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Deployable Wastewater Treatment Technology Evaluation

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AFRL/MLQD is expanding the Deployable Waste Disposal System to include bare base wastewater treatment. The goal of AFRL/MLQD is for the deployable wastewater treatment system to be integrated into a waste treatment system that will treat both solid and aqueous waste.

The US Army (TARDEC) and the Air Force (AAC/WMO) have been involved in preliminary studies that provide extensive useful background information for this project. These studies show that EC is effective in highly concentrated wastewater, but has difficulty reaching low levels of BOD. Ozone treatment is inefficient for use with untreated wastewater, but ozone can oxidize treated materials to low BOD levels. As a result, a combination of these two systems could produce an effective wastewater treatment system that accepts strong wastewater and produces an effluent that meets international standards. Based on these studies, AFRL/MLQD chose a combination of electro-coagulation (EC) and ozonation as the candidate technologies for this demonstration. After the Air Force investigated potential sources for EC they selected Ecoloquip, Inc. of Houston, TX to supply the EC technology.

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Executive Summary

The objective of this effort was to expand the Deployable Waste Disposal System to include bare base wastewater treatment. The overall goal of the AFRL/MLQD is for the deployable wastewater treatment system to be integrated into a waste treatment system that will treat both solid and aqueous waste.

The US Army (TARDEC) and the Air Force (AAC/WMO) have been involved in preliminary studies that provide extensive useful background information for this project. These studies show that Electro-Coagulation (EC) is effective in highly concentrated wastewater, but has difficulty reaching low levels of BOD. Ozone treatment is inefficient for use with untreated wastewater, but ozone can oxidize treated materials to low BOD levels. As a result, a combination of these two systems could produce an effective wastewater treatment system that accepts strong wastewater and produces an effluent that meets international standards. Based on these studies, AFRL/MLQD chose a combination of electro-coagulation (EC) and ozonation as the candidate technologies for this demonstration. After the Air Force investigated potential sources for EC they selected Ecoloquip, Inc. of Houston, TX to supply the EC technology.

Deployable Wastewater Treatment Technology Evaluation

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Deployable Wastewater Treatment Technology Evaluation

I. Objective

A series of experiments were conducted to evaluate the performance of the Deployable Wastewater Treatment System manufactured by Ecoloquip, Inc. of Houston, Texas. The main goal of the evaluation was to treat both surrogate and actual wastewater, producing effluents meeting the following characteristics: Biological Oxygen Demand (BOD_5) of 20 ppm, Total Suspended Solids (TSS) of 20 ppm, a Total Kjeldahl Nitrogen (TKN) of 4 ppm, and a Total Phosphorus (TP) of 0.1 ppm.

II. Background

AFRL/MLQD is expanding the Deployable Waste Disposal System to include bare base wastewater treatment. The goal of AFRL/MLQD is for the deployable wastewater treatment system to be integrated into a waste treatment system that will treat both solid and aqueous waste.

The US Army (TARDEC) and the Air Force (AAC/WMO) have been involved in preliminary studies that provide extensive useful background information for this project. These studies show that EC is effective in highly concentrated wastewater, but has difficulty reaching low levels of BOD. Ozone treatment is inefficient for use with untreated wastewater, but ozone can oxidize treated materials to low BOD levels. As a result, a combination of these two systems could produce an effective wastewater treatment system that accepts strong wastewater and produces an effluent that meets international standards. Based on these studies, AFRL/MLQD chose a combination of electro-coagulation (EC) and ozonation as the candidate technologies for this demonstration. After the Air Force investigated potential sources for EC they selected Ecoloquip, Inc. of Houston, TX to supply the EC technology.

III. Equipment Summary

Descriptions of the major components of the USAF Mobile EC Trailer are provided below.

a. Trailer

The trailer is a custom-built 12,000 pound capacity, enclosed trailer measuring 20 feet in length, and 8 feet in width (Pace American, McGregor, TX). The trailer has three side panels that open into awnings, a set of double-back doors, and a front door for access to the control area. When open, sufficient ventilation is provided for system operation. Electrical service connection is achieved through a cable opening on the right side of the trailer next to the access door. Electrical cables passed through the opening to make the appropriate service connection. A cap covers the opening when not in use. All wastewater (influent and effluent) and potable water connections are located at the rear left side of the trailer (Figure 1). Cam-lock connections are provided to facilitate installation. These connections are covered with caps when not in use. Wastewater is supplied to the trailer via the raw feed pump-- a submersible pump that is located away from the trailer. The electrical outlet for this pump is located on the same side of the trailer as the electrical feed. A block-flow diagram of major unit operations is shown in Figure 7.

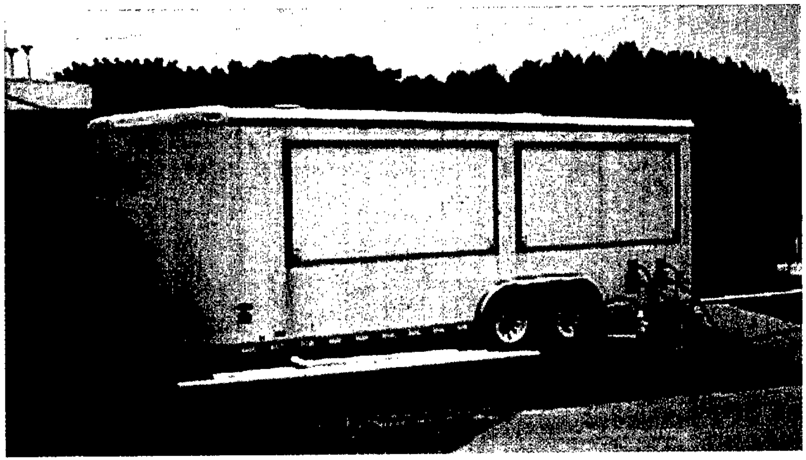


Figure 1. USAF Mobile EC Trailer

b. Programmable Logic Controller

The system is controlled in the automatic mode using a MicroLogix 1000 Programmable Controller and RSLogix 500 Programming Software (Allen-Bradley/Rockwell Automation, Milwaukee, WI). There is also an Allen-Bradley touch screen monitor located above the system hand switches on the front of the system control cabinet (Figure 2). This display is connected to the PLC via an RS-232 cable and allows the operator to monitor system pump activity and have the ability to change pump timer settings.

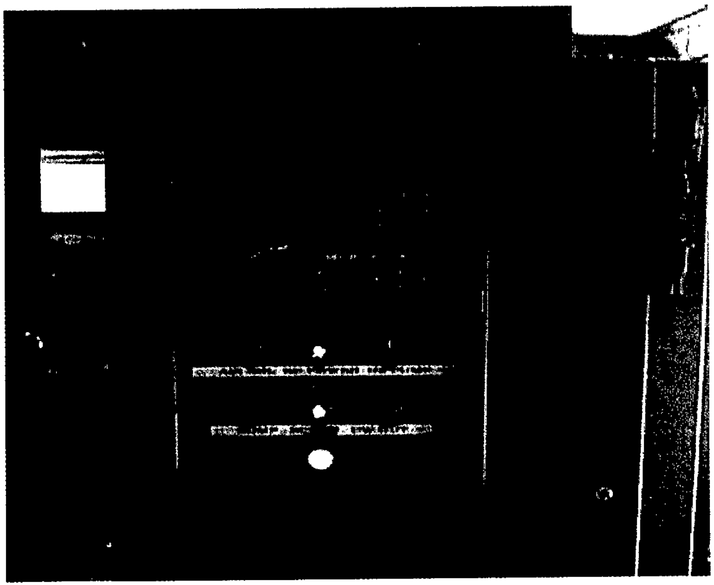


Figure 2. System Control Panel

c. Raw Feed Delivery and Storage

Wastewater is pumped to the trailer using a WaterAce R2SA submersible grinder pump designed for raw sewage installations (Myers, Ashland, OH). The raw feed pump delivers wastewater at a rate of 30 gpm into the trailer through duplex basket strainers to remove gross suspended or floating solids from the influent. An in-line totalizer measures flow from the strainer to the wastewater surge tank. The surge tank is a 150-gallon polyethylene conical bottom tank resting in a painted steel stand. An electric mixer is supplied to provide a homogenous feed. When the system is operated in the automatic mode, level switches in the surge tank maintain tank levels and control the raw feed pump and EC feed pump.

d. EC Feed Pump and Coagulation Tank

A Sequence 1000 centrifugal pump delivers water to the JOULE EC™ Unit at measurable flow rates up to 10 gpm. Flow rates are measured using a rotometer located on a manifold at the front of the EC system. Flow rate is controlled using ball valves: one valve provides backpressure by controlling recycle flow to the surge tank; additional valves control the flow to the EC system. Treated wastewater then flows to the coagulation tank where adequate residence time (30-60 minutes) is provided to allow the solids to flocculate. The coagulation tank is a 300-gallon, polyethylene, conical bottom tank resting in a painted steel stand.

e. Joule EC™ Unit

The JOULE EC™ Unit (Ecoloquip, Inc., Houston, TX) is an electrocoagulation unit designed to provide wastewater treatment for flow rates ranging from 5 to 30 gpm. The unit consists of five (5) treatment cells, an aluminum frame to support the treatment cells (vertically), and a dual power supply that provides constant current. Treatment cells are constructed of Schedule 80 PVC and contain either iron or aluminum electrodes (anode and cathode). Treatment cells are connected by feed and discharge manifolds that are used to configure the flow path through the cells. Wastewater is treated sequentially by the iron cells first and then by the aluminum cells (Figure 3). In the current configuration, two iron cells are connected in series followed by three aluminum cells connected in series. Iron and aluminum cell sets may be arranged in parallel, but there is currently no provision to assure equal flow through each cell. Therefore, it is recommended that the cells remain in a series configuration. Treated wastewater flows to the coagulation tank where solids the solids to flocculate.

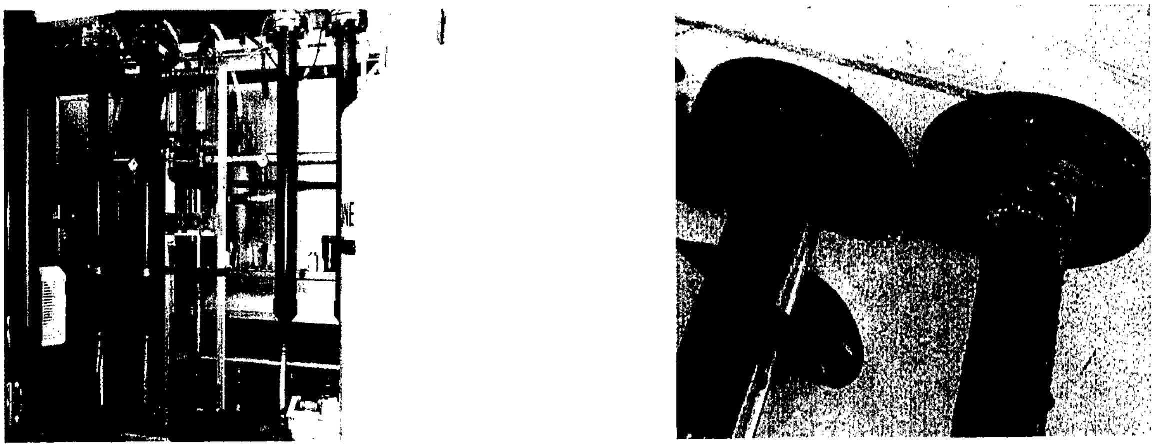


Figure 3. EC Manifold and Cell Electrodes

The dual power supply, PowerPort Technology Model 17020, was designed specifically for use with electrocoagulation treatment systems. The power supply uses 220 VAC to produce a constant DC current up to 50 amps. The current is adjustable using controls on the front panel of the unit (Figure 4). DC current polarity is reversed periodically (30-90 seconds) and the frequency is adjustable using controls on the front panel of the unit. Controls on the left side of the panel control the iron cells, and the right side controls the aluminum cells. Output voltage, current, and status are displayed for each side. Output current is automatically regulated to the value set by the operator by voltage compensation up to the maximum output voltage rating of 80 volts. At 80 volts the power supply will automatically shutdown. Output voltage will vary based on conductivity of the wastewater being treated and the condition of the electrodes. In both the iron and aluminum cell sets, cells electrode connections are series.

