EPA Research Grant Annual Report Summary

Period Covered by the Report: September 1, 2020 – September 1, 2021
Date of Report: November 2021
EPA Agreement Number: 84008601
Title: When a Detour Becomes a Shortcut: Going Full-Scale with Partial Denitrification/Anammox as an Alternative Strategy for Mainstream Deammonification and Incorporating Biological Phosphorus Removal
Investigators: Fevig, Stephanie; Chandran, Kartik; De Clippeleir, Haydee; Klaus, Stephanie; Riffat, Rumana; Wells, George
Institution: The Water Research Foundation (WRF), Columbia University (CU), District of Columbia Water and Sewer Authority (DC Water), Hampton Roads Sanitation District (HRSD), George Washington University (GWU), Northwestern University (NU)
Research Category: Harmful Algal Blooms, Water, Clean Water, Water Quality
Project Period: Year 1 (September 1, 2020 – September 1, 2021)

Objective of Research:

The goal of this project is to develop proof of principle for different partial denitrification anammox (PdNA) configurations, with the integration of biological phosphorus (bio-P), and move PdNA into full-scale application. PdNA with bio-P has the potential to achieve low nutrient effluent concentrations with reductions in energy, chemicals, and treatment footprint. Ultimately, implementation of this process can provide significant cost savings to utilities while reducing nutrient discharges to the watershed and mitigating the formation of harmful algal blooms (HABs).

There are four key objectives of this research, each supported by a series of tasks with task leads and supporting team members:

- Objective 1: Develop new PdNA concepts using denitrifying phosphate accumulating organisms (dPAO)
- Objective 2: Develop proof of principle for different PdNA configurations
- Objective 3: Move PdNA into full-scale applications
- Objective 4: Conduct outreach and technology transfer, in particular to utilities in regions with HABs

Progress Summary/Accomplishments (Outputs/Outcomes):

With the opportunity for innovative full-scale process deployment over the timeframe of this three-year project, important components of the project will be outreach and technology transfer to water resource recovery facilities in HAB hotspots and other regions nationally. Below are the accomplishments to date for the key outputs/outcomes of this project:

Development of New PdNA Concepts Using Denitrifying PAO

- Lab-scale testing to date has shown that the inoculation biomass has robust bio-P removal behavior after a short acclimation period.

- Low levels of anoxic P uptake with NO_3- reduction and small levels of NO_2- accumulation were observed without available COD, indicating the potential existence of dPAO.

Development of Proof of Principle for Different PdNA Configurations

- Both mainstream polishing PdNA MBBR and PdNA IFAS reactors can produce low effluent TIN concentrations with relatively low carbon requirements compared to the conventional nitrification/denitrification nitrogen removal process, even with relatively low and unstable PdN efficiencies.
- The PdNA in IFAS configuration occurred with the PdN coming from internally stored carbon following an A2O process. At the James River Treatment Plant, there was enough influent soluble COD to be stored and utilized for both EBPR and PdNA.

Movement of PdNA into Full-Scale Applications

- MBBR Application
    - Startup of a mainstream anammox MBBR is possible within 2-3 months without anammox biomass seeding.
    - Preliminary biofilm improved startup time by 1 month over virgin media.
    - Growing anammox did not require high ammonia or nitrite concentrations.
    - PdNA MBBR startup without anammox seed has been demonstrated and should be achievable at other utilities.
- Filter Application
    - Higher PdN efficiencies, PdNA rates, and PdNA contribution to overall TIN removal were observed in the glycerol filter, although this was not different enough to justify switching from methanol to glycerol in the full-scale filter.
    - Anammox could not be washed out of the system under the extreme stresses applied to the filters. In fact, extreme backwashing improved performance in the methanol filter.
    - The polishing filter is robust and reliable enough to reach low effluent TIN (< 3 mg/L N), and upstream AvN control is the most important control parameter.

Publications/Presentations:

Publications

In progress: Startup Strategies for Mainstream Anammox Polishing in Moving Bed Biofilm Reactors. Submitted to *Water Environment Research*, IPE Conference Special Issue. Coauthors: Sarah Schoepflin, Justin Macmanus, Kester McCullough, Chenghua Long, Stephanie Klaus, Haydee De Clippeleir, Kartik Chandran, Chris Wilson, Charles Bott.

In progress: Nitrogen Removal Capacity and Carbon Demand Requirements of Partial Denitrification/Anammox MBBR and IFAS Processes. Target Journal: *Water Environment Research*. Coauthors: Justin Macmanus, Chenghua Long, Stephanie Klaus, Michael Parsons, Haydee De Clippeleir, Kartik Chandran, Charles Bott.

