NUTRIENT REDUCTION THROUGH USE OF AN ADVANCED BIOLOGICAL NUTRIENT RECOVERY PROCESS

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The growing importance of sustainable water practices continues to be an area of high importance to governmental and industrial entities. This importance has been highlighted in recent years through both climatological and environmental impacts. For example, the potential environmental consequences of nutrient laden discharge effluents are evident in the findings of The US Environmental Protection Agency (EPA) Nutrient Innovations Task Group Report issued August 2009 (USEPA 2009), which noted:

- Nutrient pollution is one of the top causes of water quality impairments affecting over 14,000 water segments

- Over 809,000 ha (2M ac) of lakes and reservoirs across the US are impaired and do not meet water quality standards due to excess nutrients

- 78% of continental US coastal areas exhibit symptoms of eutrophication

A recent example of the consequences of excessive nutrient pollution occurred in August, 2014 when the city of Toledo, OH suspended drinking water supply to nearly 500,000 residents for 2 days due to the detection of toxins produced from cyanobacteria (New York Times, 2014).

In June 2015, Ohio, Michigan and the Province of Ontario agreed to the phosphorus reduction targets recommended by the Great Lakes Water Quality Agreement. These target a 40% reduction of phosphorus (relative to 2008) in Lake Erie. In addition, a reduction of 860MT Total Phosphorus and 186MT of Dissolved Reactive Phosphorus Load during the Spring-time (March – July) was identified. In order to realize these objectives, it will take a comprehensive approach to overall nutrient management consisting of education, best management practices and adoption of innovative technology solutions.

In the summer of 2015, the city of Perrysburg, Ohio (one of the cities impacted by the August, 2014 water crisis in Toledo) decided to undertake an initiative to host the demonstration of technologies which have the potential to contribute to the reduction of phosphorus loading in Lake Erie. One such technology was an advanced biological nutrient recovery (ABNR) technology developed by Clearas Water Recovery which relies on the existing microbiology in a conventionally treated wastewater stream to consume dissolved nutrients, such as nitrogen and phosphorus.

OVERALL TECHNOLOGY DESCRIPTION

Modelled similar to a suspended growth activated sludge process, ABNR uses the existing microbiology within a wastewater effluent stream to naturally consume nutrients without the use of supplemental chemical additions. Through the process of photosynthesis, this process also recycles carbon dioxide (CO_2) and releases oxygen (O_2) into the treated stream. Similar to activated sludge, a defined food-to-mass ratio is maintained to ensure that adequate biological mass is available to consume the food (i.e. nutrients) available. This microbiology consists of algae, bacteria and other biological material inherent in the wastewater treatment process employed. By using microbiology indigenous to the particular installation, ABNR takes advantage of microbiology which has naturally adapted to the particular plant and its specific process. Figure 1 is a high level overview of the ABNR process.

