

SUMMARY: SAFE DISCHARGE OF LANDFILL LEACHATE TO THE ENVIRONMENT, YEAR TWO

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Some closed or partially closed landfills still produce important quantities of leachate, but instead of blending this material with active Class I leachate for disposal, there may be better alternatives. If a relatively inexpensive way to pretreat the leachate and safely dispose of it onsite can be developed, a giant step toward the potential for zero liquid discharge can be achieved. FAU has pioneered the advancement of landfill leachate treatment systems using the photochemical iron-mediated aeration process and the TiO₂ photocatalytic process at laboratory scale in previous research funded by the Hinkley Center, which has led to the development of reactor prototypes for pilot scale testing. The objective of the proposed research is to test a prototype photooxidative reactor at pilot scale for the removal of COD/BOD, heavy metals (i.e. arsenic, lead, and iron), ammonia, color, chlorides, and pathogens to determine the feasibility of safely discharging or reusing this leachate as a resource, such as irrigation for top caps and side slopes.

In previous work funded by the HCSHWM, 23 different engineering alternatives for long-term leachate management were evaluated (Meeroff and Teegavarapu 2010). For on-site treatment to work, some form of aerobic treatment would be expected to reduce leachate strength prior to discharge. However, biological systems are not well-suited for the removal of bio-toxics from water and are inefficient in dealing with wastes of varying quality, such as leachate. Thus post-treatment, using constructed wetlands, combined physicochemical treatment, or evaporation systems, would then be required. Unfortunately, technologies such as activated carbon and certain advanced treatment processes, such as ozone, do not adequately address inorganics, and membrane systems or air stripping merely transfer organics to another phase or create a side stream, like concentrate brine that cannot be discharged readily. Furthermore, multiple barrier systems are complicated to operate, costly, and generally inefficient. For on-site treatment options, the most effective strategies involve technologies that can destroy different classes of harmful contaminants all at once, without producing adverse byproducts and residuals.

Fortunately, FAU has been working to address this need for sustainable, economical options for routine leachate treatment and safe discharge to the environment by investigating energized processes, such as photocatalytic oxidation. In our previous studies involving the use of photocatalytic oxidation technologies for treatment of landfill leachate, we were able to demonstrate destruction of 1400 – 2500 mg/L of COD in just 24 hours. But these leachates had initial COD concentrations on the order of 6,000–10,000 mg/L, so if we start with a less concentrated material (e.g. partially closed landfill leachate), it should be possible to completely destroy the COD with the added potential of meeting the requirements of F.A.C. 62-302 for metals and 62-777 for surface water target levels or even meeting the less stringent industrial water quality guidelines for onsite beneficial reuse of this material.

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PROGRESS REPORT

(September 2015)

Project Title: Safe Discharge of Landfill Leachate to the Environment

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The experiments conducted during the period of June 2015 – September 2015 focused on: 1) recovery of TiO₂ from leachate by using centrifugation and sedimentation, and 2) using a falling film photocatalytic pilot scale reactor + EMOH to remove COD/BOD, ammonia, heavy metals, color, and pathogens from leachate. For centrifugation, experiments were conducted with varying centrifuge times and rotational velocities to determine the optimum conditions for TiO₂ recovery after use in treatment. For sedimentation, TiO₂ settling tests were conducted in order to determine the optimum ultimate settling time (t_u) of the TiO₂ using different concentrations in 100 mL of leachate. These settling tests aided in determining appropriate tank dimensions to conduct a TiO₂ settling recovery pilot study. For falling film reactor tests, the goal is to determine the appropriate conditions (UV intensity, pH, and temperature) to maximize removal of the aforementioned water quality parameters. Once optimal conditions are found, the cost of treatment in dollars per gallon will be determined.