Presentations

Fofana, R., Bachmann, M., Akyon, B., Jones, K., Delgado, J., Klaus, S., Parsons, M., Bott, C., deBarbadillo, C., and De Clippeleir, H. 2021. Carbon Source Selection for Deep-Bed Partial Denitrification: Anammox (PdNA) Polishing Filters. WEFTEC 2021. Chicago, IL: WEF.

Fofana, R., Bachmann, M., Akyon, B., Jones, K., Delgado, J., Klaus, S., Parsons, M., Bott, C., deBarbadillo, C., and De Clippeleir, H. 2021. Optimizing and Validating Mainstream Partial Denitrification-Anammox (PdNA) in Deep-Bed Polishing Filters: Assessment of Media Type and Carbon Source. WEF Innovations and Process Engineering 2021. Virtual Conference.: WEF.

Ladipo-Obasa, M., Forney, N., Riffat, R., Wett, B., deBarbadillo, C., Bott, C., and De Clippeleir, H. 2021. Addressing Aeration Control Needs for PdNA Integration. WEFTEC 2021. Chicago, IL: WEF.

Forney, N., Ladipo-Obasa, M., Riffat, R., Wett, B., deBarbadillo, C., Bott, C., and De Clippeleir, H. 2021. Overcoming Limiting Factors for PdNA in Integrated Suspended Process Schemes. WEFTEC 2021. Chicago, IL: WEF.

Ladipo-Obasa, M., Huynh, H., Forney, N., Chen, H., Riffat, R., Wett, B., deBarbadillo, C., Bott, C., and De Clippeleir, H. 2021. AnAOB Integration Options for Mainstream Short-Cut Nitrogen Removal via Partial Denitrification (PdNA). IWA Biofilm 2020. Virtual Conference. IWA.

Macmanus, J., Schoepflin, S., Klaus, S., Parsons, M., and Bott, C. 2021. Mainstream Anammox Implementation in MBBRs: Journey from Pilot-Scale PNA to Full-Scale PdNA Design. WEF Innovations and Process Engineering 2021. Virtual Conference. WEF.

Macmanus, J., Schoepflin, S., Klaus, S., Parsons, M., and Bott, C. 2021. Starting Up and Developing Design Criteria for Mainstream Polishing Partial Denitrification/Anammox MBBR. WEFTEC 2021. Chicago, Ill.: WEF. Manuscript submitted, WER paper in progress.

Al-Omari, A., Wadhawan T., Takacs I., Klaus S., Le T., Jimenez J., Murthy S., Bott C., and De Clippeleir H. 2020. Partial Denitrification Model Development in the Context of Shortcut Nitrogen Removal Processes. WEFTEC 20 proceedings, Virtual Conference.

Future Activities:

Objective 1: Develop New PdNA Concepts Using Denitrifying PAO

- Conduct routine reactor performance monitoring via nutrient analysis.
- Conduct molecular analysis (qPCR and amplicon sequencing) to quantify the abundance of *Accumulibacter* during the acclimatization period.
- Enrich *Accumulibacter* dPAO and track its abundance dynamics at the same time.
- Initiate investigation of operational parameters for coupled dPAO activity with partial denitrification.

Objective 2: Develop Proof of Principle for Different PdNA Configurations

- Prepare a journal paper that (1) discusses the impact of anammox retention methods (IFAS vs suspended) using acetate as a carbon source, and (2) compares results.

- Continue experimental runs, pre-anoxic concept using IFAS anammox, with fermentate (centrate).

Objective 3: Move PdNA into Full-Scale Applications

- Complete the startup experiment for the pilot polishing filter at York River Treatment Plant.
- Continue the PdNA IFAS pilot reactor startup experiment.
- Begin construction of the full-scale MIFAS/FIFAS post-anoxic PdNA IFAS demonstration at James River Treatment Plant.
- Compile completed 16S rRNA sequencing and qPCR analysis results (performed by CU) for the James River pilot MBBR startup and MBBR vs IFAS operation.
- Extend the PdN model to cover other biomass, including denitrifying PAOs and glycogen accumulating organisms to consider the use of internally stored carbon and the potential for partial denitrification based on observed data.

Objective 4: Conduct Outreach and Technology Transfer

Work on this objective is anticipated to begin in late 2022.

Supplemental Keywords:

Biological Nutrient Removal (BNR), Nutrients, Treatment, Nitrogen, Phosphorus

Relevant Websites:

https://www.waterrf.org/harmful-algal-blooms-habs-when-detour-becomes-shortcut, https://www.waterrf.org/research/projects/mainstream-deammonification-biological-phosphorus-removal-1