Like Dating Before Marriage

Experiences from wetland treatability testing result in a stronger match

BY JIM HIGGINS AND MARK LINER

Making a perfect match between a project and design is one of the most important decisions engineers and wastewater professionals make. It is a decision that is best not made without serious pause. The wastewater issues of today pose serious challenges and those charged with preserving and protecting the environment and public health have a tough assignment just staying ahead of the potential solutions available to them.

As wastewater quality becomes more complex and the effluent limits more stringent, the options for wastewater design become increasingly varied. The job of determining the most effective and most efficient approach to a particular wastewater management issue also rises in difficulty. In these scenarios, having data that simulate the way that the system will operate in the context of the application, in advance of final design of the system, is a tremendous asset.

Treatability studies, like dating before marriage, provide real experience and data that can be used to gauge how the final design will work. Pilot test facilities exist throughout the United States, often associated with colleges and universities—or, as in the case of the Massachusetts Alternative Septic System Test Center, with state departments of environmental protection. Many have differing focuses, but in each case they provide regulators, engineers, and wastewater professionals with real world data that can greatly help in system selection, sizing, and operation.

Treatability Studies

Engineered wetlands (EWs) are playing a leading role in the new, "green" wastewater treatment infrastructure of the 21st century. As experience with wetlands has grown, new types of wetland systems have been developed. Within the last 30 years, there has been a progression from using natural wetlands to the use of man-made constructed wetland systems. Engineered wetlands are advanced, semi-passive kinds of constructed wetlands that are "engineered" in many ways to solve environmental problems. One example is tidal flow wetlands in which influent streams to wetland cells are varied in flow rate or periodically turned off to optimize system performance. In other systems, effluents from various points in a wetland may be recycled to improve nitrogen removal or ordinary substrates like sand or gravel may be replaced with special ones that have the ability to adsorb phosphorus. In other scenarios, heat, chemicals, or air may be added and wetland vegetation may be selected for its phytoremediating properties.

Engineered wetlands can be modified in a number of ways. In fact, the typical design changes are simple and involve basic, well-understood engineering components like blowers, actuated valves, and control panels. Although these components are easy to integrate into the physical design of a system, addressing how they impact the process design is another story. The mechanisms responsible for treatment can be biological, chemical, or physical in nature, each reaction with its own particular process equation. So, using a simplified, canned model approach to an engineered wetland design can result in a design that does not address particular reactions unique to the project. Here, treatability studies provide the necessary data to understand the way the combination of reactions will work for a specific configuration, treating a specific wastewater, under specific conditions.

Like any good design, the design of an engineered wetland system is also a marriage between theory and empiricism. Process theory provides the necessary foundation for a design and allows the size and performance of a system to be quantified. This knowledge is typically encapsulated in a process equation. However, as wastewater engineers are well aware, rarely do wastewater streams occur in steady state. Although an equation and its variables may work well with one type of wastewater, they may not be appropriate for another. Variables derived in the treatability tests account for specific conditions and enable the appropriate modification of equations such that the design is sized correctly based on the engineered enhancements.

Testing the Value of Aeration

One kind of advanced engineered wetland is an aerated, vertical subsurface flow wetland (VSSF) in which air (supplied by blowers) is introduced under the gravel substrate, countercurrent to the downward percolating wastewater. Many aerated VSSF wetlands are currently in operation for cluster developments in Minnesota and other northern states. Operating experience from these systems has provided a foundation for improvements in their design, which has resulted in more robust systems that are capable of meeting stringent effluent requirements. Aeration of these systems is central to their success.

The use of forced bed aeration in engineered wetland systems has improved and broadened the application of treatment wetland technology. For this reason, engineered wetland systems are gaining wide acceptance as an effective approach to wastewater treatment outside the onsite wastewater treatment market. However, how the introduction of forced air improves process performance is a matter still under investigation. Recent treatability studies, presented here for a large municipality and a gold mine, have investigated how the use of aeration can be used to improve a wetland design.

Treatment wetlands can be modeled using chemical reactor-based modeling methods by assuming that they act either as plug flow reactors (PFRs), continuously stirred reactors (CSRs) or Tanks-In–Series (TIS). Although there is no doubt that the aeration enhances the ability of a wetland to treat wastewater, the extent to which aeration mixes the wetland cell must be quantified. Design equations should accurately reflect the actual wetland hydraulics and be based on the correct reactor-based model and related equations. Treatability testing provides insight into what model and equations are appropriate and, more important, provides necessary corrections to the variables in them.

To address the design of aerated VSSFs, treatability testing was conducted at an indoor pilot-scale treatability test unit at Alfred College in Ontario, Canada. The Pilot Unit consists of several components including a raw feedstock storage tank, a mixing tank, gravel bed EW cells, an automatic sampler, refrigeration equipment, and a grow light system.