TiO₂ Recovery Via Centrifuge Experiments

There were 16 centrifuge experiments conducted on the recovery of TiO₂ from leachate between June 1, 2015 and September 30, 2015. The mass of TiO₂ and volumes of leachate varied with these experiments; however, the dose of photocatalyst did not change. All of these tests were performed using 20 g/L TiO₂ in leachate. The type of leachate tested for these experiments came from Pump Station A at the Solid Waste Authority (SWA) in West Palm Beach, FL collected on May 14, 2015. This leachate had a pH of 6.76, dissolved oxygen of 0.48 mg/L, and TDS of 37,000 mg/L. During these tests, the TDS played an important role because when measuring the initial and final (recovered) weights of TiO₂, salts from the leachate itself were precipitating on the photocatalyst, causing the recovered TiO₂ weight to be over 200% recovery, which is impossible. Therefore, the leachate itself had to be centrifuged and dried alongside of the TiO₂. Then the dry weight of the leachate was subtracted out of the recovered TiO₂ result in order to get a true TiO₂ recovery result.

During these 16 experiments, different adjustments to the leachate qualities were made. For the first ten experiments, only raw leachate (TDS = 37,000 mg/L) was used. In the last six experiments, the raw leachate was diluted in a 1:20 ratio in a 1L sample. The purpose of dilution (TDS ~ 2,000 mg/L) was to decrease the TDS of the leachate for the upcoming centrifuge experiments and for other types of experiments conducted after this time period. Some other changes to the centrifuge methodology were as follows. At first, a general procedure consisted of mixing weighed TiO₂ with a measured volume of leachate, pouring the mixed samples into

centrifuge tubes, centrifuging, pouring the centrifuged samples into ceramic/aluminum dishes, putting those dishes into a drying oven for 24 hours at 103°C, and then desiccating the samples for one hour after drying before weighing them to a constant weight. One change was to pour enough leachate for three experiments at a time into a 1L sample bottle. That bottle would be shaken for 60 seconds in order to disperse the heavy solids in the leachate to make sure they were used in the experiment. Another addition was to ignite the leachate in a muffle furnace at 550°C for 15 minutes after the 24 hour drying and one hour desiccating step; the purpose of this was to ignite off any organic matter in both the leachate and the used TiO₂ samples before weighing them. However, that step was eliminated because it did not improve the results.

After conducting those experiments with different centrifuge velocities and times and with either raw or diluted leachate, the following optimum TiO₂ recovery results were determined. First, centrifuging for two minutes at 2,000 rpm generally produced the best recovery results. Second, diluting the leachate helped to produce TiO₂ recovery results near to 100%. *Table 1* shows the leachate and centrifuge parameters tested and their results for the 16 experiments. It should be noted that the experiments that obtained >100% recovery were not used for statistical analysis. These preliminary results indicated insufficient consistency in the TiO₂ recoveries, which meant that more experiments were required for reproducibility.

Table 1: Leachate and Centrifuge Testing Parameters and Recovery Results

Date	Leachate (Raw or Diluted)	TiO ₂ Mass (g)	Leachate Volume (mL)	Centrifuge Velocity (rpm)	Centrifuge Time (min)	Igniting (Yes/No)	TiO ₂ recovery (%)
6/3/15	Raw	2	100	6,000	2	No	91*
6/3/15	Raw	2	100	4,000	2	No	109
6/3/15	Raw	2	100	2,000	2	No	109
6/5/15	Raw	1	50	6,000	2	Yes	106
6/5/15	Raw	1	50	4,000	2	Yes	107*
6/5/15	Raw	1	50	2,000	2	Yes	101
7/8/15	Raw	1	50	3,000	2	Yes	-75
7/9/15	Raw	1	50	2,000	2	Yes	86
7/9/15	Raw	1	50	1,000	2	Yes	117
7/18/15	Raw	0.5	25	2,000	2	Yes	126
8/6/15	Diluted	1	50	2,000	2	No	101
8/8/15	Diluted	1	50	2,000	2	No	101
8/11/15	Diluted	1	50	2,000	2	No	100
9/28/15	Diluted	1	50	2,000	2	No	99
9/28/15	Diluted	1	50	2,000	2	No	100
9/29/15	Diluted	1	50	2,000	2	No	99

*Spill caused results to be invalid.