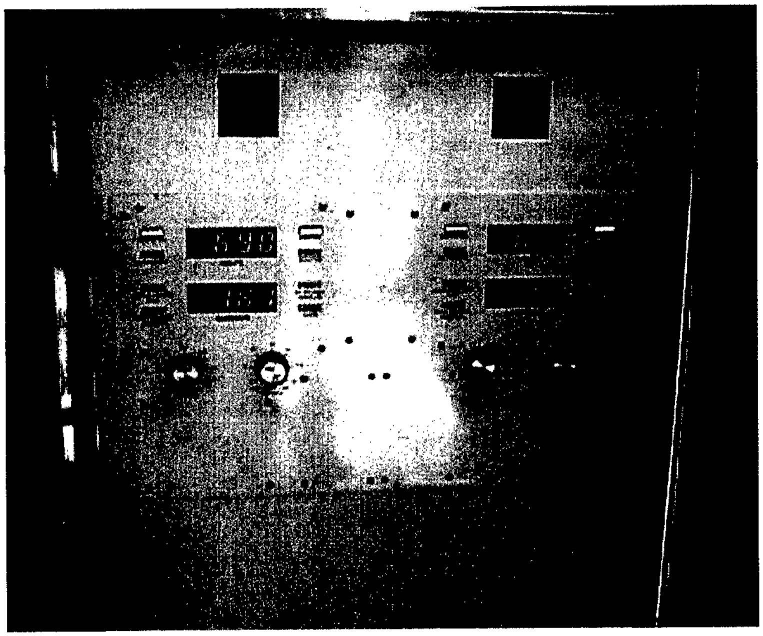


Figure 4. EC Power Supply

f. Dissolved Air Flotation Unit

Dissolved air flotation is based on the attraction of particles to the surface of water (surface tension). By placing bubbles in a water column, particles are attracted to the surface of the bubble and lifted to the surface. Ideally, microbubbles are desired, as they will mix with and attract the smaller, more dispersed particles. These bubbles are created by mixing air with clarified water from the clean water weir, which is then injected into the wastewater from the coagulation tank as it enters the clarifier. Microbubbles and coagulated wastewater solids enter a stilling well which slowly directs the mixture to the surface of the clarifier. Solids are skimmed into a collection box which gravity feeds to a collection tank located outside the trailer. Clarified water gravity flows from the clean water weir into an ozonated water contact tank for disinfection.

The deployable wastewater treatment system contains a VanAire Dissolved Air Flotation (DAF) Unit that uses high-pressure air to supersaturate clarified wastewater with microbubbles in a polyethylene conical bottom clarifier. Using an EBARA EVMU2 multistage high-pressure pump and venturi, the high-pressure, dissolved air depressurizes creating a profusion of microbubbles. A Craftsman two-stage compressor (model no. 919.165610) supplies a regulated air supply (140 psig) to the DAF unit. The wastewater solids and microbubbles move through a stilling well which directs the milky white mixture to the surface of the clarifier. At the surface, a skimmer continuously removes the froth and solids from the water surface.

g. Ozonation System

Ozone is an oxidizer and one of the major chemical means of disinfection used in water treatment today. Ozone requires onsite generation and the use of sensitive monitoring equipment. The trailer system utilizes the Agrimond Tech$_2$ Ozone Wastewater Treatment System, a packaged system designed and built for this purpose by Agrimond, L.L.C. (Cape Canaveral, FL).

This system operates independently of the Mobile EC Trailer and automatically produces ozone-saturated water. Excess ozone gas from the water storage tank is vented to a serviceable ozone destructor. The system consists of an automated control system (PLC), an ozone generator (corona discharge), stainless steel contacting columns, a stainless steel recirculation pump, and a polyethylene water storage tank. Piping consists of stainless steel tubing, flexible pipe, and associated fittings. All fittings are either NPT or compression fittings (Figure 5).

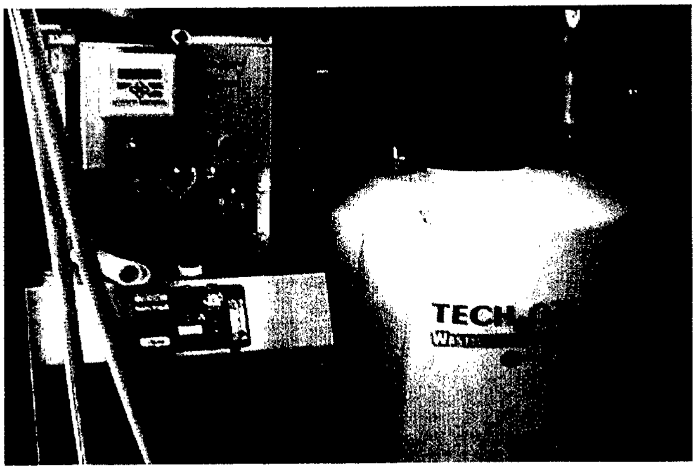


Figure 5. Ozonation System

Ozonated water is metered from the storage tank into the clean water downtube/overflow tube with a March TE-5 Series centrifugal pump (March Mfg. Inc., Glenview IL) and a 0-5 gpm rotameter (Dwyer, Inc.). This mixture flows through the downtube to the ozone contact tank where additional contact time allows the ozone to react with remaining contaminants (Figure 6).

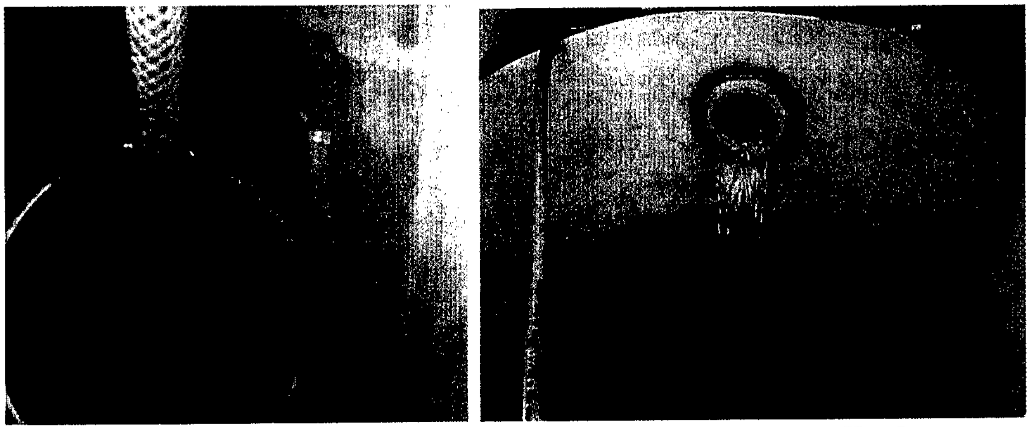


Figure 6. Clean Water Downtube and Ozone Contact Tank

h. Clean Water Discharge

Through the PLC, a level switch energizes the clean water discharge pump (March TE-5 Series, March Mfg. Inc., Glenview, IL). The clean water flows through the duplex bag filters (Model BP-410-1, 1 micron, US Filter, Sheboygan, WI) where remaining suspended solids are filtered out as a final polishing step. These filters are arranged in parallel to enable operators to isolate and replace filters as necessary during operations. Filtered clean water may either be discharged to drain, or recycled for reuse in the ozonated water system. A Fischer backpressure valve provides the necessary backpressure for recycling the clean water to the ozone tank.

IV. System Testing and Results

System testing consisted of the following tasks:

Task 1 – Clean water functional testing (ARA High Avenue facility)
Task 2 – Performance testing on surrogate wastewater at High Avenue
Task 3 – Performance testing on actual wastewater at Tyndall AFB

Chemical, physical, and other performance parameters were measured at the frequency and accuracy necessary to enable the overall performance of this system to be evaluated for the application of treating a typical bare-base effluent. Samples were evaluated at both the ARA Panama City Facility and a local analytical laboratory, the Water Spigot.

a. Task 1: Clean Water Functional Testing

1. Objective

The objective was to demonstrate both the individual components and the Deployable Wastewater Treatment Technology trailer as a whole in order to evaluate intended operational capability. Figure 7 shows the layout of the system as built.

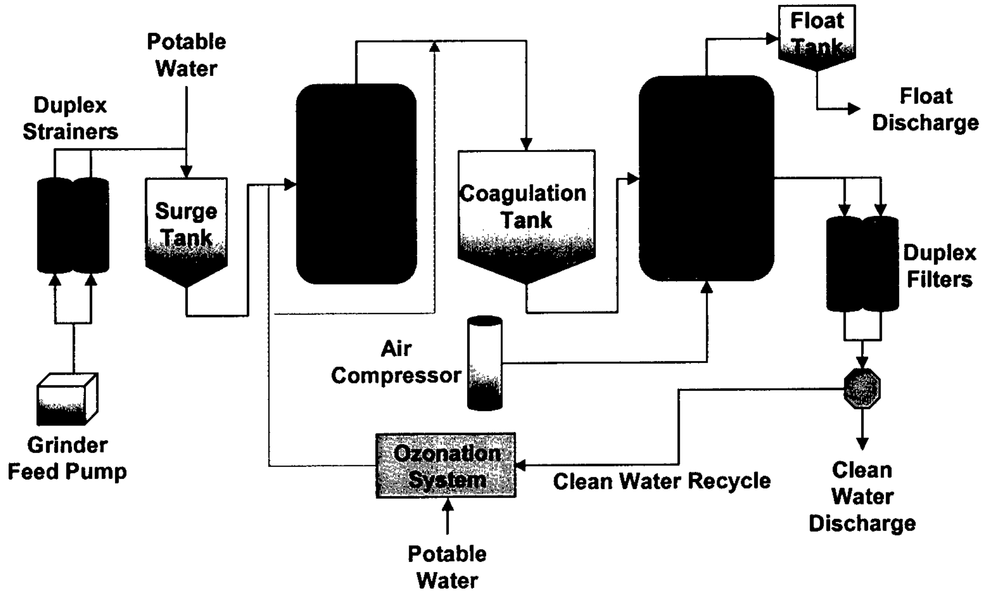


Figure 7. Deployable Wastewater Treatment Technology Trailer (as-built)

Additional objectives accomplished during clean water testing were as follows: evaluation of the O&M Manual; determined minimum period of time necessary to achieve steady-state operation (based on a "dry" startup) and provided the necessary training for operators.

2. Approach

Once construction of the trailer system was complete, the unit was transported from Houston, TX, to the ARA High Avenue facility. After receipt of the unit, the trailer was setup and connected to 240V service. Leak testing was conducted to ensure system integrity after delivery. Once leaks were repaired, design and performance of all system components were demonstrated by operating on potable water. Flows, pressures, and other system parameters were evaluated to develop operational procedures for system startup, tank filling, and system equilibration. ARA operators were present during all phases of water testing. Water testing enabled operators to develop a working knowledge of system operations and equipment locations.

3. Initial Problems

i. Power Supply

During initial testing by Ecoloquip in Houston, TX, problems were encountered with the custom-built EC power supply. The portion of the power supply controlling the aluminum cells experienced over voltage conditions that led to failure of the power supply (an over voltage condition requires more than 80 VDC to produce the desired current output). The manufacturer repaired the power supply prior to shipment. However, during clean water testing, the power supply failed again. The manufacturer was brought onsite to monitor and repair the system. A third failure led the manufacturer returned to redesign the power supply. The system was repaired and safety devices and interlocks were added to the power supply to prevent future failures. The system performed satisfactorily for the remainder of the test program.

ii. PLC

During clean water testing several flaws were discovered in the ladder logic of the PLC programming that prevented tank level switches and pumps from working properly. The PLC was monitored using a laptop to troubleshoot the software. Once the problems were identified, the ladder logic was repaired, and tested/monitored. The system has performed without any further problems.

iii. Ozone System

During preliminary testing and clean water testing, several problems were encountered with the ozonation system. During preliminary testing ozone leaked extensively from the unit. Leaks were repaired and the ozone destruct unit was replaced. During subsequent clean water testing, the system would not turn on. The ozonation system vendor (Agrimond, Cape Canaveral, FL) made a visit to assist Ecoloquip with troubleshooting and repair. A faulty PLC processor card and a bent, incorrectly installed level sensor were the main problems. The vendor installed a new PLC card and repaired the sensor column. Leaks were re-sealed. The system has operated without any additional problems.

iv. Faulty Relays

During clean water testing, the ozone supply pump would not operate. The pump was damaged and the motor was replaced. During testing of the new pump, electrical relay failures were encountered. It was discovered that an AC relay had been installed instead of the necessary DC relay. Once the correct relay was installed, no further problems were experienced.

v. Dissolved Air Flotation Unit

The venturi pump in the DAF unit was overheating and tripping the circuit breaker. The manufacturer of the DAF unit suggested removing some of the impellers from the pump. A new pump was shipped, installed, and tested. No further problems have been encountered.

vi. Coagulation Tank Level Control

The original level sensor was a pressure-type switch that had a small port for liquid to enter and pressurize a diaphragm. Due to the high solids content of the coagulation tank, the port quickly became plugged and the switch rendered inoperable. This level sensor was replaced with a float switch. No problems were experienced after the sensor was replaced.