The studies demonstrated specifically that aerated wetlands can successfully treat ammonia-containing wastewaters at high hydraulic loading rates and at low operating temperatures. Ammonia-nitrogen removal rate constants were found to be up to an order of magnitude or higher than those achievable in ordinary wetlands. The results provide an assurance that aerated wetlands are a good and appropriate match for the design and the project.

As a result of the data collected from the studies, two very large VSSF systems have been designed by Jacques Whitford Limited & North American Wetland Engineering (NAWE) and are under construction. One is for a Canadian municipality (5,500 cubic meters per day) and the other is for a large gold mine in South America (16,000 cubic meters per day). Both of these new high-rate systems use a proprietary "hammer-and-sickle" configuration, a high-performance, aerated lagoon used for bulk pollutant removal and the evening out of flows. This is followed by a multiple cell VSSF EW using NAWE's patented Forced Bed Aeration system.

The Alfred Pilot Unit

The heart of the Pilot Unit was a single, heated and aerated, downflow VSSF-engineered wetland cell. It was constructed from a 1.0-meter by 1.2-meter by 0.9-meter chemical tote with its top removed. Its major components were a bottom outlet (effluent) collection distributor, a heater assembly, an aeration header assembly located under the

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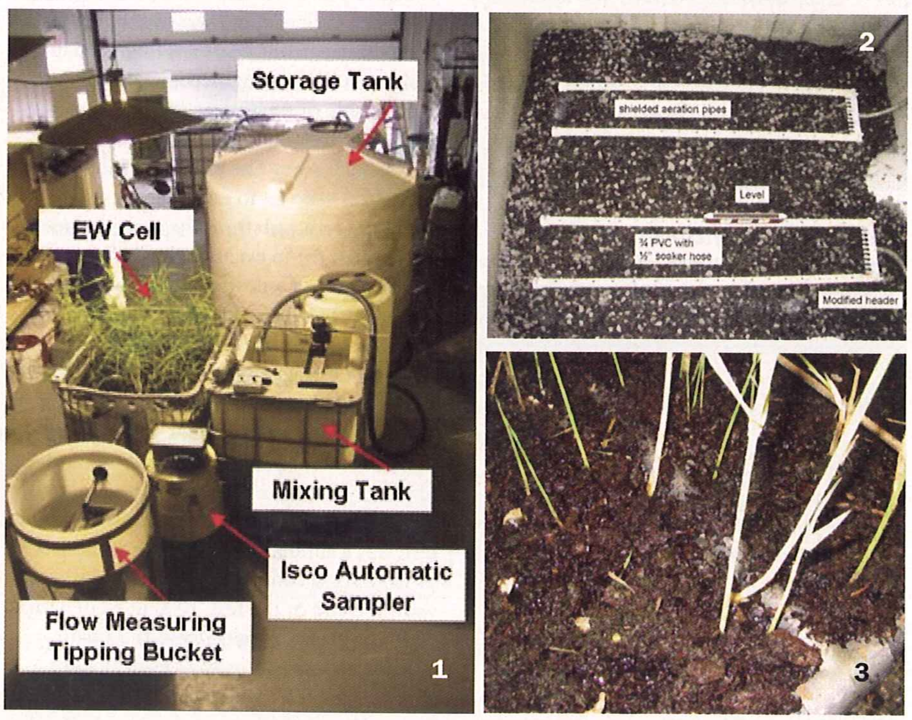

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Table 1: Synopsis of Test # 1 Operating Data

	Category A Feb. 15 to Mar. 11		Category B Mar. 11 to Mar. 18		Category C Mar. 23 to Mar. 29		Category D Mar. 29 to Apr. 6	
Q (L/day)	159				129.6			
Events	Synthetic & Air On		Synthetic & Air Off		Actual & Air On		Synthetic & Air On	
Sampling	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
NH3-N (mg/L)	17.31	0.31	12.96	3.90	5.71	0.05	14.65	0.08
NO3-N (mg/L)	2.15	21.44	12.83	8.96	2.59	20.61	2.65	21.23

1.3-centimeter washed gravel (0.46 porosity) substrate, and an inlet (influent) distributor on the gravel surface.

The aeration header consisted of two U-shaped loops of 3⁄4-inch PVC piping with 1⁄2-inch SDS soaker-hose tubing inside. The purpose of the PVC piping was to protect the permeable SDS tubing from the weight of the gravel bed on top of it.

The EW cell was vegetated with common reeds collected from roadside ditches near the Alfred College. Plants were acclimatized for two weeks by placing collected clumps in peat in a greenhouse in an aerated, open vessel containing shallow water. Fertilizer was added to the water. The roots of viable reeds were then removed and anchored in the gravel of the cell. Finally, a layer of peat was laid on top to wick the influent from the inlet distributor assembly tubing holes.