Sedimentation Experiments

The sedimentation experiments consisted of performing TiO₂ settling tests on the same leachate used for centrifuge experiments, and this leachate was not diluted for settling tests. Different

TiO₂ doses were settled in 100 mL of leachate to obtain their settling velocities and their ultimate settling time (t_u) by plotting the TiO₂ settling interface height vs. time. The settling curve would then be dissected via the Talmadge and Fitch method. *Table 2* shows the different settling parameters tested and their results. The sedimentation tests all followed type 1 discrete settling; however, terminal settling velocity did not decrease with an increase in TiO₂ dose for the initial tests conducted on 06/20/2015, which were for 30 minutes. On 07/07/2015, extended settling tests were conducted for 480 minutes, but these tests were too long. Therefore, future settling tests will be performed for 1-2 hours at different TiO₂ doses in order to obtain more useful results.

Table 2: Settling Test Parameters and Results

Date	TiO ₂ Dose (g/100 mL)	Time Settled (min)	Type 1 Settling Velocity (cm/min)	Ultimate Settling Time (min)
06/20/15	1	20.5	0.70	11
06/20/15	2	27.25	0.35	19
06/20/15	5	30.5	0.78	13
07/07/15	4	480	0.97	90
07/07/15	5	480	0.57	80

Falling Film Reactor Improvements

It was initially thought that the leachate was gaining heat from the photocatalytic reaction. A suggestion from one of the TAG members (Roshan Jachuk, Ph.D.) encouraged active cooling of the lamp to be the solution. With passive lamp cooling, water temperatures in the inner lens reached 81.1°C. With this high temperature, the inner lens radiates heat into the reaction chamber, where the falling liquid gains heat energy. To change from passive to active cooling of the lamp, a Sweetwater SL22 linear air pump, pumping 2 cfm was attached to a 3/4-inch plastic hose submerged in an ice bath then routed to 8 separate pipette injection tips placed in passive cooling holes (see Figure 1).



Figure 1: New Active Cooling of Lamp

The active cooling reduced the inner lens temperature from 81.1°C to 41.6°C, on average. This enabled the VWR Recirculating Chiller temperature to be raised from 8.0°C to 24.0°C and still maintain constant running temperatures of 25°C during any length of experiment.

Falling Film + EMOH Combined Treatment

Since the trailer based EMOH system was observed to function well, pilot scale testing with the EMOH and photocatalytic process was hypothesized to improve the overall process removal efficiency. All experiments were conducted with the ½-inch venturi installed. The experiment on July 9, 2015 ran for 6 hours. The experiment on July 18, 2015 ran for 9.5 hours.

COD Removal Using Falling Film + EMOH Combined Treatment

The EMOH introduces aeration directly before the reaction chamber, possibly increasing COD removal. An experiment (07/09/2015) was conducted with UV/EMOH. This experiment contained no TiO₂, but did utilize the EMOH and UV lamp. This gave an understanding of how much removal the EMOH and UV lamp can achieve before the TiO₂ is added. The average COD removal is 20% for all non-EMOH experiments containing TiO₂. Both of the EMOH experiments had better than 20% COD removal, including UV/EMOH, which had 22% removal of COD. The second experiment with 5 g/L of TiO₂ performed even better with 43% removal. A summary of experimental results can be seen in Table 3.

Table 3: COD Removal using EMOH and UV/TiO₂

Experiment	TiO ₂ (g/L)	Type of Reactor	Lamp (W)	Avg. Temp. (°C)	Avg. pH	COD mg/L as O ₂ C _o	COD mg/L as O ₂ C _f	Treatment Goal Met *	COD % Removal
07/09/2015	0	UV/EMOH	150	22.8	7.8	424	331	RW,DW	22
07/18/2015	5	Falling Film + EMOH	150	25.2	8.5	305	175	RW,DW	43

*SD=Surface Discharge, RW=Reclaimed Water, DW=Dilution Water

During the two experiments, the COD was reduced enough for each to be used for reclaimed water and dilution water applications. The COD surface discharge goal of 125 mg/L as O₂ was not achieved in the time frame, longer tests will be conducted in the future to determine needed treatment time.

