AAEES – 100 Years of the Activated Sludge Process

Nitrogen Removal: The Anammox Process

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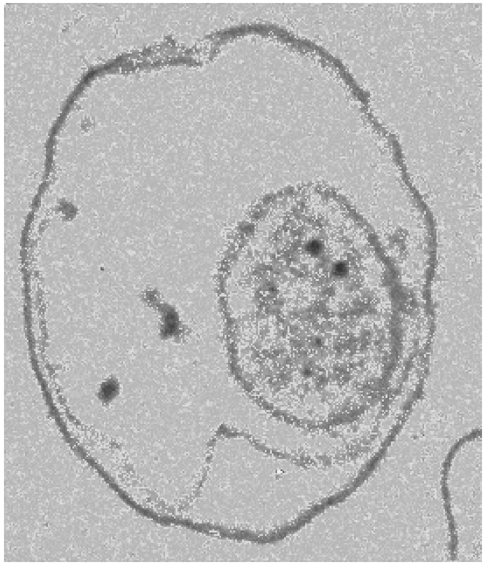
Supported by:

What is anammox?

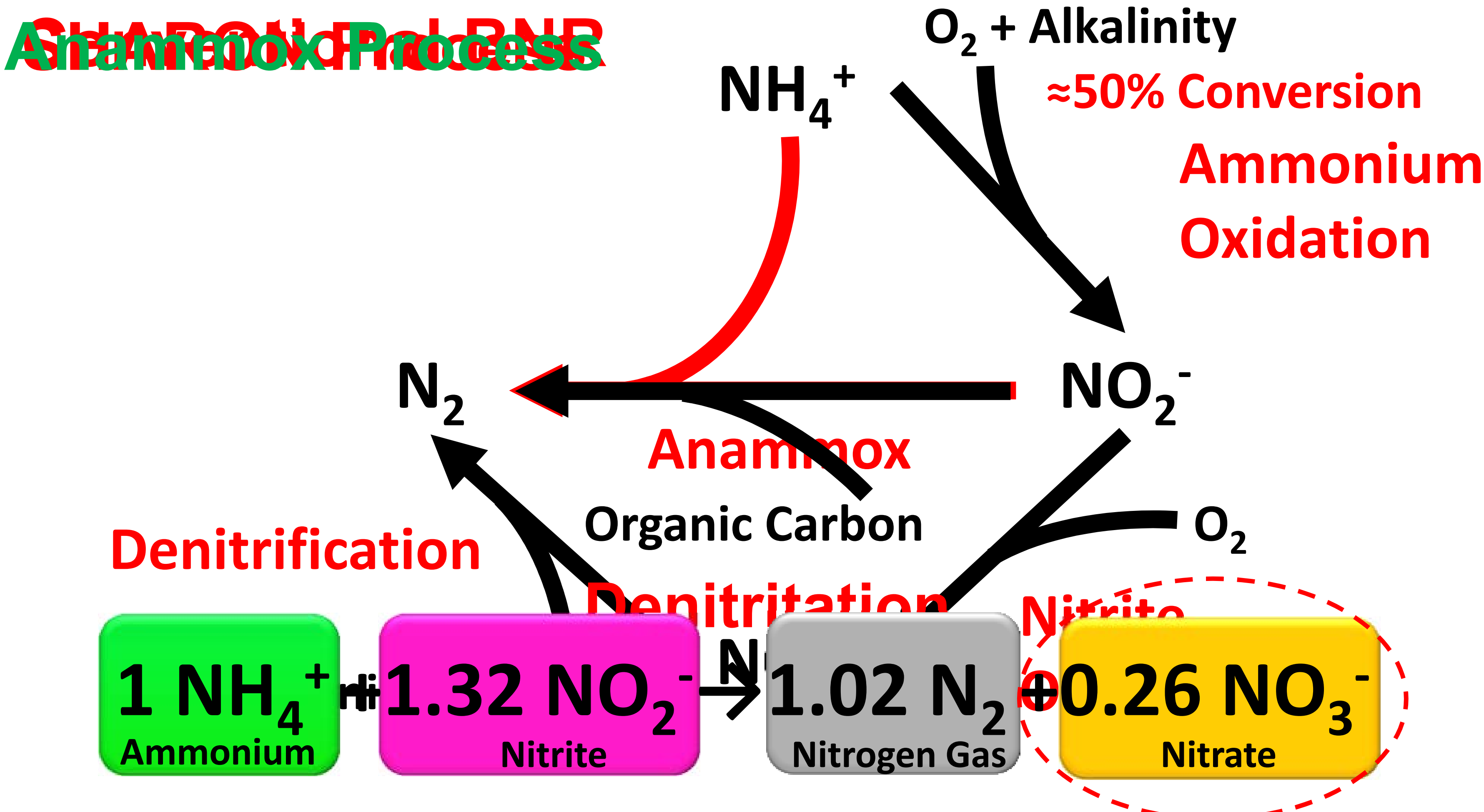
- Biological process
- **an**aerobic **amm**onium **ox**idation
- First documented in the Netherlands in 1990[1]
- Several species of bacteria



