et al. (2006) Landfill leachate treatment methods: a review. *Environmental Chemistry Letters* 4: 51--<il.

Yang L andTsai KY(2011)Treatment ofl andftll leachate with high levels of ammonia by constructed wetland systems. *Journal of Environmental Science and Health Part A* 46: 736-741.