Ammonia Removal Using Falling Film + EMOH Combined Treatment

The average ammonia removal is 32% for all non-EMOH experiments. The UV/EMOH alone showed 35% removal; this can be attributed to the new aeration method using the EMOH. The July 18, 2015 experiment with the combined treatment had 47% ammonia removal, surpassing most other experiments. This higher removal is due to the availability of oxygen micro-bubbles to the TiO₂ in the UV reaction chamber. A summary of experimental results can be seen in Table 4.

Table 4: Ammonia Removal using EMOH and UV/TiO₂

Experiment	TiO ₂ (g/L)	Type of Reactor	Lamp (W)	Avg. Temp. (°C)	Avg. pH	NH ₃ -N mg/L C _o	NH ₃ -N Mg/L C _f	Treatment Goal Met *	NH ₃ -N % Removal
07/09/2015	0	UV/EMOH	150	22.8	7.8	423	276	DW	35
07/18/2015	5	Falling Film + EMOH	150	25.2	8.5	317	167	DW	47

*SD=Surface Discharge, RW=Reclaimed Water, DW=Dilution Water

The surface discharge goal of 4.9 mg/L as NH₃-N and reclaimed water goal of 20 mg/L as NH₃-N were not met. However, since ammonia removal exhibits first order reaction kinetics, a longer reaction time should yield removal goals.

Alkalinity Removal using Falling Film + EMOH Combined Treatment

The average alkalinity removal is 36% for all non-EMOH experiments. The UV/EMOH experiment had 30% alkalinity removal, essentially the same. While the July 18, 2015 had 55% alkalinity removal, a 19% increase over the average. This increase in removal is related to the active light cooling used in the July 18, 2015 experiment. A summary of experimental results is provided in Table 5.

Table 5: Alkalinity Removal using EMOH and UV/TiO₂

Experiment	TiO ₂ (g/L)	Type of Test	Lamp (W)	Avg. Temp. (°C)	Avg. pH	Alk. as CaCO ₃ mg/L C ₀	Alk. as CaCO ₃ mg/L C _f	Treatment Goal Met *	Alk. % Removal
07/09/2015	0	UV/EMOH	150	22.8	7.8	1840	1290	None	30
07/18/2015	5	Falling Film + EMOH	150	25.2	8.5	1066	477	SD,DW	55

*SD=Surface Discharge, RW=Reclaimed Water, DW=Dilution Water

The UV/EMOH was not expected to meet any of the three discharge goals. The surface discharge goal of less than 600 mg/L as CaCO₃ was met by the July 18, 2015 experiment. The reclaimed water discharge goal of 330 mg/L as CaCO₃ was not.

Calcium Removal using Falling Film + EMOH Combined Treatment

The average calcium removal is 51% for all non-EMOH experiments. The UV/EMOH experiment had 77% calcium removal; this is a 26% increase over the average non-EMOH experiments. The July 18, 2015 experiment had 96% calcium removal, which was below the surface discharge goal of 50 mg/L as CaCO₃. This high amount of calcium removal makes the leachate very corrosive to pipes and is not normally desirable, except for dilution purposes. A summary of experimental results is provided in Table 6.