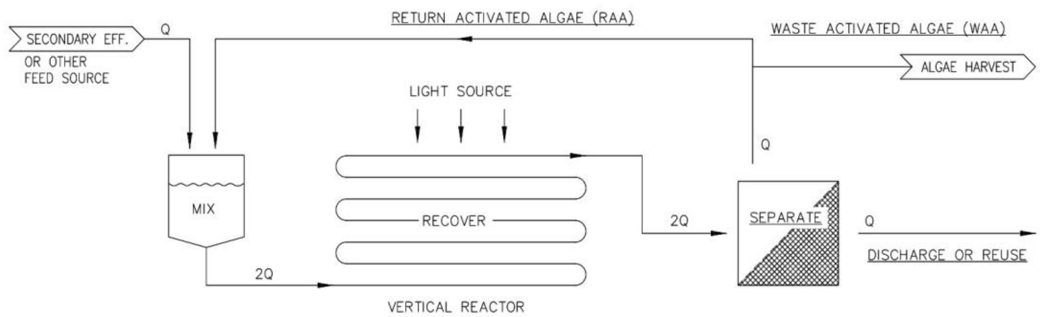


FIGURE 1: HIGH-LEVEL ABNR PROCESS FLOW

The food-to-mass ratio is maintained through a process referred to as the Constant Mixed Algae Suspended Solids (CMASS) method. This method allows the operator to select a specific CMASS density range (measured in mg/L) of the Mixture Flow to produce the highest quality effluent. The CMASS range is pre-determined by modeling and confirmed (optimized) via on-site demonstration. CMASS recognizes that for the algae in the incoming, to-be-treated effluent to duplicate, it will consume nitrogen and phosphorus in a defined and predictable ratio. This ratio is typically 1 part phosphorus to 6-8 parts nitrogen. The specific ratio (N:P) is defined by a number of parameters, most importantly, the composition of the nitrogen fraction. As a general guideline, algae will consume ammonia and nitrates first, followed by the fraction of organic nitrogen which becomes bioavailable through the treatment process.

The Separation Stage is accomplished through the use of micro-filtration. In order to achieve the level of nutrient reduction realized, it is critical that all microbiology be removed in this final stage. In pilot programs, this is commonly accomplished through the use of flat-sheet submerged membranes. Unlike conventional Membrane Bioreactor (MBR) technology where biological activity is occurring in the MBR, the ABNR process uses the membranes in a thickening capacity to achieve a defined concentration of the Mixture Flow. This allows for lower energy costs (relative to a conventional MBR) and increased membrane life.

RESULTS

ABNR has successfully demonstrated the ability to reduce Total Phosphorus (TP) to near non-detect levels at multiple industrial and municipal facilities. Recent field evaluations have also shown it to be effective at Surface Water Applications which include waterbodies fed by nutrient-impaired tributaries. The following summarizes point source performance based on 3 examples of extended duration continuous flow demonstration programs: one industrial and two municipal. In discussing performance demonstrated, data summarized is based on 24-hour composite samples and all testing has been performed at independent third party labs to eliminate any potential bias. All results were performed using EPA recognized test methods, such as Test Method 4500-PE for TP. Results obtained at, or below, the level of detection for the method (for example, 0.010mg/L for TP) were reported as "Non-Detect" by the testing lab.

Inland Empire Paper (Industrial)

Inland Empire Paper (IEP) is a direct discharge Pulp and Paper Mill located in the Pacific Northwest US. With an average daily flow of 11,400 M^3/D (3MGD), IEP was facing the need to meet a new permit limit of 0.075mg/L TP. Over a 3 year period of testing and demonstration, ABNR consistently exceeded this level of performance and is currently progressing through final design testing in advance of full scale engineering design in late 2016. During the most recent 5 month time frame, the average incoming to be treated water (feed) TP was 0.126mg/L, while the average treated stream (permeate) was 0.022mg/L, well below the target of 0.075mg/L.

Upper Blackstone Water Pollution Abatement District (UBWPAD)

The UBWPAD facility is the second largest municipal wastewater facility in the state of Massachusetts and is located approximately 1 hour west of Boston. With an average daily flow of approximately 171,000 M^3/D (45MGD), the facility provides treatment to approximately 250,000 residents and handles biosolids for 14 different communities. UBWPAD also has a sizeable industrial base which includes 26 Significant Industrial Users (SIU). A "SIU" is a categorical description defined by the EPA as "…any industrial user that has a reasonable potential for adversely affecting the operation of the collection system or treatment plant, or violating any pretreatment requirement" (Massachusetts Water Resource Authority). UBWPAD is a chemical-free plant that uses an anaerobic/anoxic/oxic (A2O) process and was faced with a seasonal permit limit (April – October) of

0.1mg/L for TP and 5.0mg/L for total nitrogen (TN). During the most recent 9 month period, the average feed TP was 0.254mg/L and the average permeate TP was 0.015mg/L, and TN was 3.414mg/L. Of particular interest, there were several periods of time when results coming back from the 3rd party lab were being reported as "Non-Detect" for TP.

Perrysburg, OH

As noted earlier, the City of Perrysburg, OH hosted a Demonstration Program at its facility in summer 2015. To help put the significance of the Perrysburg location in perspective, Figure 2 is an image of the western basin of Lake Erie with the location of the Perrysburg site indicated (National Oceanic and Atmospheric Administration, 2015).