Table 2: Calculated Volumetric Rate Constants (day 1) for Ammonia Nitrification

Category	Feedstock Type/ Aeration	k25oC, PFR	k25oC, CSR
A	Synthetic, On	1.53	20.9
B	Synthetic, Off	0.46	0.89
C	Actual, On	1.47	35.2
D	Synthetic, On	1.62	56.6

Table 3: Summary of Results at High Temperature (~25 °C)

Concentration	Influent	Effluent
Ammonia-N	9.27	0.24
Nitrate-N	2.7	17.00
TKN	13.5	2.8
Org-N	4.2	2.6
Dissolved Oxygen	3.4	5.7
cBOD	16.0	4.7
TSS	26.7	11.4
Nitrogen Balance	16.2	19.8
Total Phosphorus	0.91	0.75
Alkalinity as CaCO3	209	147

Treatment for ammonia was a primary driver for both projects; each project has a surface-water discharge with an effluent limit for ammonia. The limit is established to address aquatic toxicity associated with high levels of ammonia. Ammonia removal is also important for discharge to soil-based systems that are increasingly permitted with total Nitrogen limits. Ammonia removal is well understood in conventional activated sludge design and necessitates that an engineer account for the oxygen necessary to transform ammonia to nitrate. Conventional wetland systems rely on atmospheric diffusion of oxygen to meet bacterial oxygen demands. Wetlands engineered with forced bed aeration permit the controlled supply of oxygen, similar in approach to activated sludge systems, which greatly facilitates ammonia removal.

Alfred Pilot Unit Test No. 1

The ability of a treatment wetland to treat a goldmine tailings pond was evaluated. Data from this treatability test is being used to design a full-scale engineered wetland system capable of treating 16,000 cubic meters per day of reclaim water prior to discharge into a small river. The purpose of the treatability test was: 1.) to establish the extent of ammonia removal from the cyanide-laden wastewater; 2.) to evaluate the design and performance of a down-flow, aerated, vertical, subsurface-flow wetland; 3.) to determine wastewater-specific kinetic rates for ammonia nitrogen removal; and 4.) to better define the design and proposed operating philosophy for a subsequent, more sophisticated outdoor pilot unit to be built and operated at the site of the gold mine.

The initial feedstock for the treatability test was a simulated wastewater indicative of worst-case conditions. Additionally, toward the end of the test, 1000 liters of actual wastewater was shipped from the site in South America and used as feedstock for a short period. Hydraulic loading rates ranged from 130 to 159 liters per day, and hydraulic retention times were calculated as being between 2.8 and 3.5 days. After initial acclimatization and calibration, the pilot unit was operated during the spring of 2005, 24 hours per day, at 25C degrees, and with grow lights turned on between 6 a.m. and 6 p.m.

The test was highly successful, showing that 1.) the concept of using an aerated vertical flow wetland to treat ammonia- and cyanide-contaminated waters from the tailings pond is feasible; 2.) soluble cyanide species in the wastewater do not inhibit ammonia nitrification; and 3.) for an aerated, PFR model an ammonia nitrification rate constant value between 1.47 and 1.62 can be used in sizing, and for an aerated CSR model, a rate constant value of between 20.9 and 56.6 can be used for sizing of the engineered wetland. The aerated PFR ammonia nitrogen rate constants found during the treatability test may be compared with literature values in the 0.3 – 0.4/d range.

A synopsis of operating results for the pilot-scale treatability test is provided in Table 1. Based on the results, it is apparent that the wetland, as operated, was capable of efficiently removing ammonia to very low levels. More important, the results confirm that aeration of the VSSF EW substrate greatly increases the ability of the unit to transform ammonia to nitrate.

Any determination of kinetic parameters and reaction dynamics for a treatability test must address how wastewater flows through the wetland; be it plug flow (PFR), complete mix (CSR), or somewhere in between. Tracer work was not conducted on this round of testing, so the exact flow patterns are not known. It is helpful, however, to use the results of the study to establish idealized plug flow and complete mix rates as performance is expected to be bracketed between these two extremes. The calculated ammonia nitrogen removal rates is provided in Table 2.

Alfred Pilot Test No. 2

The extent to which a wetland can treat to meet increasingly stringent ammonia nitrogen discharge levels was evaluated for a municipality in a northern climate. Data from the treatability test was used to design a full-scale system capable of treating 5,500 cubic meters per day (now under construction). For the treatability test, the major challenges were defining how well ammonia and other contaminants were removed from raw sewage over a wide temperature range, and whether minor contaminants affected the microbial degradation of ammonia.