Micrograph by Helen Markewich CCNY

1. van de Graaf et al 1990

Anammox and Wastewater Treatment



- Maximum Nitrogen Removal = 89% (theoretical)
- NO_3^- Formation = 11% (theoretical)

Principal Challenge

- Anammox bacteria grow very slowly compared to other microorganisms
- Doubling time = 10-20 days!
- Solution → biomass retention

Sequencing Batch Reactor (SBR)

Moving Bed Biofilm Reactor (MBBR)

Anammox: Proven Technology

- **Side Stream Treatment – mature**
- **Main Stream – Proof of Concept**

Applications of Anammox

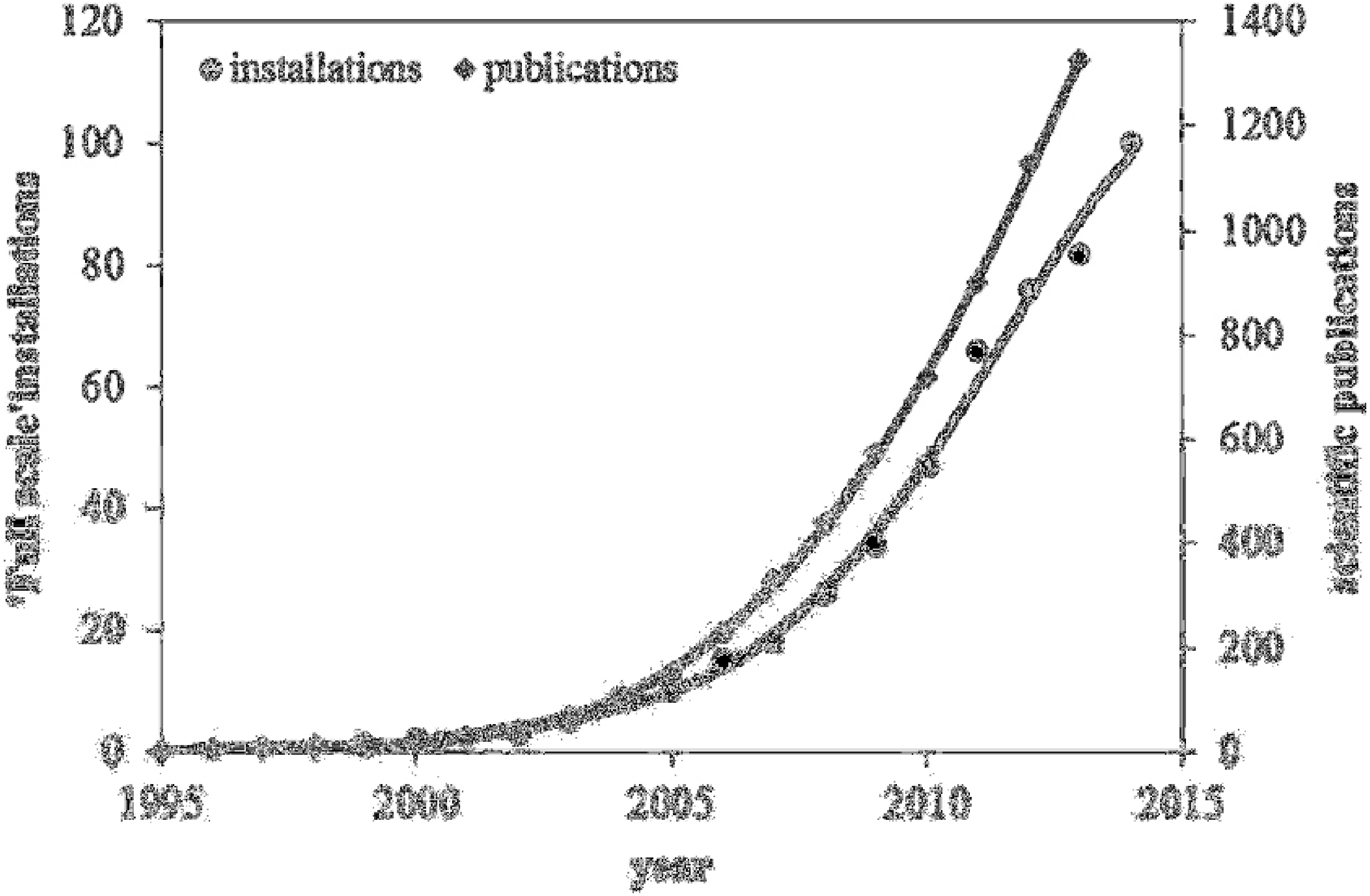
- High Ammonium waste streams
  - Digester sludge reject water (centrate)
  - Landfill leachate
  - Industrial wastewater