4. System Modifications

Initial clean water testing and surrogate batch testing indicated that there was no benefit to feeding ozonated water into the two original injection points: 1) the waste stream prior to EC treatment; and 2) the EC-treated water before entering the coagulation tank. The high solids and high organic content of the EC-treated water in the coagulation tank resulted in rapid and complete consumption of ozone with little or no improvement of discharge water quality. Instead, it was decided to reconfigure the process to add the ozonated water to the clarified effluent from the DAF unit. A small contact tank was added to the process to increase the ozone residence time prior to discharge. Ideally, ozonation should take place after filtration/removal of the remaining solids and act as a polishing step. However, the extent of the required process modifications were beyond the scope of this project.

b. Task 2: Performance Testing on Surrogate Wastewater

1. Objective.

The objective was to demonstrate system performance using non-sewage, surrogate wastewater representative of wastewater produced during bare-base operations. The surrogate testing would be used to develop a better understanding of operational parameters and prepare for operation with actual wastewater. A general layout of the modified system is shown below in Figure 8.

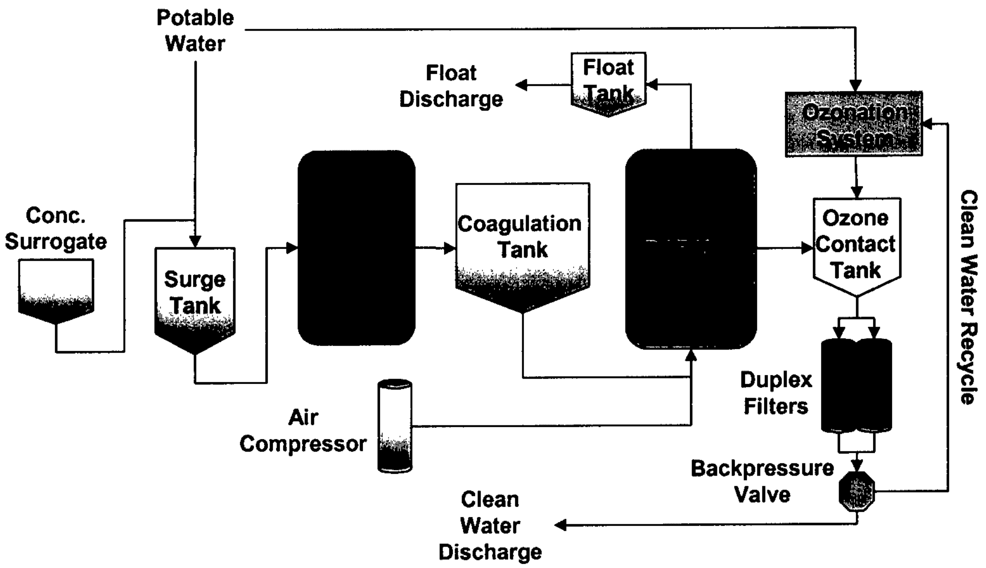


Figure 8. Deployable Wastewater Treatment Technology Trailer (Surrogate Demonstration)

2. Approach

For this series of tests, a non-sewage surrogate was developed that exhibits properties shown in Table 1. The BOD and TSS ranges are representative of the wastewater criteria described in Table 5.4-2 of the Deployable Waste Management Study, AAC Technical Report 00-009 (June 21, 2000). To simplify surrogate preparation, the properties of the surrogate wastewater are assumed to be proportional to BOD. This enabled all wastewater concentrations to be generated from one surrogate concentrate formulation that was blended in different proportions with potable water entering the surge tank.

Table 1. Surrogate and Wastewater Matrices

	Concentrations (mg/L)				
Surrogate Conc.	BOD_5	TDS	TSS	TKN	TP
Low	200	446	182	33	10
Municipal	300	675	275	50	15
Standard	600	1,350	550	100	30
High	1,000	2,255	919	167	50

Surrogate was prepared from the components shown in Table 2. To enhance conductivity of the surrogate, sodium chloride was added. The quantity of each surrogate component necessary (in g/L) to obtain the "standard" surrogate concentration is shown in the column to the right of each component.

Table 2. Surrogate Component Properties

		Component Properties Based on 1 g/L				
Component	**g/L**	**BOD_5**	**TDS**	**TSS**	**TKN**	**TP**
Brewer's Yeast	1.0	400	500	500	23	10
Cheese Whey	0.5	400	900	100	16	0.3
Urea	0.146	3	1,000	0	470	0
Na_2HPO_4	0.0043	0	1,000	0	0	4,580
NaCl	0.25	0	1,000	0	0	0
Standard Surrogate		600	1,350	550	100	30

The surrogate concentrate was based on 100 times the concentration of the standard formulation. This enabled each of the surrogate formulations to be generated continuously in the surge tank by the addition of the percent concentrate shown in Table 3.

Table 3. Surrogate Wastewater Concentrations

		Concentrations (mg/L)				
Surrogate Concentration	**Percent Flow**	**BOD_5**	**TDS**	**TSS**	**TKN**	**TP**
Low	0.33%	200	446	182	33	10
"Municipal"	0.50%	300	675	275	50	15
Standard	1.00%	600	1,350	550	100	30
High	1.67%	1,000	2,255	919	167	50
100X Conc.	n/a	60,000	135,000	55,000	10,000	3,000

Concentrated surrogate solution was prepared in a separate 50-gallon feed tank that was continuously agitated. Concentrate could not be stored and was prepared daily for each test. A peristaltic pump fed concentrated surrogate continuously into the surge tank. Wastewater concentration for each condition determined the feed rate.

i. Sampling

Performance test samples were taken two hours after steady state conditions were achieved. Prior to the onset of the sampling period, the DAF float collection tank was drained, cleaned, and isolated. Operational parameters and ozonated water concentration were recorded. The duration of the sample collection period was one hour. Feed samples were taken at the beginning of the collection period. The clean water sample was a composite of samples taken at the beginning and end of each sample period. DAF float material was composited throughout the sample period in a collection tank. At the end of the sample period, the float material was thoroughly mixed before a sample was taken. Once sampling was complete, operators recorded operational parameters and ozonated water concentration. Digital photos were taken of all samples and tanks during sampling for comparison purposes.

ii. Analysis

Samples were split for analysis by ARA at the Panama City Research Facility and by the Water Spigot and labeled appropriately. The sample and analysis plan for surrogate testing is shown in Table 4. All samples were stored and analyzed according to procedures listed in "Standard Test Methods for The Examination of Water and Wastewater, 20th Edition" (1998). Ozone concentration was determined at the time of sampling by taking probe readings from the ozone system. ARA performed COD, TDS, and TSS analyses at the Panama City Research Facility. The Water Spigot performed BOD, TKN, and TP analyses.

Table 4. Sampling and Analysis Plan for Surrogate Testing

Analysis	Ozonated Water Tank	Surge Tank	Clean Water Discharge	Float Tank
Ozone	Initial/Final			
pH		Initial	Composite	Composite
Conductivity		Initial	Composite	Composite
Temperature		Initial	Composite	Composite
COD		Initial	Composite	Composite
BOD		Initial	Composite	Composite
TDS		Initial	Composite	Composite
TSS		Initial	Composite	Composite
TKN		Initial	Composite	Composite
TP		Initial	Composite	Composite

3. Test Conditions

The conditions for surrogate testing are shown below in Table 5. Test conditions were dictated by the performance and capability of the system.

Table 5. Surrogate Wastewater Test Conditions

Test #	BOD Conc.	Feed Rate	Ozone Feed Rate	Recycle?	EC Current Levels (Amps)	
	mg/L	gpm	gpm	Y/N	Fe	Al
1	600	5.0	1.0	N	27.0	48.8
2	600	5.0	1.0	N	49.6	48.7
3	600	5.0	1.0	N	35.9	33.9
4	300	3.0	3.0	N	25.0	35.0
5	300	3.0	3.0	Y	25.0	26.0

4. Test Results

General test results for surrogate testing are shown below in Table 6. Brief descriptions of each test run are found below. Detailed Summary Test Reports are found in Appendix A, while material balances for each test are found in Appendix B.

Table 6. Surrogate Test Results

Test #	Surrogate Feed Concentrations (mg/L)				Clean Water Discharge Concentrations (mg/L)				Percent BOD Removal
	BOD	TSS	TKN	TP	BOD	TSS	TKN	TP	
1	750	640	183.27	21.54	274	164	64.39	7.10	63.5
2	1,020	476	90.23	15.65	495	82	57.56	6.88	51.5
3	593	315	79.97	10.47	397	188	64.97	9.56	33.1
4	359	245	541.97	7.46	57	13.25	16.43	1.13	84.1
5	472	344	610.20	10.08	51	15.4	31.16	1.52	89.2

5. Discussion

i. Test #1 (050202)

This test run was the initial run performed at the standard BOD concentration of 600 mg/L with a 5 gpm influent rate and 1 gpm ozone feed rate. Target cell currents were 25 A for the iron and 50 A for the aluminum. The EC was configured with the iron cells in parallel and the aluminum in series. Potable water feed was used for the ozonation system.

Actual EC cell currents were 27.0 A for the iron cells and 48.8 A for the aluminum cells. Surrogate feed BOD concentration was slightly higher than anticipated and coagulation and solids removal was evident as shown in Figure 9.

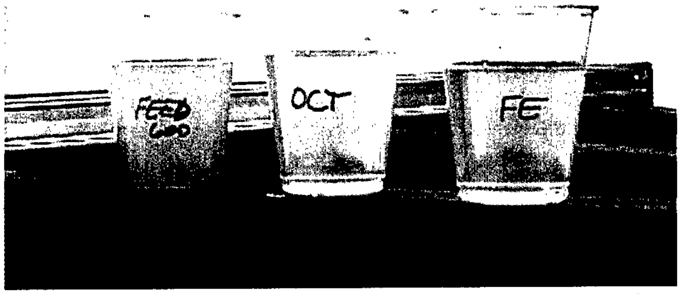


Figure 9. Feed/Ozone Contact Tank/Final Effluent Samples

Table 6 shows that expected discharge concentrations were not achieved. Although 63.5 % of BOD was removed and significant reductions in TSS, TKN, and TP occurred, desired discharge concentrations were not met.

Material balance calculations were performed for each test. One would predict that TKN and TP would be conserved during testing, since physical and chemical processes to remove nitrogen and phosphorous are not anticipated. BOD should not be totally conserved due to oxidation of organics with ozone. One would predict that TSS would increase because the EC process, by function, generates suspended solids that are removed in the coagulation tank/DAF unit. During Test 1, additional TSS was generated as expected. BOD, TKN, and TP recoveries were lower than expected. Low recovery rates are attributed to the shortness of the testing periods, which may not have allowed the entire process to reach equilibrium. Since flow to the DAF unit came from the bottom of the coagulation tank, good material balances were dependent on the suspended solids in the coagulation tank being in equilibrium with settled solids. The small volume of float solids collected during the short test periods also contributed to less accurate material balance calculations. Material balances are provided in Appendix B.

ii. Test #2 (050602)

Test conditions were identical to Test 1, except with higher current settings for both the iron and aluminum cells (60 A each). During testing, the iron cells frequently overheated, indicating either intermittent flow to the cells (vapor lock), or some type of blockage or obstruction within the cells. In an attempt to temporarily alleviate overheating, currents were reduced to 49.6 A for the iron cells and 48.7 A for the aluminum cells. To avoid future overheating problems, the iron cells were connected in series at the conclusion of this test. Figure 10 shows that product samples were similar in appearance to Test #1 samples.