Some of the objectives for the treatability test were to: 1.) define the treatability of raw sewage; 2.) evaluate the hydraulics for a system using saturated downflow VSSF EWs wetlands; 3) define initial kinetics for the removal of contaminants, especially ammonia,

The EW cell was vegetated with common reeds collected from roadside ditches.

at low- and high-design basis temperatures; and 4.) carry out a tracer test to determine expected residence time distribution of wastewater for the full-scale facilities. Raw sewage from an existing outdated treatment facility was periodically shipped to the pilot unit at Alfred College and there stored in a 5,000-liter plastic storage tank. Hydraulic loading rates ranged from 32.8 to 33.5 cubic meters per day and average hydraulic retention time was calculated at 1.2 days. After initial acclimatization and calibration, the indoor pilot unit was operated for roughly five months over the summer of 2005, 24 hours per day and 7 days per week. Target operating temperatures were 4-6 degrees C and 25 degrees C, and the grow lights were turned on between 6 a.m. and 6 p.m. A walk-in refrigeration unit was used for the low temperature testing and temperatures as low as 4 degrees C were possible with it. The treatability test achieved its objectives in that ammonia nitrogen removal for the unit was found to be very efficient at any temperature; there seemed to be no undefined components in the sewage that negatively affected nitrifying bacteria. Relatively high hydraulic loading rates and short, nominal residence times do not negatively affect treatment performance. Nitrification reactions in an aerated EW can be successfully carried out at temperatures as low as 4 degrees C and tracer testing indicated that the process is best modeled by a complete mix reactor model (for prudent design, a slightly more conservative 2TIS model may be used.) Tables 3 and 4 provide evidence that the aerated wetlands are capable of achieving extremely efficient ammonia removal to almost non-detect levels over a wide range of temperatures at relatively high hydraulic throughputs. A tracer test was conducted to establish the flow patterns through the wetland cell. Results indicate that the conditions in the wetland cell are best approximated by a complete mix reactor model, which can be attributed to the uniform influent distribution and flow disturbance introduced by aerating the cell.

Volumetric removal rates for the high and low temperature results were calculated based on plug flow, complete mix, and two-tank-in-series (2TIS) models. Based on results, it is expected that use of the 2TIS model will be conservative and is appropriate for full-scale design. Tables 5 and 6 provide the calculated average volumetric removal rate constants.

Wine and Roses

In each case, one for a gold mine in South America and one for a municipality in Canada, the treatability tests provide invaluable insight into the performance of the systems for a specific wastewater. Moreover, the sampling results and calculated kinetic constants provide real input into the design process for each distinct situation. So, as the projects progress to final design, the engineers can go forward with confidence in the selection and sizing of the wetlands. For these cases, it appears that the dates will result in strong marriages. The marriage metaphor aside, the results from these tests are particularly noteworthy for two reasons: 1.) they establish and quantify rates for nitrification in VSSF EW systems; and 2.) they provide clarity in defining VSSF EW process hydraulics. With these two pieces of the puzzle determined, the use of aerated wetlands to achieve ammonia removal is further established.

Passive systems, like wetlands, can be used for more than onsite treatment, particularly when they are engineered to meet the specific requirements of the project. The use of such systems requires additional, case-specific knowledge, however. For example, treatability testing is currently underway for stormwater runoff contaminated with airport deicing fluid; results will undoubtedly provide further insight into the appropriate equations and variables to be used for final design.

As more treatability tests are conducted on different configurations and different wastewaters, the core knowledge for the design of engineered wetlands, particularly those with aeration, increases and broadens their application. OW

Table 4: Summary of Results at Low Temperature (~4-6 °C)

Concentration	Influent	Effluent
Ammonia	14.67	0.44
Nitrate	3.4	18.6
TKN	20.0	4.6
Org-N	5.4	4.2
Dissolved Oxygen	7.1	7.0
cBOD	13.8	3.0
TSS	29.7	8.9
Nitrogen Balance	23.5	23.2
Total Phosphorus	0.46	0.37
Alkalinity as CaCO3	183	135

Table 5: Calculated Volumetric Rate Constants at high temperatures (~25 °C)

Rate Constants	k25oC, PFR(d-1)	k25oC, CSR(d-1)	k25oC, 2TIS(d-1)
Ammonia (mg/l)	3.3	38.5	10.0
cBOD (mg/l)	1.1	2.1	1.5

Table 6: Calculated Volumetric Rate Constants at low temperatures (~4-6 °C)

Rate Constants	k6oC, PFR (d-1)	k6oC, CSR(d-1)	k6oC, 2TIS(d-1)
Ammonia (mg/l)	3.0	29.4	8.4
cBOD (mg/l)	1.3	3.1	1.9

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