    (typically with a very low C:N ratio)

Anaerobic Digestor
Newtown Creek WWTP, NYC

- **With NYC centrate, ≈70% nitrogen removal is achievable without alkalinity addition**

Anammox Worldwide Installations



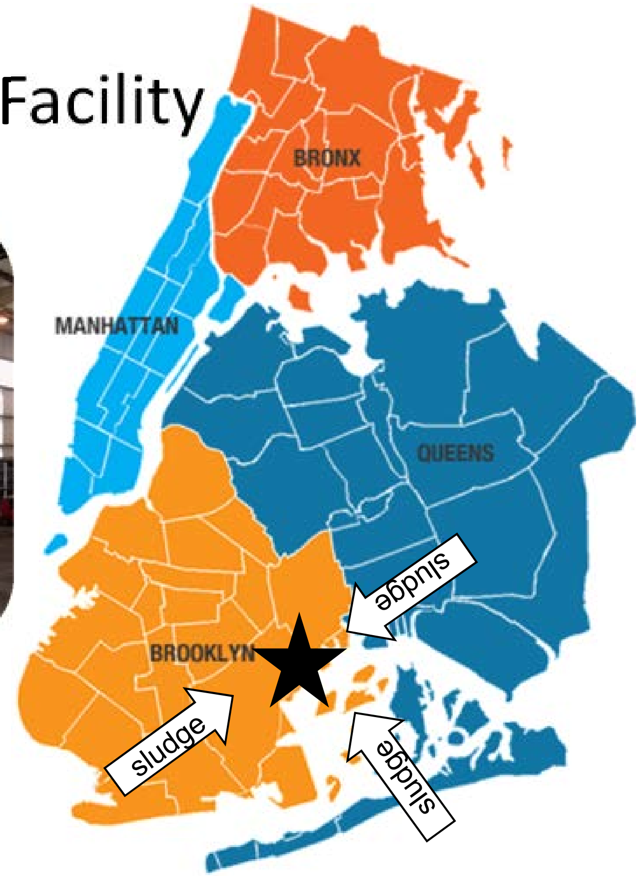
Reference: Water Research v55 (2014) pg 292-303; http://dx.doi.org/10.1016/j.watres.2014.02.032

Full Scale US Anammox Installations

USA (In progress)	Status
York River, VA	Operational 2012
James River, VA	Operational 2013
Alexandria, VA	Construction
Pierce County, WA	Design Stage
Philadelphia, PA	Design Stage
Washington, DC	Design Stage
Egan, IL	Construction
Orlando, Fl	Design Stage
South Durham, NC	Construction
New York City	Pilot Study Completed