Figure 10. Feed/Ozone Contact Tank/Final Effluent Samples

Table 6 shows that the BOD feed concentration was nearly two times higher than planned and not consistent with other surrogate parameters. Based on other analytical results, the actual feed BOD concentration was likely close to 600 mg/L and the discrepancy due to analytical error. Analytical results showed that reduction did not meet the desired discharge concentrations. The material balance shows good recovery for TKN (86%); while BOD, TP, and TSS recoveries were all lower than expected. Inconsistent results from this test may be due to reasons previously discussed and iron cell overheating/flow problems experienced during testing.

iii. Test #3 (050702)

The objective of Test 3 was to operate the system at the identical conditions as Tests 1 and 2, but at a mid-level current. The iron cell-overheating problem during the previous test led to reconfiguring the iron cells to operate in series. This appeared to solve the overheating problem. Aluminum and iron cell currents were set lower than intended due to over voltage conditions that were experienced with the aluminum cell power supply. Product samples for Test #3 are shown in Figure 11.

Figure 11. Feed/Ozone Contact Tank/Final Effluent Samples

Table 6 shows that the desired discharge concentrations were not met during Test 3. BOD removal was only 33.1%, which was lower than previous tests. The material balance indicates that TSS and BOD recoveries were acceptable, while TKN and TP recoveries were slightly higher than expected.

iv. Test #4 (051402)

The surrogate feed BOD concentration was reduced to 300 mg/L for this test. This was done in anticipation of treating actual domestic wastewater at Tyndall AFB that had a measured BOD of 300 mg/L. In addition, the aluminum cell power supply was set at a maximum current setting that did not produce over voltage conditions, while the iron cells were set at 25.0 A. Surrogate feed rates were decreased to 3.0 gpm, while the ozone feed rate was raised to 3.0 gpm in an attempt to provide the process with more ozone to further oxidize the BOD and other organics/solids. Figure 12 shows that contact tank and final effluent sample appearances greatly improved.

Figure 12. Feed/Ozone Contact Tank/Final Effluent Samples

Table 6 shows that BOD removal was much higher at this test condition (84%) and TSS was reduced to an acceptable 13.25 mg/L. TKN and TP results improved, but were still not within required discharge specifications. The material balance shows that BOD, TP, and TSS recoveries were acceptable, while TKN recovery could not be substantiated by the material balance evaluation.

v. Test #5 (051502)

Test 5 conditions and Test 4 conditions were identical, with the exception that clean, treated water from the process was recycled to ozone water system instead of potable water. The recycle mode was used in an attempt to maximize ozone treatment by reacting all generated ozone with the organics in the recycle. This resulted in no ozone loss in the ozone generation system since very low (<0.2 mg/L) ozone concentrations were maintained in the ozonated water storage tank. Figure 13 shows the product sample pictures.

Figure 13. Feed/Ozone Contact Tank/Final Effluent Samples

Table 6 shows BOD feed concentration (472 mg/L) was more concentrated than projected (300 mg/L). Despite the elevated feed concentration, this test achieved the highest BOD removal (89.2%) during surrogate testing. TSS results were again within desired discharge limits, while TKN and TP were not. However, the material balance calculation showed very poor recovery, which was possibly due to excess solids being retained in the coagulation tank.

vi. Summary of Surrogate Test Results

The surrogate used during the first phase of testing may not have been the ideal simulant for demonstration of the EC technology. The surrogate contained simple organic molecules, for the most part, which were actually in solution vs. the more typical colloidal suspension in wastewater. The high dissolved organic content may have contributed to fouling of the electrodes, which increased cell resistance and prevented use of high current settings for the aluminum cells (see Figure 14).

Figure 14. Aluminum Cell Fouling (after 29.4 hours)

The fouling shown in Figure 14 was a gradual process as evident by a gradual increase in cell resistance, i.e., higher voltages were required to achieve the same current.

Attempts were also made to determine weight loss and degradation of the aluminum cells during system operation. Aluminum cell weights were obtained during cell maintenance and cleaning. The extensive fouling of the electrodes during surrogate testing and the limited operational time made weight determination inaccurate and cell weight-loss data inconclusive.

It was also determined that at operational flow rates tested, turbulent flow may not have been achieved in the cells. This lack of turbulent flow may have further enabled solids to accumulate on the cell surfaces and caused the iron cells to overheat. Hydraulically connecting the cells in series may have helped to alleviate this problem.

Analytical results from Table 6 show inconsistencies in surrogate and effluent analyses. For example, results for the surrogate feed BOD concentration (1,020 mg/L) in Test 2 are suspect, and do not follow analytical trends. BOD feed concentration for Test 2 should be closer to 600 mg/L, while clean water discharge BOD results for Tests 4 and 5 appear to be inconsistent with other results. This also appears to be the case with surrogate feed TKN concentrations in Tests 1, 4, and 5. Throughout testing, surrogate feed was prepared in a consistent manner using the same lots of each component. Surrogate feed flow rates were also consistent through each test using the same computer-controlled peristaltic pump. In addition, samples were composited and stored in a systematic, consistent manner. Analytical inconsistencies may be the result of dilution errors generated by the outsourced laboratory.

DAF float production varied from 2.8% to 6.7% of the total water volume treated, averaging 4.1%. The DAF float material contained an average of 75% of the solids in the combined DAF float and clean water discharged streams. In Tests 4 and 5, the DAF float contained 93% and 94% of the solids. Full analytical results of the float materials can be found in the detailed test reports in Appendix A. It was desirable to have a high fraction (~90% or greater) of the solids in the float material. Lower performance in Tests 1, 2, and 3 may be attributed to problems analyzing the float material, the small volume of float recovered, short test periods, surrogate properties, and non-optimized DAF operating conditions.

Experimental results from surrogate testing indicate that electrocoagulation treatment reduced TKN approximately 40%. The best result for TKN was in Test 4 where TKN was reduced to 16.4 mg/L, which was still four times greater than the target concentration of 4 mg/L. Significant total phosphorus (TP) reduction was observed. Tests 1 and 2 averaged 61.5% reduction and tests 4 and 5 averaged 70% TP reduction. This resulted in final TP levels of 1-2 mg/L, which still did not meet the goal of 0.1 mg/L.

6. Special Tests

During surrogate testing, three special tests were conducted to better understand the operational parameters of the electrocoagulation unit. Brief descriptions of each test follow. Detailed results are in Appendix B.

i. Special Test #1

This test was conducted to determine if the cell electrical resistance was constant as a function of cell current. Cell currents were set at 10, 20, 30, and 40 A and allowed to stabilize for 10 minutes at each current setting. Flow was constant at 5.0 gpm. Voltage and current settings were recorded and resistance was calculated from these readings. Results in Table 7 show that as current increased in the iron cells, calculated resistance remained stable. On the other hand, as current increased in the aluminum cells, calculated resistance increased causing the aluminum cell power supply to experience over voltage conditions.

Table 7. Results of Special Test #1

Test	Aluminum			Iron		
	Volts	Amps	Resistance	Volts	Amps	Resistance
1	15.5	10	1.55	4.6	10	0.46
2	46.8	20	2.34	9.8	20	0.49
3	OV	30		14.6	30	0.49
4	OV	40		18.5	40	0.46

ii. Special Test #2

This test was conducted to determine the effect of wastewater flow rate on cell electrical resistance. It was postulated that gas bubbles or films on the surface of the aluminum electrodes could increase cell resistance, which may be dependent on flow rate. The BOD feed concentration was 300 mg/L. The initial flow rate was set at 2.0. The aluminum cells were set at the maximum current possible without exceeding 50 V. The iron cells were set to the same current. Test conditions at each flow rate were allowed to stabilize for 10 minutes. Samples were obtained from the EC sampling manifold (prior to discharge to the coagulation tank). Once sample and digital photos were taken, operators increased the flow to the next condition, 4.0 gpm. The same processes were repeated until the 10.0 gpm flow condition was attained. Table 8 shows increases in flow had little or no effect on cell resistance.

Table 8. Results of Special Test #2

Flow	Aluminum			Iron		
(gpm)	Volts	Amps	Resistance	Volts	Amps	Resistance
2	36.6	42.4	0.86	17.8	42.3	0.42
4	31.7	41.1	0.77	20.0	43.0	0.47
6	39.4	41.1	0.96	21.7	42.9	0.51
8	38.4	41.1	0.93	22.0	42.9	0.51
10	38.9	41.1	0.95	21.1	43.0	0.49

COD (filtered), TSS, and TDS analyses were performed on each sample. Figure 14 shows that as flow increased, TDS and TSS concentrations decreased but eventually leveled out. Filtered COD concentration appeared to increase initially as flow increased, then remained constant.

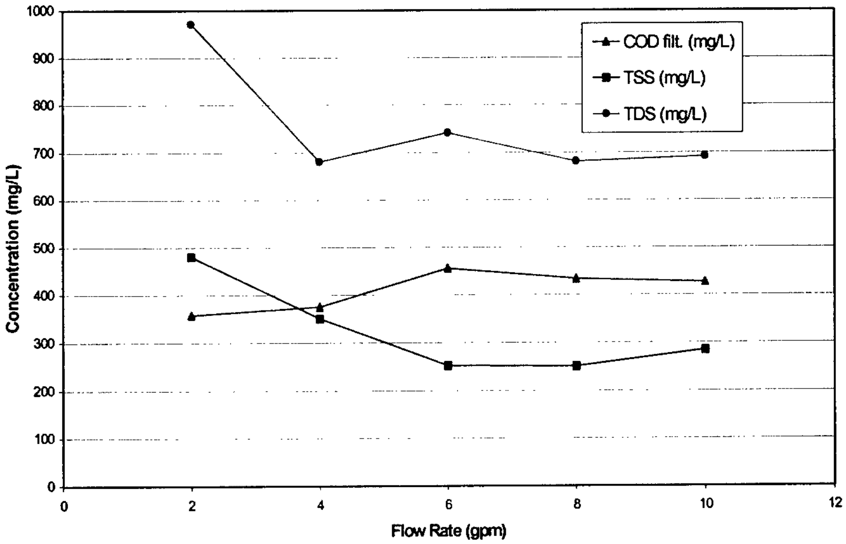


Figure 14. Analytical Results of Special Test #2

iii. Special Test #3

This test was developed to determine the effect of the aluminum cell current on the electrocoagulation process. Test conditions were set at 5.0 gpm with a surrogate feed BOD concentration of 300 mg/L. Iron cell current was set at 25.0 A, while the aluminum cell current was set at the maximum current attainable without going above 60 V (60 A). The system was allowed to stabilize for 10 minutes prior to sampling. Voltages and currents were recorded when samples were collected at the sampling manifold prior to discharge to the coagulation tank. Digital photos were taken of all samples. Samples were also collected at 75%, 50%, and 25% of the initial aluminum cell current setting. Table 9 shows that varying the aluminum cell current had little effect on aluminum cell resistance.

Table 9. Results of Special Test #3

% Current Setting	Aluminum			Iron		
	Volts	Amps	Resistance	Volts	Amps	Resistance
100	59.2	59.8	0.98	13.5	25.0	0.54
75	45.8	44.2	1.04	14.4	25.0	0.58
50	31.1	29.9	1.04	14.4	25.0	0.58
25	17.6	14.9	1.18	14.7	25.0	0.59

COD (filtered), TSS, and TDS analyses were performed on each sample. Results are shown in Figure 15. Trends in TSS and filtered COD were in the direction anticipated. TSS increased with current and COD decrease somewhat with current.