Table 6: Calcium Removal using EMOH and UV/TiO₂

Experiment	TiO ₂ (g/L)	Type of Reactor	Lamp (W)	Avg. Temp. (°C)	Avg. pH	Cal. as CaCO ₃ mg/L C ₀	Cal. as CaCO ₃ mg/L C _f	Treatment Goal Met *	Cal. % Removal
07/09/2015	0	UV/EMOH	150	22.9	7.88	440	100	None	77
07/18/2015	5	Falling Film + EMOH	150	25.2	8.5	371	15	SD,RW,DW	96

*SD=Surface Discharge, RW=Reclaimed Water, DW=Dilution Water

These results shows that the 5 g/L TiO₂ dose met all three-treatment goals for calcium removal. It is speculated that the calcium is perhaps ion exchanging with the magnetic substrate in the EMOH. From this finding, more experiments should be conducted with the EMOH as part of the process.

Research planned for the upcoming months:

- Prepare draft journal article. The International Journal of Environmental Protection has invited our research group to submit a cover article on our work involving leachate treatment technologies.

- Continue work on pretreatment, post-treatment, and polishing steps involving the critical orifice unit in combination with the photocatalytic oxidation process.
- Continue work on enhanced sedimentation and centrifugation techniques for separating the catalyst.

METRICS:

1. List graduate or postdoctoral researchers **funded** by **THIS** Hinkley Center project.

Last name, first name	Rank	Department	Professor	Institution
Lakner, Joseph	MSCE Candidate	CEGE	Meeroff	FAU
Coffman, Neil	BS/MSCE Candidate	CEGE	Meeroff	FAU

2. List undergraduate researchers working on **THIS** Hinkley Center project.

Last name, first name	Department	Professor	Institution
Walecki, Eve	CEGE	Meeroff	FAU
Dacey, Justin	CEGE	Meeroff	FAU

3. List research publications resulting from **THIS** Hinkley Center project.

Meeroff, D.E. and Lakner, J. (2015). “Safe Discharge of Landfill Leachate to the Environment.” Report to the Hinkley Center for Solid and Hazardous Waste Management, Report #1332027-A.

4. List research presentations resulting from **THIS** Hinkley Center project

TAG meeting presentations (May 27, 2014, January 30, 2015, March 26, 2015)
February 26, 2015 Engineering Week Graduate Student Poster Showcase, FAU.
July 16, 2015 Thesis credits progress report presentation, Neil Coffman
August 4, 2015 Thesis credits progress report presentation, Joseph Lakner
September 24, 2015 Research Symposium, Tallahassee, FL “Research Updates from FAU Lab.EES”

5. List who has referenced or cited your publications from this project:

None so far

6. How have the research results from **THIS** Hinkley Center project been leveraged to secure additional research funding?

Year two funding from the Hinkley Center for Solid and Hazardous Waste Management was secured. Additional funding is being pursued through the Solid Waste Authority of Palm Beach County and Waste Management. Owrang Kashef, a senior project manager from CH2MHill visited FAU from his office in Calgary, Canada to arrange a demonstration of our technology and to find a way to work together on future leachate treatment projects. Recently, a company called R3Fusion and a partner venture capital company, Beck Family Office, have entered into negotiations for an agreement with FAU and Dr. Meeroff to license technology and perform research/development activities at a larger scale.

7.. What new collaborations were initiated based on **THIS** Hinkley Center project?

F. Bloetscher, Ph.D., P.E., LEED AP, Craig K. Jones, Ph.D., Owrang Kashef, MBA, P.E., Roshan Jachuck, Ph.D., Ryan Beck, Esq., Ted Batkin

8/. How have the results from **THIS** Hinkley Center funded project been used by FDEP or other stakeholders?

To date, the results have not been used by stakeholders yet.

TAG members:

Mark Eyeington, Mark Maclean, Mark Bruner, Owrang Kashef, D.V. Reddy, Craig Ash, Ravi Kadambala, Ron Schultz, Jeff Roccapriore, André McBarnette, Dan Schauer, Damaris Lugo, Amanda Krupa, Richard Meyers, Amede Dimonnay, Art Torvela, Ted Batkin, Roshan Jachuk

TAG meetings:

January 30, 2015 (FAU)

March 26, 2015 (Private TAG meeting held at SWA)

January 2016 (Proposed)