Anammox MBBR Pilot Study

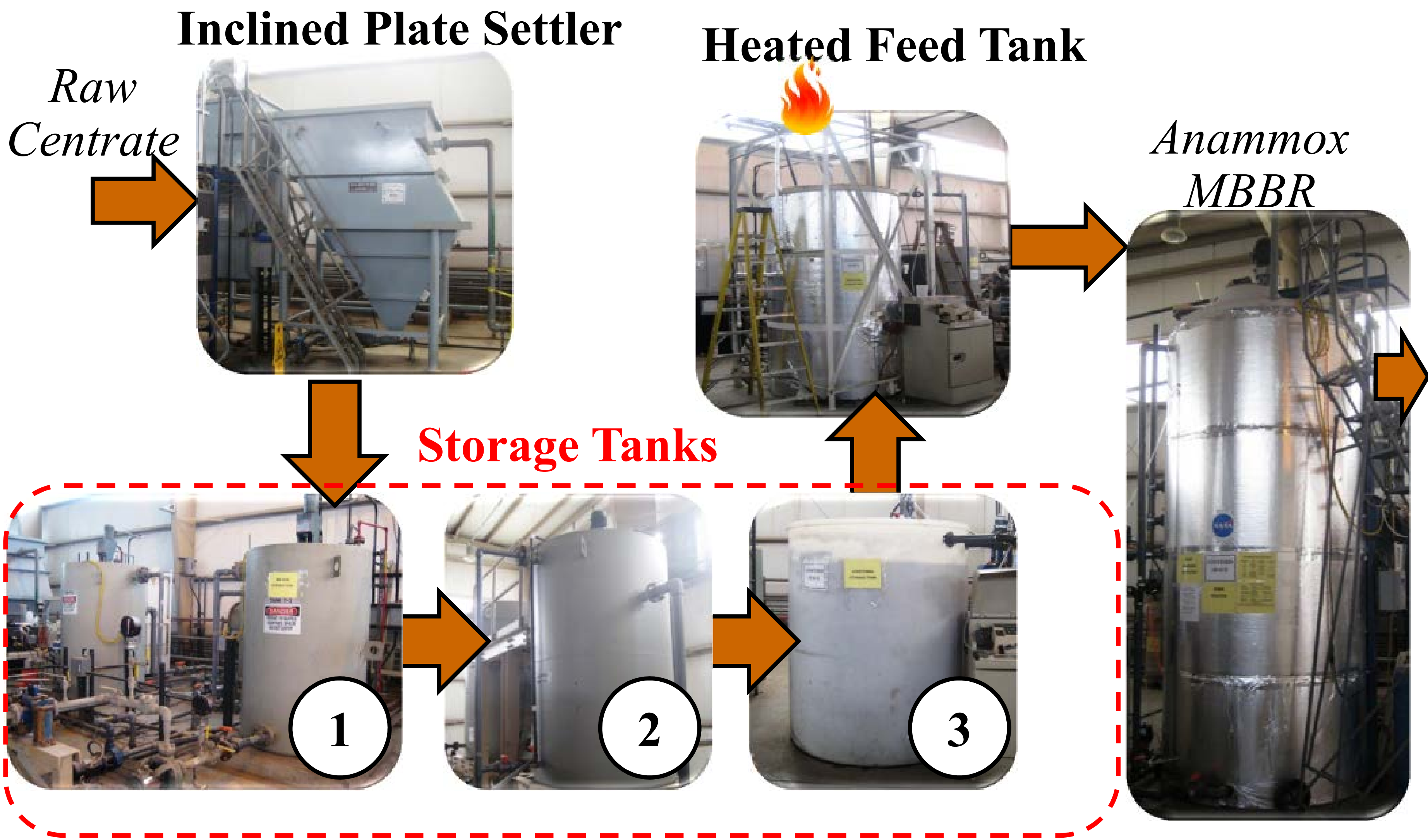
- **Located at 26th Ward WWTP**
  - Brooklyn, NY
  - Centralized Dewatering Facility



Source: http://nycrc.com/

Operational since March 2011

Flow Scheme



- To ensure continuous flow operation
- Equalization of centrate

Raw Centrate Characteristics

	Alkalinity	NH_3-N	NO_2-N	NO_3-N	sCOD	TSS	VSS	pH
	(mg/L as $CaCO_3$)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
Avg.	1289	378	0.0	0.9	584	1427	1364	7.59
St. Dev.	355	171	0.1	0.3	517	1357	1335	0.29
Max	2140	774	0.3	1.6	2576	9732	7632	8.19