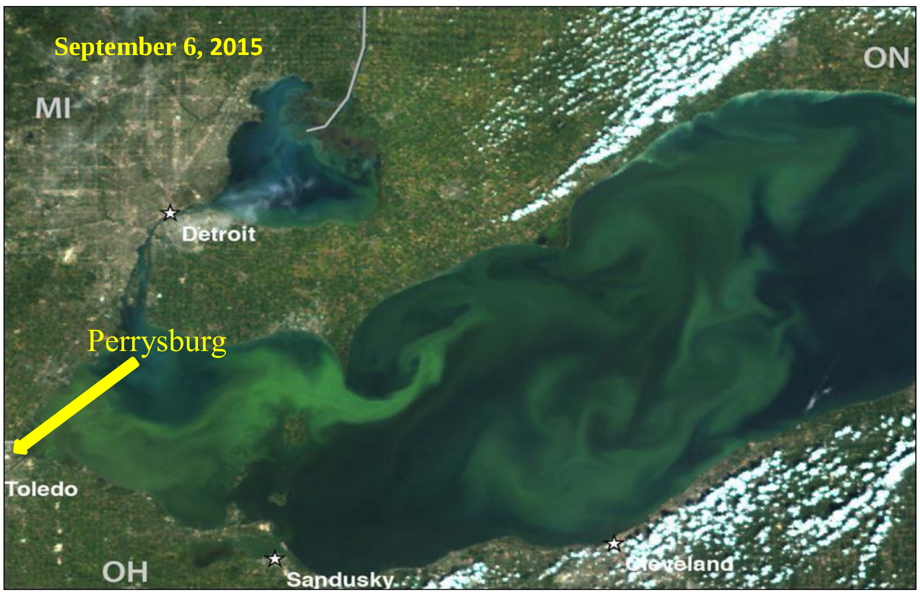


FIGURE 2: PERRYSBURG, OH DEMONSTRATION LOCATION

The Perrysburg program ran for a total of 3 months and the average feed TP during the trial period was 0.306mg/L while the average permeate during the same time period was 0.014mg/L, a 95.4% reduction. Similar to both Inland Empire Paper and UBWPAD, several results of "Non-Detect" were also reported.

As noted in the section on OVERALL TECHNOLOGY DESCRIPTION, ABNR recycles carbon dioxide (CO_2) and releases oxygen (O_2). A summary of average Dissolved Oxygen (DO) results from both UBWPAD and Perrysburg show an increase in DO in the permeate stream of greater than 40%. The positive impact of this on the receiving waterbody will be realized through an improved aquatic environment.

As noted earlier, in order to maintain a defined food-to-mass ratio, excess biomass is harvested or wasted. This biomass has potential value in a number of industries, including specialty chemicals, soil enhancement, bioplastics, and as a source of fuel for co-generation applications. By its nature, the fat content of the biomass will be relatively low, so its application as a source of traditional biofuel type feedstocks is limited.

ECONOMICS

To model the direct economic benefits of ABNR, a series of Monte Carlo Simulations were performed. For purposes of this analysis, a comparison of ABNR to a conventional chemical solution for an 18,930 M^3/D (5MGD) average daily flow facility with a need to reduce TP from 1.0mg/L to 0.05mg/L was simulated. The level of phosphorus reduction modelled is similar to the challenge facing several watersheds within the Midwest US (such as the state of Wisconsin) and certain Regions within Ontario. A total of 11 different independent variables were used with a low-medium-high value identified for each. The independent variables modelled included:

- Cost of CO_2
- Capital equipment cost
- Molar ratio (it was assumed that ferric chloride was the coagulant used)
- Cost of ferric chloride
- Buffering agents required to offset alkalinity changes
- Cost of buffering agents
- Use of dewatering polymers
- Cost of dewatering polymers
- Cost of sludge disposal
- ABNR Biomass recovery efficiency
- Value of Biomass

A total of 5,000 simulations were performed to model Total Cost of Ownership over a 20 year period, resulting in the curves shown in Figure 3. The simulation showed that the 20 year Total Cost of Ownership (Capital cost plus 20 years of Operation and Maintenance Expense on a present worth basis) showed a favorable cost benefit to ABNR over traditional chemical solution. The median value for a traditional chemical solution was predicted to be \$12.3MM (CAD) vs. \$5.5MM (CAD) for the ABNR solution.