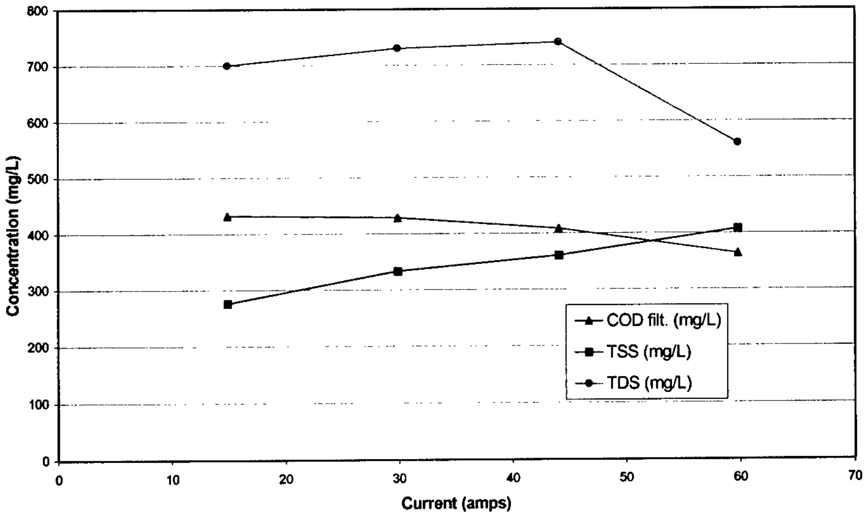


Figure 15. Results of Special Test #3

c. Task 3: Performance Testing on Actual Wastewater

1. Objective

Task 3 involved operating the trailer system using actual wastewater. Wastewater was pumped from a lift station located at the old trickling filter plant on Tyndall AFB, FL. Figure 16 shows the treatment system configuration for the wastewater demonstration.

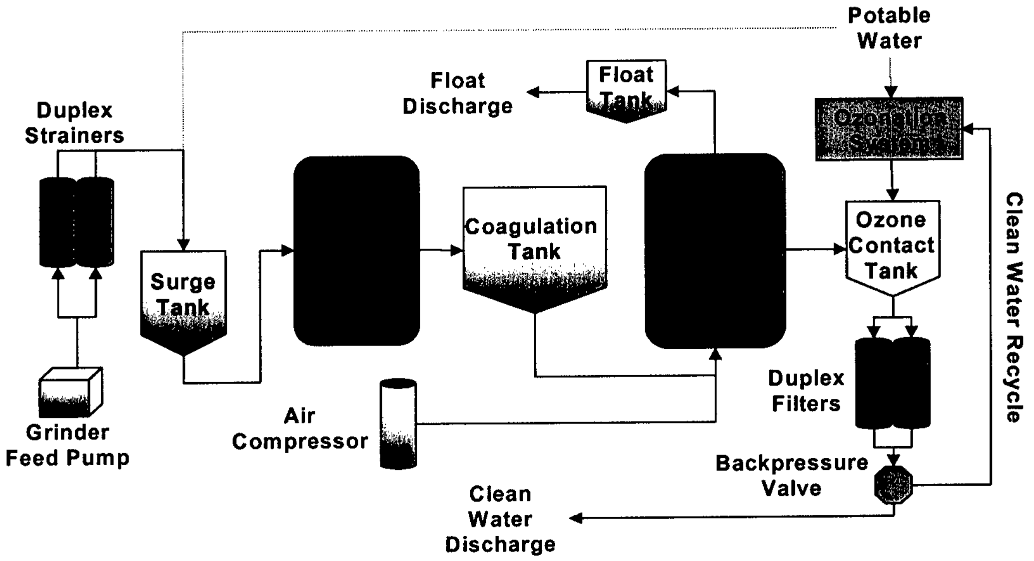


Figure 16. Deployable Wastewater Treatment Technology Trailer (Wastewater Demonstration)

2. Approach

The system was delivered to the Tyndall AFB site and prepared for operations. During this demonstration, power to operate the trailer was obtained from a military diesel generator that produced a constant 208 V. The submersible grinder pump was placed in the lift station and secured to the railing encircling the lift station. Tests were conducted to verify operational performance compared to surrogate test performance. After each experiment, all components of the system and piping were drained, cleaned, and inspected. Solids were thoroughly rinsed from the DAF unit and all filters were checked and cleaned. DAF float (solids), clean water discharge, and other liquids were re-directed to the lift station.

i. Sampling

Samples and digital photos were taken according to procedures established during surrogate testing. Additional samples of the ozone water supply tank and the clean water discharge were drawn for fecal coliform testing.

ii. Analysis

All samples were split and analyzed according to procedures followed during surrogate testing (see Table 10). Additional fecal coliform analyses were performed during wastewater testing.

Table 10. Sampling and Analysis Plan for Actual Wastewater

Analysis	Ozonated Water Tank	Surge Tank	Clean Water Discharge	Float Tank
Ozone	Initial/Final			
pH	Composite	Initial	Composite	Composite
Conductivity	Composite	Initial	Composite	Composite
Temperature	Composite	Initial	Composite	Composite
COD	Composite	Initial	Composite	Composite
BOD	Composite	Initial	Composite	Composite
TDS	Composite	Initial	Composite	Composite
TSS	Composite	Initial	Composite	Composite
TKN		Initial	Composite	Composite
TP		Initial	Composite	Composite
Fecal Coliform	Final		Final	

3. Test Conditions

Conditions selected for wastewater testing are shown in Table 11. These conditions were selected based upon results obtained during surrogate testing.

Table 11. Surrogate Wastewater Test Conditions

Test #	BOD Conc.	Feed Rate	Ozone Feed Rate	Recycle ?	EC Current Levels (Amps)	
	mg/L	gpm	gpm	Y/N	Fe	Al
6	Actual	5.0	5.0	Y	25.0	25.0
7	Actual	3.0	5.0	Y	15.0	30.0

4. Test Results

General test results for wastewater testing are shown in Table 12. Brief descriptions of each test run follows, but detailed Summary Test Reports are found in Appendix A.

Table 12. Wastewater Test Results

Test #	Wastewater Feed Concentrations (mg/L)				Clean Water Discharge Concentrations (mg/L)				Percent BOD Removal
	BOD	TSS	TKN	TP	BOD	TSS	TKN	TP	
6	241	272	34.57	6.33	33	44	28.89	1.77	86.3
7	224	180	34.49	4.75	22	21	20.15	< 0.2	90.2

5. Discussion

i. Test #6 (061302)

This test was the initial run conducted on wastewater at the Tyndall AFB site. The actual influent BOD concentration was 241 mg/L, which was less than surrogate test water. Target cell current was 25.0 A for both the iron and aluminum cells. The test was run at a wastewater feed rate of 5.0 gpm with a 5.0 gpm ozonated water feed supplied by clean water recycle. Product sample appearance (Figure 17) was similar to samples collected during surrogate testing.

Figure 17. Feed/Ozone Contact Tank/Final Effluent Samples

Table 6 shows that, in addition to BOD, TSS, TKN, and TP feed concentrations were also lower than in previous surrogate experiments. An 86.3% BOD reduction was achieved. TKN and TP reductions were 16% and 72%, which were similar to surrogate test results. None of the parameters met the required discharge requirements. The material balance in Appendix B showed good recovery for TKN. However, BOD, TSS, and TP exhibited very low recovery rates which may be attributed to factors previously discussed (short test periods, hold-up in coagulation tank, small float volume, etc.).

ii. Test #7 (062702)

Based upon previous results, current levels for this test were set at 15 A for the iron cells and 30 A for the aluminum cells. This was based upon Special Test 4 and recommendations from Ecoloquip. Raw feed flow was reduced to 3.0 gpm, while the ozone feed rate remained at 5.0 gpm to provide maximum ozone treatment. A product sample picture is shown in Figure 18.

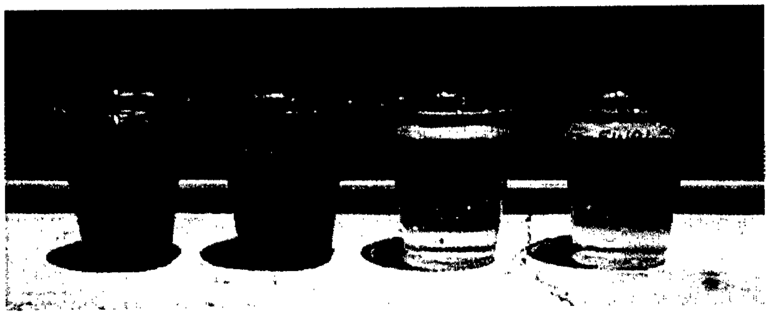


Figure 18. Feed, Float, Ozone Contact Tank, and Final Effluent Samples

Analytical results show that BOD and TSS were reduced just short of required discharge limits (20 mg/L each) to 22 mg/L and 21 mg/L, respectively. Percent BOD removal was 90.2%, the highest achieved during both surrogate and wastewater testing. Total phosphorus was reduced to non-detect limits of the laboratory's analytical method (0.2 mg/L), indicating that requirements may have been met for TP (0.1 mg/L). Although TKN was reduced from 34.49 mg/L to 20.15 mg/L (41.6%), reduction was still short of the requirement (4 mg/L). Material balance calculations were inconclusive.

iii. Summary of Wastewater Test Results

The municipal wastewater used during this segment of testing was slightly less concentrated than the surrogate wastewater previously used. Electrode fouling was not experienced to the degree experienced during surrogate testing. When the cells were cleaned, the electrodes were covered with materials more closely resembling scale rather than the sludge-type fouling shown in Figure 14. Operators were able to remove most of this scale with a water hose and brush.

As during surrogate testing, attempts were made to determine weight loss and degradation rates of the aluminum cells during system operation. Aluminum cell weights were obtained during cell maintenance and cleaning. Again, fouling of the electrodes during testing made weight determination difficult. This, coupled with the limited operational time, resulted in cell weight data that is inconclusive.

Very little DAF float was collected during the sample periods. Float production was only 0.7% of the feed flow for Test 6 and only 1.1% for Test 7. TSS analysis showed that the DAF float material accounted for 66% (Test 6) and 86% (Test 7) of solids discharged in the DAF float and clean water streams. Reasons for relatively poor DAF performance were discussed in the summary of surrogate test results. Full analytical results of the float materials are in the detailed test reports in Appendix A.

Ozone is not as widely used as chlorine for sterilization because it cannot maintain a residual disinfecting capability like chlorine. In the current configuration of the Ecoloquip system, organic solids that remain in the clean water from the DAF unit consume residual ozone. Fecal coliform results (for both the ozonated water tank and clean water samples) were reported as >1600 colonies per 100 milliliters (mpn/100 ml) of sample in both tests. Since the Florida DEP discharge requirements for a WWTP using basic disinfection is 200 mpn/100 ml, it can be assumed that little or no disinfection was effected.

During Test 7, an additional sample of filtered clean water was collected to see if additional filtration would assist in BOD reduction. This sample was filtered using a 1-micron filter in a laboratory filtration apparatus at the ARA Panama City Research Facility prior to third party analysis. Results indicated that TP remained at non-detect levels, while TKN was slightly reduced to 17.69 ppm as might be expected. BOD was reduced an additional 45% to 12 ppm, well below discharge limits. TSS analysis was not performed, but based on previous results, TSS reduction would be proportional to BOD reduction and would likely meet the 20 mg/L discharge limit.

6. Special Test #4

This special test was run during wastewater testing to determine the effect of iron cell currents on EC cell performance. Wastewater samples collected from the sample manifold were black in appearance, possibly from excess iron being deposited during treatment. To test this theory, wastewater from the lift station was used as the feed source at a flow rate of 5.0 gpm. Aluminum cell current was set at the maximum current possible without experiencing over voltage conditions. Iron cell current was initially set at 0 A. Once the iron current level was established, operators allowed the process to stabilize for 10 minutes before a sample was collected and photos taken. The test was repeated for each 5 A incremental increase in the iron cell current from 10 A through 35 A. COD (filtered), TSS, and TDS analyses were performed on each sample. Samples collected are shown in Figure 19.

