Mainstream Deammonification—*A New "Blue Print" for Cost Effective, Sustainable Nutrient Removal*

Introduction

District of Columbia Water and Sewer Authority (DC Water) and Hampton Roads Sanitation District (HRSD) in Virginia, have successfully led a group of scientists, engineers and wastewater practitioners from around the globe to identify and demonstrate the key engineering mechanisms that provide for the repression of nitrite oxidizing bacteria (NOB) and that enable the highly efficient anammox bacteria to operate effectively in mainstream wastewater environments. This has never before been accomplished and represents a major breakthrough for the wastewater sector, opening the door to an era of unprecedented sustainability, environmental protection and cost savings. Indeed, it has been said that this work represents the most significant leap forward in wastewater management since the discovery of activated sludge a century ago in 1914.

For the past century, the principles of wastewater treatment have been founded on the use of energy intensive aerobic treatment processes (treatments dependent of the presence of oxygen) to oxidize what have traditionally been referred to as pollutants in wastewater (e.g. carbon and nutrients). One hundred years later, the findings from this project represent a paradigm shift for the wastewater sector; a shift towards energy efficient anaerobic treatment processes (treatment in the absence of oxygen) through the use of the novel anammox bacteria. The anammox organism was discovered about 10 years ago and is remarkable in that it employs completely different metabolic pathways than the bacteria traditionally used in wastewater treatment. These organisms can reliably remove nitrogen from wastewater under anaerobic conditions and in the absence of organic carbon. In theory therefore, they can purify wastewater to very stringent environmental standards while using significantly less oxygen / energy (65%) and carbon (90%).

Until now however, scientists were unable to unlock this potential in the cold dilute wastewater environment. The team working on this project has overcome that barrier and has identified not only the fundamental scientific secrets of success but has gone on to develop and demonstrate an integrated control

strategy that can be used to transform conventional wastewater treatment plants into energy and resource recovery facilities, and has even demonstrated this revolutionary process at full scale under some of the most aggressive operating conditions imaginable in wastewater treatment. By successfully unlocking the scientific secrets that enable this highly efficient anaerobic bacteria, anammox, to thrive and function in conventional mainstream wastewater environments, this project team has truly revolutionized the fundamentals for wastewater treatment and identified a roadmap for sustainable wastewater management for the 21st century with significant environmental, economic and societal benefits.

Complexity of the Problem and Innovative Solutions

DC Water and HRSD are currently implementing some of the most advanced and sustainable wastewater treatment facilities in the world at the 391-mgd Blue Plains AWTP in Washington D.C. and HRSD's WWTPs in Coastal Virginia with a combined flow of 249 mgd. There are multiple drivers but at the heart of their efforts is their continued commitment to environmental protection and in particular to the restoration of the regional waterways and the Chesapeake Bay, which was declared a national treasure by President Obama in 2009.

After extensive research, the team identified several promising scientific and technical approaches to bring the plant of the 21st century vision to a reality. They narrowed the critical challenges down to four key areas of complexity that had to be overcome for success: (1) growth and retention of the anammox organism, (2) growth and retention of the ammonia oxidizing bacteria (AOB), (3) suppression/washout of the nitrite oxidizing bacteria (NOB), and (4) controlled growth of the ordinary heterotrophic organisms (OHO).

To overcome each of these challenges the team developed a host of novel science based control strategies. In general, evaluation of the innovative solutions began at the bench scale with development of the fundamental scientific mechanisms. From there the engineering and control strategies were tested at pilot scale and then verified at full scale. The complexity of the project was mitigated by adopting a "divide and conquer"

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approach; by dividing the work load, (see Table 1) the team was able to progress on parallel paths with unprecedented speed.

Table 1: Overview of the technology approaches to meet the 5 main objectives at the Blue Plains and Chesapeake Elizabeth pilot plants operated by DC Water and the Hampton Roads Sanitation District, respectively

Objective	Approaches for Implementation at	
	Blue Plains	Chesapeake Elizabeth
NOB out-selection	Rapid transient conditions High dissolved oxygen (DO) Residual ammonium AOB bioaugmentation Anammox competition for NO_2^- Controlled COD input	Rapid transient conditions High DO Residual ammonium AVN Control Heterotrophic competition for NO_2^- Controlled COD input with AOB rate maximization
Selective anammox retention	Sieves/cyclones	Attached growth
Meeting stringent permits	1. Nitrite production from nitrate by *Methyloversatilis* followed by anammox 2. Complete Denitrification through anammox (*Brocardia*)	Anammox moving-bed biofilm reactor (MBBR)
Managing Poor Settling with SND Conditions	Dual purpose Sieves/cyclones for settling improvement and anammox retention	Cyclone used for settling improvement only

Potential for Replication/Up-scaling Based on Local Conditions

Implementing mainstream deammonification at full-scale was an ambitious and complex objective from both a scientific and practical perspective. Because of the sensitivity of the organisms to temperature, the team was concerned that the process may not be globally applicable and may only operate reliably in warm climates. So, the project team decided to implement two full scale demonstration facilities under two different climatic conditions: a cold climate demonstration at the Strass WWTP, Austria under the guidance of Dr. Bernhard Wett; and a warm climate demonstration at the Changi Water Reclamation Plant, Singapore under the guidance of Dr. Yeshi Cao. Both full scale demonstrations were in fact very successful, yielding proof of concept, confirmation of the potential for scale-up and full scale replication. The demonstrations proved the viability and validity of the vision for the 21st century energy neutral resource recovery plant.

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DC Water and HRSD have also implemented a new approach for remaining at the cutting edge while providing additional research funding for the Water Environment Research Foundation (WERF). Along with many wastewater process advancements, this project has resulted in the development of two discrete technologies, S-select and AVN. S-select includes the use of an external gravimetric selector (e.g. a hydrocyclone) for biomass wasting as a means of improving mixed liquor settleability. This technology is now being installed full-scale at the HRSD James River Treatment Plant, and there is considerable interest by many utilities around the world. The AVN technology represents the core of the ideas needed to implement mainstream nitrite shunt and mainstream deammonification and includes anammox bioaugmentation, the control system and process approach for NOB outselection, and an anammox polishing process. An agreement between DC Water and HRSD allows the joint ownership and mutual commercialization of these technologies, both of which were developed jointly as a result of collaboration and consistent interaction among the two research groups. Both of these technologies are being commercialized by reputable wastewater technology providers, and ALL of the royalty generated through the implementation of these new technologies will be allocated to a WERF research fund. This novel arrangement is an example of collaborative success supporting future innovation.

Conclusion: As a result of the visionary stewardship of DC Water, HRSD and their international partners and consultants, wastewater utilities now have a new "blue-print" to use to achieve cost effective sustainable nutrient removal while also pursuing energy neutrality, reduced greenhouse gas emissions and high quality water reuse. This project will help to: promote the cost effective implementation of nutrient removal WWTPs that will serve to protect and revive impaired water bodies; support sustainable water recovery and reuse in water resource constrained areas of the world; support the growth of local communities, industry and tourism while enhancing the quality of life; keep rate payer costs low; and reduce greenhouse gases emissions by converting WWTPs into energy recovery facilities that can export green electricity to the grid.