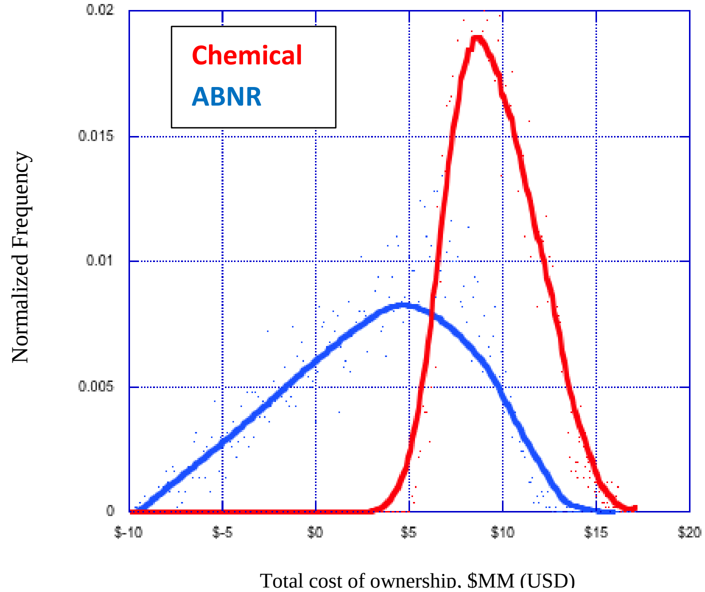
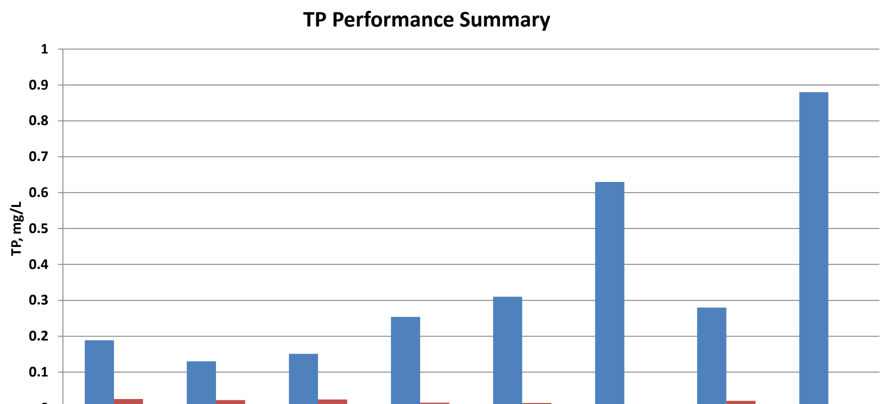


FIGURE 3: MONTE CARLO SIMULATION OF ABNR VS. CHEMICAL SOLUTION

CONCLUSIONS

Figure 4 summarizes available Demonstration Performance Data for the ability of ABNR to achieve low phosphorus reduction, with near "Non-Detect" levels of performance demonstrated at both industrial and municipal applications.

ABNR offers proven and compelling low phosphorus performance without the use of chemical coagulation. In addition to being a sustainable and natural process, ABNR offers multi-constituent performance and several beneficial secondary co-products: recycled CO_2, significant increase in DO, and a biomass product with beneficial secondary market application.



	NRT Avg	Ind - R10	Muni - R10	Muni - R1	Muni - R5	SWP -R8	SWP - R5	Muni - R5
Feed	0.189	0.130	0.151	0.254	0.310	0.630	0.280	0.880
Permeate	0.025	0.022	0.024	0.015	0.014	0.006	0.020	0.010

Application - Location

FIGURE 4: LOW PHOSPHORUS PERFORMANCE SUMMARY

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