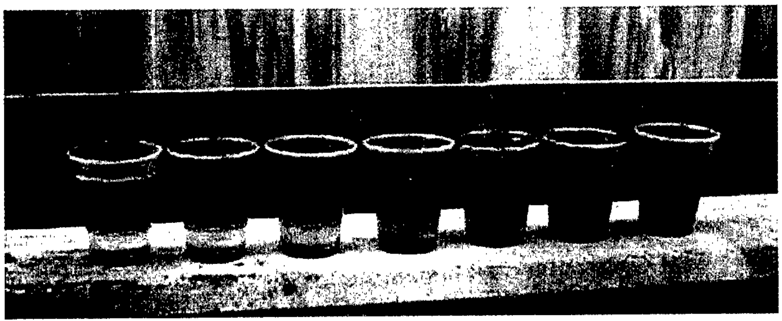


Figure 19. Samples at 0, 10, 15, 20, 25, 30, 35 A (l to r)

As can be seen, sample opacity increased proportional to current settings. Analytical results are shown below in Figure 20. No conclusive relationships were established. Based on sample appearances and recommendations from Ecoloquip, iron cell current was set at one-half the maximum aluminum cell current for Test 7.

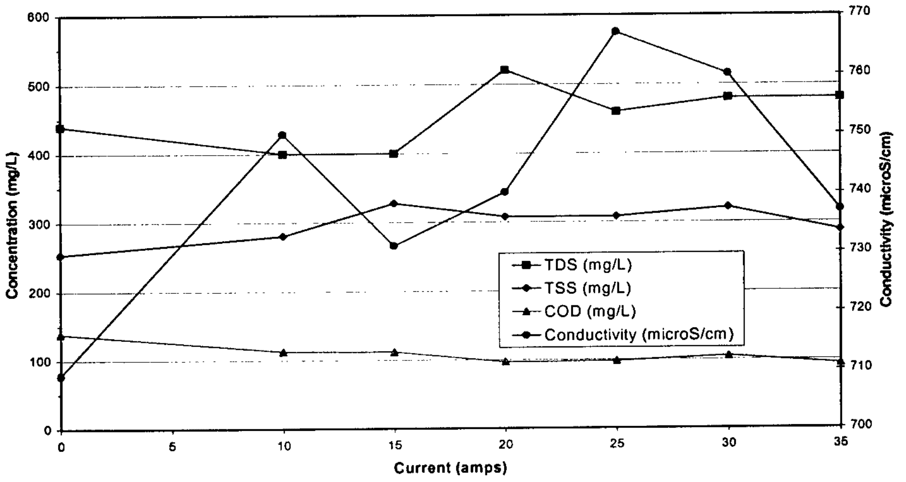


Figure 20. Results of Special Test #4

V. Conclusions and Recommendations

a. EC System

The EC system appeared to perform as designed on actual wastewater. Aluminum cell fouling is a concern, but direct impact to performance or maintenance requirements could be not be determined from the limited tests conducted. The proper operational balance (electrode current and/or surface area) of aluminum and iron operation is not known. It is known that these cells are sacrificial, however; insufficient operating time was logged to determine actual weight loss. Based on the preliminary tests conducted, the following future work is recommended:

i. Determine operational parameters (current and surface area) for an integrated iron-aluminum EC process for treating wastewater.
ii. Determine maintenance requirements necessary to maintain cell performance
iii. Determine electrode weight loss and expected service life based on optimal operational parameters

b. DAF /Coagulation System

The coagulation tank and DAF process appeared to perform as designed. However the need for a coagulation tank and the residence time required for optimal coagulation is not known. The size of the coagulation tank is proportional to the wastewater flow rate and removal would result in considerable space savings. In addition, compressed air is required for the DAF unit; this is the only reason an air compressor is required. The DAF unit discharges a solids concentrate (float material) that could be 1-5% of the process flow. This material must be dewatered and an appropriate means of disposal devised. Recommendations for future work are:

i. Determine if solids can be removed from EC treated water without the need for a coagulation tank
ii. Evaluate the cost and technical benefit of replacing the coagulation tank and DAF unit operations with a single unit operation such as a lamella clarifier
iii. Develop a solids dewatering and handling system

c. Additional Filtration

It is clear from the preliminary tests conducted as part of this project that residual solids in the clean water discharge from the DAF unit are the primary cause of high BOD in the clean water discharge. The filtration test conducted during Test 7 demonstrated that laboratory filtration through a 1-micron filter reduced BOD by 45%. This also demonstrated the 1-micron bag filter in the system did not perform well. Therefore, we have the following recommendations:

i. Evaluate an improved filtration process for secondary solids removal from DAF or other clarifier clean water discharge. The secondary filtration process, such as micro filtration, must be capable of removing micron and sub-micron size particles.

ii. Reconfigure process flow to effect primary filtration (DAF or lamella clarifier) and secondary filtration before ozone treatment.

d. Ozonation System

Ozone treatment, as designed in this process, can only effect minimal reduction in BOD (tens of mg/L). To make ozone treatment effective, residual solids must be removed to the greatest extent possible (see previous section). Tests performed as part of this project showed that disinfection was not obtained. This was likely due to an undersized ozone system and inefficient solids removal, which resulted in rapid depletion of ozone. Recommendations:

i. Determine the optimal size for an ozone process to be effective
ii. Evaluate the need for filtration after ozone treatment
iii. Determine the ability for ozone to effect sterilization in an optimized process with effective solids removal

Appendix A

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #1 (050202)

Type of Report: Final

Date of Report: 02 May, 2002

Test Objective: Initial test run at 600 BOD

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	Aluminum
5.0 gpm	1.0 gpm	600 mg/L	25	25

Surrogate Preparation:

Test duration	Feed vol.	Feed vol.	Surrogate conc.	Surrogate vol.
8 hr	2,400 gal	9,084 L	1%	91.2 liters

Component	100X Unit conc., g/L	100X Surrogate vol.	Total component weight	
			Calculated	Actual
Brewer's Yeast	100	92 liters (24.3 gal)	9.20 kg	9.20 kg
Cheese Whey	50		4.50 kg	4.50 kg
Urea	14.6		1.34 kg	1.34 kg
Na_2HPO_4	0.43		39.56 g	39.56 g
NaCl	25		2.30 kg	2.30 kg

Test Timeline Summary:

Time	Activity
1140	Initiated flow to EC
1235	Initiated air flow to DAF
1315	Initiate ozone flow
1415	Initiate sample period
1522	End sample period

Analysis	Result
Time at steady state before sample period:	60 min
Time of sample period:	67 min
Water treated (SS + sample period):	635 gal
DAF float collected during sample period:	20 gal
O_3 conc. during sampling, init./final (ppm):	5.456/5.193

Test Results:

Analysis	Surge (Feed) Tank	Clean Water Discharge	Float Tank
	Initial	Composite	Composite
pH	6.21	6.31	5.78
Conductivity, μS/cm	821	648	1,047
Temperature, ^{0}C	12.5	12.1	13.2
COD, (filtered) mg/L	1,031	583	
COD, (unfiltered) mg/L	1,845	682	13,500
BOD, mg/L	750	274	1,140
TDS, mg/L	1,300	807	1,480
TSS, mg/L	640	164	11,510
TKN, mg/L	183.27	64.39	681.72
TP, mg/L	21.54	7.10	94.73

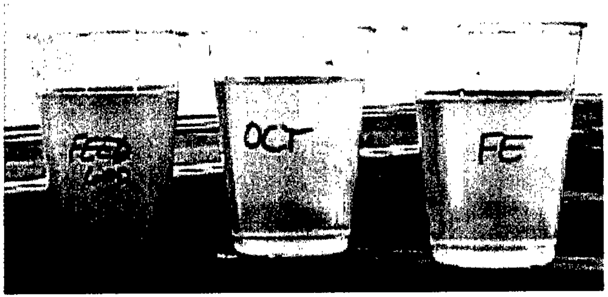
System Configuration:

-Current settings set at 25 A (knob setting) with 60 sec reversal time for both Fe and Al power supplies
- 2 Fe cells (parallel flow) and 3 Al cells (series flow)
-Potable water (PW) feed for ozonation system used
    - Results in 20% dilution of clean water (analyses on page 1 are not corrected)
-Single polishing filter (1 micron) used
-Coagulation tank set to gravity feed into DAF unit
    -Close valve D8 (drain valve)
    -Open valve D9 (influent stack valve)
    -Isolate air pump and close off air supply to air pump

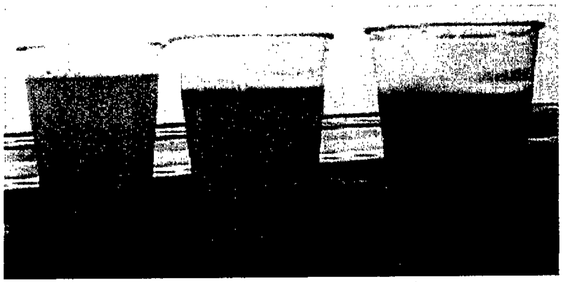
Comments:

1. Ozone concentration ran lower than normal, but all conditions with the ozone generator were normal; may need to change out ozonated water feed tank and recalibrate probe.
2. Problems with thermal dispersion flow switch; kept shutting down system in automatic mode; performed troubleshooting and research—determined that flow switch was improperly installed (according to manufacturers instructions) and that the flow/fluid is either not contacting the sensor or an "air pocket" is developing around the sensor (because of the install); subsequently disconnected the sensor so the system would operate in the auto mode.
3. Voltage levels remained low, indicating that higher current levels could be applied at the 600 BOD concentration.

Pictures:



Feed Clean Water (O_3 tank) Filtered CW



EC effluent at 15, 10 & 5 min

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #2 (050602)

Type of Report: Final

Date of Report: 07 May, 2002

Test Objective: Test 600 BOD at higher current levels

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	Aluminum
5.0 gpm	1.0 gpm	600 mg/L	60	60

Surrogate Preparation:

Test duration	Feed water vol.	Feed water vol.	Surrogate conc.	Surrogate vol.
8 hr	2,400 gal	9,084 L	1.0 %	91.2 liters

Component	100X Unit conc., g/L	100X Surrogate vol.	Total component weight	
			Calculated	Actual
Brewer's Yeast	100	92 liters (24.3 gal)	9.20 kg	9.20 kg
Cheese Whey	50		4.60 kg	4.60 kg
Urea	14.6		1.34 kg	1.34 kg
Na_2HPO_4	0.43		39.56 g	39.56 g
NaCl	25		2.30 kg	2.30 kg

Test Timeline Summary:

Time	Activity
0938	Initiated flow to EC
1051	Initiated air flow to DAF
1128	Initiate ozone flow
1328	Initiate sample period
1430	End sample period

Analysis	Result
Time at steady state before sample period:	120 min
Time of sample period:	62 min
Water treated (SS + sample period):	910 gal
DAF float collected during sample period:	11.0 gal
O_3 conc. during sampling, init./final (ppm):	4.651/4.646

Test Results:

Analysis	Surge (Feed) Tank	Clean Water Discharge	Float Tank
	Initial	*Composite*	*Composite*
pH	6.27	7.16	7.35
Conductivity, μS/cm	670	636	746
Temperature, ^{0}C	29.7	33.0	31.3
COD, (filtered) mg/L	730	585	[illegible]
COD, (unfiltered) mg/L	1,320	634	3,725
BOD, mg/L	1,020	495	>2,460
TDS, mg/L	1,110	965	1,310
TSS, mg/L	476	82	2,859
TKN, mg/L	90.23	57.56	292.16
TP, mg/L	15.65	6.88	45.56

System Configuration:

-Current settings set at 60 A (knob setting) with 60 sec reversal time for both Fe and Al power supplies

- 2 Fe cells (parallel flow) and 3 Al cells (series flow)

-Potable water (PW) feed for ozonation system used

  - Results in 20% dilution of clean water (analyses on page 1 are not corrected)

-Single polishing filter (1 micron) used

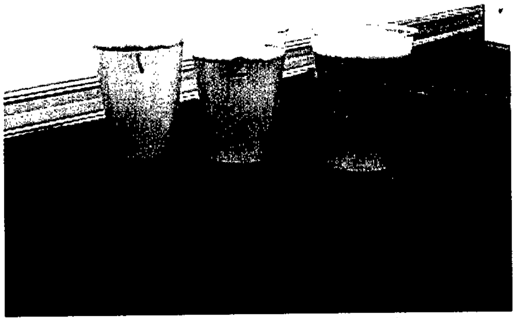
-Coagulation tank set to gravity feed into DAF unit

Comments:

1. One of the iron cells overheated during the test. This indicated no flow through that cell. We suspected a vapor lock or other type blockage. By intermittently forcing all the flow to go through one cell the problem could be temporarily corrected. Propose to operate future tests with iron cells plumbed in series to prevent recurrence of this problem.
2. Ozone levels are not as high as achieved previously. This could be simply the result of the humidity and temperature; calling the manufacturer (Agramond- Todd Willoughby).

Pictures:

Feed Clean Water (O_3 tank) Filtered Eff



EC effluent at 15, 10 & 5 min

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #3 (050702)

Type of Report: Final

Date of Report: 08 May, 2002

Test Objective: Test 600 BOD at a mid-level current

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	Aluminum
5.0 gpm	1.0 gpm	600 ppm	40	40

Surrogate Preparation:

Test duration	Feed water vol.	Feed water vol.	Surrogate conc.	Surrogate vol.
8 hr	2,400 gal	9,084 liters	1.0 %	91.2 liters

Component	100X Unit conc., g/L	100X Surrogate vol.	Total component weight	
			Calculated	Actual
Brewer's Yeast	100	92 liters (24.3 gal)	9.20 kg	9.20 kg
Cheese Whey	50		4.60 kg	4.60 kg
Urea	14.6		1.34 kg	1.34 kg
Na_2HPO_4	0.43		39.56 g	39.56 g
NaCl	25		2.30 kg	2.30 kg

Test Timeline Summary:

Time	Activity
0910	Initiated flow to EC
1023	Initiated air flow to DAF
1100	Initiate ozone flow
1300	Initiate sample period
1400	End sample period

Analysis	Result
Time at steady state before sample period:	120 min
Time of sample period:	60 min
Water treated (SS + sample period):	900 gal
DAF float collected during sample period:	10 gal
O_3 conc. during sampling, init./final (ppm):	5.003/

Test Results:

Analysis	Surge (Feed) Tank	Clean Water Discharge	Float Tank
	Initial	Composite	Composite
pH	6.83	7.05	6.98
Conductivity, μS/cm	519	624	745
Temperature, ^{0}C	29.9	32.8	30.9
COD, (filtered) mg/L	544	520	
COD, (unfiltered) mg/L	966	680	10,995
BOD, mg/L	593	397	> 2,400
TDS, mg/L	780	960	1,180
TSS, mg/L	315	188	9,420
TKN, mg/L	79.97	64.97	654.84
TP, mg/L	10.47	9.56	80.40

System Configuration:

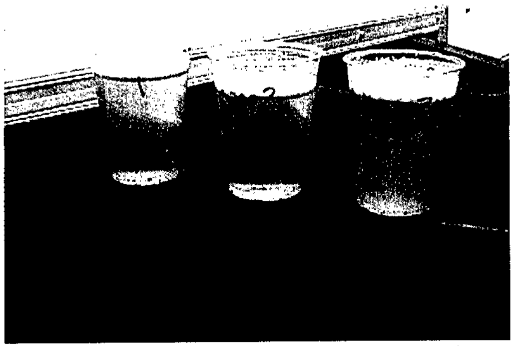
-Current settings set at 40 A with 60 sec reversal time for both Fe and Al power supplies
- 2 Fe cells (series flow) and 3 Al cells (series flow)
-Potable water (PW) feed for ozonation system used
    - Results in 20% dilution of clean water (analyses on page 1 are not corrected)
-Single polishing filter (1 micron) used
-Coagulation tank set to gravity feed into DAF unit

Comments:

1. Contacted Todd Willoughby at Agramond about recent low ozone concentrations in the ozonated water feed tank. Ozone's solubility curve is similar to oxygen—the higher the temperature, the less soluble it will be in water. Mr. Willoughby stated that 5-6 ppm at current temperatures (87-89 ^{0}C) was normal.
2. Collected 10G of float liquid during sample period, although the total volume was closer to 18G. The foam would not break, and there was concern that antifoam agents would affect analyses.
3. Over voltages in the Al cells occurred frequently.
4. There was no overheating in Fe cells (now plumbed in series).

Pictures:

Feed Clean Water (O_3 tank) Filtered CW



EC effluent at 15, 10 & 5 min

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #4 (051402)

Type of Report: Final

Date of Report: 15 May, 2002

Test Objective: 300 BOD at low flow rate with higher ozone flow rate

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	Aluminum
3.0 gpm	3.0 gpm	300 ppm	25	Max w/o OV

Surrogate Preparation:

Test duration	Feed water vol.	Feed water vol.	Surrogate conc.	Surrogate vol.
8 hr	1,440 gal	5,450 liters	0.5 %	27.4 liters

Component	100X Unit conc., g/L	100X Surrogate vol.	Total component weight	
			Calculated	Actual
Brewer's Yeast	100	28 liters (7.4 gal)	2.80 kg	2.80 kg
Cheese Whey	50		1.40 kg	1.40 kg
Urea	14.6		0.408 kg	0.41 kg
Na_2HPO_4	0.43		12.04 g	12.04 g
NaCl	25		0.700 kg	0.70 kg

Test Timeline Summary:

Time	Activity
0940	Initiated flow to EC
1208	Initiated air flow to DAF
1317	Initiate ozone flow
1500	Initiate sample period
1600	End sample period

Analysis	Result
Time at steady state before sample period:	103 min
Time of sample period:	60 min
Water treated (SS + sample period):	489 gal
DAF float collected during sample period:	7 gal
O_3 conc. during sampling, init./final (ppm):	5.396/5.122

Test Results:

Analysis	Surge (Feed) Tank	Clean Water Discharge	Float Tank
	Initial	Composite	Composite
pH	7.32	7.61	7.67
Conductivity, μS/cm	442	489	316
Temperature, ^{0}C	29.5	29.2	30.9
COD, (filtered) mg/L	420	190	[redacted]
COD, (unfiltered) mg/L	754	188	10,310
BOD, mg/L	359	57	> 4,860
TDS, mg/L	620	620	950
TSS, mg/L	245	13.25	9,700
TKN, mg/L	541.97	16.43	853.46
TP, mg/L	7.46	1.13	158.34

System Configuration:

-Current settings set at 25 A with 60 sec reversal time for Fe cells; max A (without overvoltage) with 60 sec reversal time for Al cells

- 2 Fe cells (series flow) and 3 Al cells (series flow)

-Potable water (PW) feed for ozonation system used

- Results in 20% dilution of clean water (analyses on page 1 are not corrected)

-Single polishing filter (1 micron) used

-Coagulation tank set to gravity feed into DAF unit

Comments:

1. Replaced an aluminum cell (cell #5) with an aluminum cell left behind by Ecoloquip. This replacement cell consisted of thicker and fewer plates (less surface area). Cell was weighed prior to installation.
2. During testing, we were unable to maintain current levels at levels used in the previous test. The aluminum cells may need to be cleaned between each run.
3. As testing progressed, overvoltages were experienced with the Al power supply.

Pictures:

Feed Clean Water (O_3 tank) Filtered CW

EC effluent at 15, 10 & 5 min

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #5 (051502)

Type of Report: Final **Date of Report:** 15 May, 2002

Test Objective: 300 BOD at low flow rate and higher ozone rate with clean water recycle

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	Aluminum
3.0 gpm	3.0 gpm	300 ppm	25	Max w/o OV

Surrogate Preparation:

Test duration	Feed water vol.	Feed water vol.	Surrogate conc.	Surrogate vol.
8 hr	1,440 gal	5,450 liters	0.5 %	27.4 liters

Component	100X Unit conc., g/L	100X Surrogate vol.	Total component weight	
			Calculated	Actual
Brewer's Yeast	100	28 liters (7.4 gal)	2.80 kg	2.80 kg
Cheese Whey	50		1.40 kg	1.40 kg
Urea	14.6		0.408 kg	0.41 kg
Na_2HPO_4	0.43		12.04 g	12.04 g
NaCl	25		0.700 kg	0.70 kg

Test Timeline Summary:

Time	Activity
0820	Initiated flow to EC
1050	Initiated air flow to DAF
1208	Initiate ozone flow
1408	Initiate sample period
1508	End sample period

Analysis	Result
Time at steady state before sample period:	120 min
Time of sample period:	60 min
Water treated (SS + sample period):	540 gal
DAF float collected during sample period:	5.0 gal
O_3 conc. during sampling, init./final (ppm):	0.109/0.103

Test Results:

Analysis	Surge (Feed) Tank	Clean Water Discharge	Float Tank
	Initial	Composite	Composite
pH	7.17	6.77	6.90
Conductivity, μS/cm	548	442	530
Temperature, ^{0}C	29.4	24.5	24.7
COD, (filtered) mg/L	568	267	[redacted]
COD, (unfiltered) mg/L	990	302	9,920
BOD, mg/L	144 (472)[1]	51	2,280
TDS, mg/L	770	470	680
TSS, mg/L	344	15.4	8,590
TKN, mg/L	610.20	31.16	492.24
TP, mg/L	10.08	1.52	84.30

System Configuration:

-Current settings set at 25 A with 60 sec reversal time for Fe cells; max A (without overvoltage) with 60 sec reversal time for Al cells

- 2 Fe cells (series flow) and 3 Al cells (series flow)

-Clean water recycle (CWR) used for ozonation system

-Single polishing filter (1 micron) used

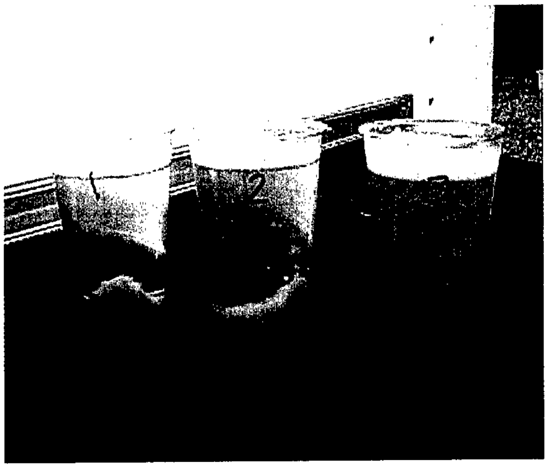
-Coagulation tank set to gravity feed into DAF unit

Comments:

1. Prior to testing, the final bag filter was changed out.
2. There was initial difficulty balancing out recycle flow to ozonation unit. Subsequently, the backpressure valve on the clean water discharge line was adjusted to its max (closed) position.
3. During startup and the actual test, there was difficulty maintaining Al power supply current levels that were used previously (current adjusted twice). The Al cells are possibly fouled, and will be cleaned prior to additional testing.

Pictures:

Feed Clean Water (O_3 tank) Filtered CW



EC effluent at 15, 10 & 5 min

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[1] The BOD_5 data for this sample does not make sense in comparison to the filtered/unfiltered COD data from this experiment and previous experiments; the 472 mg/L is calculated from/as a ratio of the unfiltered COD.

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #6 (061302)

Type of Report: Final **Date of Report:** 13 June, 2002

Test Objective: 5.0 gpm feed w/ 5.0 gpm clean water recycle to ozone system

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	**Aluminum**
5.0 gpm	5.0 gpm	300 ppm	25	25

Test Timeline Summary:

Time	Activity
0800	Initiated flow to EC
0915	Initiated air flow to DAF
0953	Initiate ozone flow
1155	Initiate sample period
1255	End sample period

Analysis	Result
Time at steady state before sample period:	122 min
Time of sample period:	60 min
Water treated (SS + sample period):	910 gal
DAF float collected during sample period:	~2.0 gal
O_3 conc. during sampling, init./final (ppm):	0.107/0.104

Test Results:

Analysis	Raw Feed Tank	Ozone Water Supply Tank	Clean Water Discharge	Float Tank
	Initial	Composite	Composite	Composite
pH	6.80	6.20	6.78	6.53
Conductivity, µS/cm	699	546	972	965
Temperature, ^{0}C	28.9	32.6	32.1	---
COD, (unfiltered) mg/L	624	88	106	19,120
COD, (filtered) mg/L	180	60	53	---
BOD, mg/L	241	23	33	> 4,440
TDS, mg/L	550	460	710	800
TSS, mg/L	272	29	44	12,650
TKN, mg/L	34.57	---	28.89	498.08
TP, mg/L	6.33	---	1.77	225.06
Fecal Coliform, mpn/100 ml		< 1,600	< 1,600	

System Configuration:

-Current settings set at 25 A with 60 sec reversal time for Fe cells; max A (without overvoltage) with 60 sec reversal time for Al cells

- 2 Fe cells (series flow) and 3 Al cells (series flow)

-5.0 gpm raw sewage feed from lift station @ Tyndall AFB (old WWTP)
-5.0 gpm clean water recycle (CWR) feed for ozonation system
-Dual polishing filters (1 micron) used

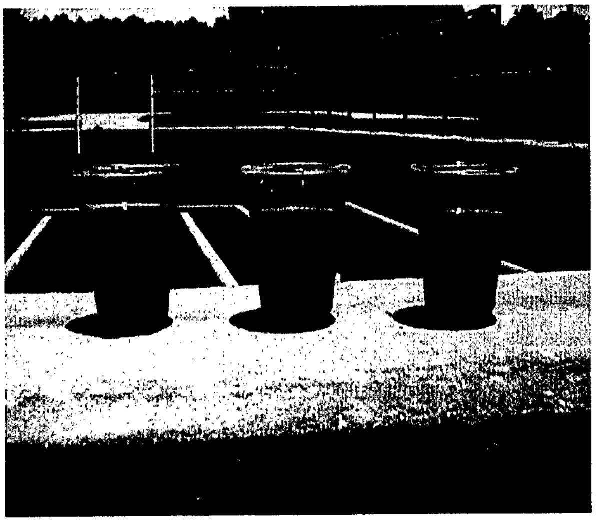
-Coagulation tank set to gravity feed into DAF unit
-Utilizing USAF diesel generator as power source (~218V/100A)

Comments:

1. Cleaned out basket strainers and checked out polishing filters before test run.
2. The ozonated water supply tank was cleaned out before test run.
3. Maximum current settings for wastewater were 25.0 A for the Al, and 25.0 A for the Fe.
4. First time the full automation package (using raw feed/grinder pump) has been utilized. No problems were encountered.
5. First time a generator was used as a power source. The only problem encountered was the occasional tripping of the ozone system breaker. Equipment checked out to be operating normally. Called manufacturer and manufacturer stated that equipment would definitely draw more current if incoming voltage from generator was not constant. If problem becomes frequent, monitor current to ozone system and notify manufacturer.
6. Treated effluent appeared black when samples were pulled at the sampling manifold. The manufacturer was contacted to identify if current levels used in the iron cells cause this condition. Ecoloquip stated that in relationship to the aluminum cell current, the iron cells' current could be reduced to 10-15 A.
7. Composite samples were pulled from the ozone water supply tank as a check to determine the effectiveness/efficiency of the ozonation system in regards to BOD and fecal coliform removal. Experimental results indicate that the ozonation system operates as more of a polishing step.

Pictures:

Feed Clean Water (O_3 tank) Filtered CW



EC effluent at 5, 10 & 15 min

Deployable Wastewater Treatment Technology Evaluation – Appendix A
Summary Test Report: Test #7 (062702)

Type of Report: Preliminary **Date of Report:** 27 June, 2002

Test Objective: 3.0 gpm feed w/ 5.0 gpm clean water recycle

Target Conditions:

Feed flow rate	Ozone flow rate	BOD level	EC current levels, amps	
			Iron	Aluminum
3.0 gpm	5.0 gpm	300 ppm	15	30

Test Timeline Summary:

Time	Activity
0810	Initiated flow to EC
1013	Initiated air flow to DAF
1118	Initiate ozone flow
1330	Initiate sample period
1430	End sample period

Analysis	Result
Time at steady state before sample period:	132 min
Time of sample period:	60 min
Water treated (SS + sample period):	576 gal
DAF float collected during sample period:	~2.0 gal
O_3 conc. during sampling, init./final (ppm):	0.092/0.092

Test Results:

Analysis	Raw Feed Tank	Ozone Water Supply Tank	Clean Water Discharge	Float Tank
	Initial	Composite	Composite	Composite
pH	6.65	6.91	6.91	6.57
Conductivity, μS/cm	690	458	510	731
Temperature, ^{0}C	34.5	33.2	34.9	35.9
COD (unfiltered), mg/L	422	52	60	14,270
COD (filtered), mg/L	150	42	37	---
BOD, mg/L	224	21	22	77,000
TDS, mg/L	420	730	330	620
TSS, mg/L	180	8	21	11,260
TKN, mg/L	34.49	14.10	20.15	489.92
TP, mg/L	4.75	< 0.2	< 0.2	6.11
Fecal Coliform, mpn/100ml		> 1,600	> 1,600	

System Configuration:

-Current settings set at 15 A with 60 sec reversal time for Fe cells; 30 A with 60 sec reversal time for Al cells

- 2 Fe cells (series flow) and 3 Al cells (series flow)

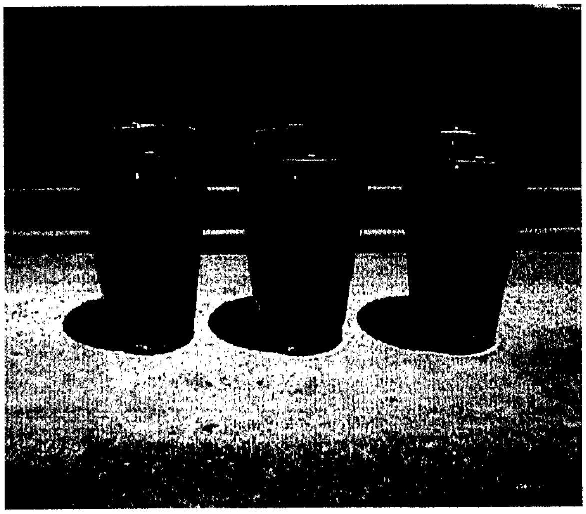
-3.0 gpm raw sewage feed from lift station @ Tyndall AFB (old WWTP)
-5.0 gpm clean water recycle (CWR) feed for ozonation system
-Dual polishing filters (1 micron) used
-Coagulation tank set to gravity feed into DAF unit
-Utilizing USAF diesel generator as power source (~218V/100A)

Comments:

1. Fe power supply current was reduced to 50% of the set Al current per Ecoloquip instructions.
2. Increased the ozone concentration treating the clarified water by reducing the influent flow rate and maintaining a higher ozone flow rate.
3. Initially used potable water to feed the ozone system to decrease solids/organics loading in ozone supply tank prior to steady state. Allowed the DAF solids to 'equilibrate' in the DAF for one hour prior to starting clean water recycle.
4. During the run, problems were experienced with the ozonation system tripping the breaker. The voltage at the USAF generator was observed to fluctuate a great deal (200-220 VAC). The ozone generator was operated at a reduced ozone production rate (80-90 %) in an attempt to alleviate the problem. This seemed to solve the problem.
5. USAF refueled the generator and checked the oil.
6. 9700 area personnel performed power consumption testing.
7. System was thoroughly disinfected and cleaned out after testing.
8. The broken potable water supply valve to the surge tank was replaced.
9. A clean water sample was re-filtered at the ARA laboratory and sent to Water Spigot for analysis. Results: BOD= 12 mg/L; TKN= 17.69 mg/L; and TP= < 0.2 mg/L. These results indicate that the system may need improved filtration to achieve the desired discharge goals set in the SOW.
10. Total phosporus results for the ozone supply tank and clean water were non-detect.
11. Fecal coliform counts results were still elevated (WWTP discharge limits in FL = 220). Depending upon military requirements, additional sterilization or ozone contact time may be necessary.

Pictures:

Feed Float O_3 Contact Tank Filtered CW



EC effluent at 5, 10 & 15 min

Appendix B

Test #1

Test date: 050202

Feed water flow rate:	5	gpm
Dilution from Ozone System:	1	gpm
Test period:	67	min

	Feed In	Ozone In	DAF out	CW out	Recovered
Gallons	335	67	20	382	
Liters	1268	254	76	1446	
BOD					
mg/L	750		1140	274	
Grams	951		86	396	51%
TKN					
mg/L	183		682	64	
Grams	232		52	93	62%
TP					
mg/L	22		95	7	
Grams	27		7	10	64%
TSS					
mg/L	640		11,510	164	
Grams	812		871	237	137%

Deployable Wastewater Treatment Technology Evaluation
Appendix B: Material Balances

Test #2

Test date: 050602

Feed water flow rate:	**5**	**gpm**
Dilution from Ozone System:	**1**	**gpm**
Test period:	**62**	**min**

	Feed In	Ozone In	DAF out	CW out	Recovered
Gallons	310	62	11	361	
Liters	1173	235	42	1366	
BOD					
mg/L	1020		2460	495	
Grams	1197		102	676	65%
TKN					
mg/L	90		292	58	
Grams	106		12	79	86%
TP					
mg/L	16		46	7	
Grams	18		2	9	62%
TSS					
mg/L	476		2,859	82	
Grams	559		119	112	41%

Test #3

Test date: 050702

Feed water flow rate:	5	gpm
Dilution from Ozone System:	1	gpm
Test period:	60	min

	Feed In	Ozone In	DAF out	CW out	Recovered
Gallons	300	60	10	350	
Liters	1136	227	38	1325	
BOD					
mg/L	593		2400	397	
Grams	673		91	526	92%
TKN					
mg/L	80		655	65	
Grams	91		25	86	122%
TP					
mg/L	10		80	10	
Grams	12		3	13	132%
TSS					
mg/L	315		9,420	188	
Grams	358		357	249	169%

Test #4

Test date: 051402

Feed water flow rate:	3	gpm
Dilution from Ozone System:	3	gpm
Test period:	60	min

	Feed In	Ozone In	DAF out	CW out	Recovered
Gallons	180	180	7	353	
Liters	681	681	26	1336	
BOD					
mg/L	359		4860	57	
Grams	245		129	76	84%
TKN					
mg/L	542		853	16	
Grams	369		23	22	12%
TP					
mg/L	7		158	1	
Grams	5		4	2	112%
TSS					
mg/L	245		9,700	13.25	
Grams	167		257	18	165%

Deployable Wastewater Treatment Technology Evaluation
Appendix B: Material Balances

Test #5

Test date: 051502

Feed water flow rate:	**3**	**gpm**
Dilution from Ozone System:	**0**	**gpm**
Test period:	**60**	**min**

	Feed In	**Ozone In**	**DAF out**	**CW out**	**Recovered**
Gallons	180	0	5	175	
Liters	681	0	19	662	
BOD					
mg/L	472		2280	51	
Grams	322		43	34	24%
TKN					
mg/L	610		492	31	
Grams	416		9	21	7%
TP					
mg/L	10		84	2	
Grams	7		2	1	38%
TSS					
mg/L	344		8,590	15.4	
Grams	234		163	10	74%

Test #6

Test date: 061302

Feed water flow rate:	5	gpm
Dilution from Ozone System:	0	gpm
Test period:	60	min

	Feed In	Ozone In	DAF out	CW out	Recovered
Gallons	300	0	2	298	
Liters	1136	0	8	1128	
BOD					
mg/L	241		4440	33	
Grams	274		34	37	26%
TKN					
mg/L	35		498	29	
Grams	39		4	33	93%
TP					
mg/L	6		225	2	
Grams	7		2	2	51%
TSS					
mg/L	272		12,650	44	
Grams	309		96	50	47%

Test #7

Test date: 062702

Feed water flow rate:	3	gpm
Dilution from Ozone System:	0	gpm
Test period:	60	min

	Feed In	Ozone In	DAF out	CW out	Recovered
Gallons	180	0	2	178	
Liters	681	0	8	674	
BOD					
mg/L	224		77000	22	
Grams	153		583	15	392%
TKN					
mg/L	34		490	20	
Grams	23		4	14	74%
TP					
mg/L	5		6	0	
Grams	3		0	0	6%
TSS					
mg/L	180		11,260	21	
Grams	123		85	14	81%