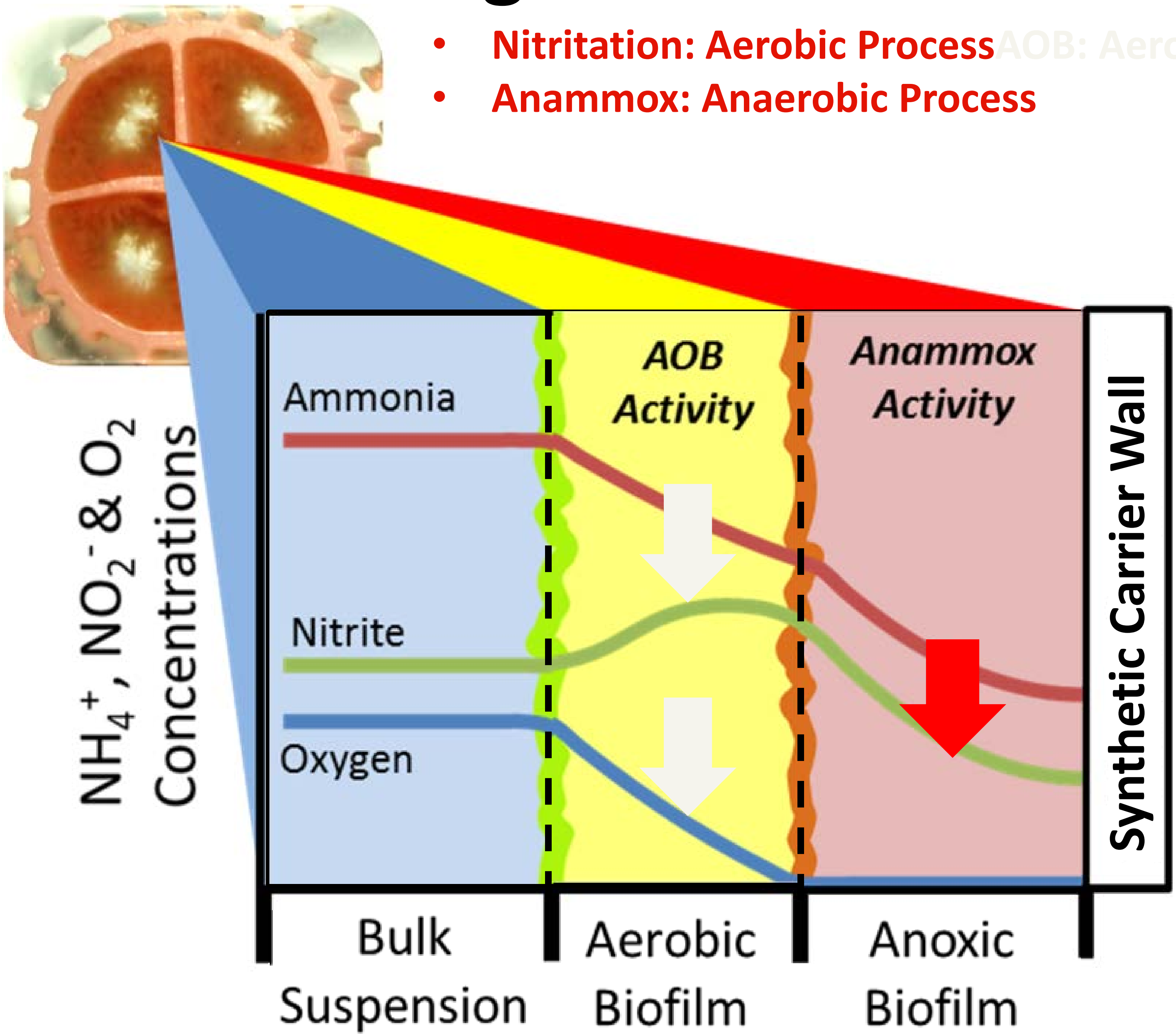
Ave Alkalinity:
1200 mg/L $CaCO_3$

Residual Alkalinity:
200-300 mg/L $CaCO_3$

→ Achievable Nitrogen removal 60-70%

The Moving Bed Biofilm Reactor

- Nitritation: Aerobic Process
- Anammox: Anaerobic Process



Anammox MBBR Start Up

- **Two stages:**

1. **Establish Ammonia Oxidizing Bacteria (AOB) biofilm layer**

2. **Establish Anammox Bacteria in the inner biofilm layer (anaerobic)**

Anammox MBBR Pilot

- **<u>Operating Conditions</u>**
  - **HRT*:** 1.5 day
  - **Aeration Mode:** DO Control
    - High DO Set Point = 2.00 mg/L
    - Low DO Set Point = 1.99 mg/L
    - Low Ammonia Set Point = 30 mg/L (Varied*)
  - **Total Airflow:** 6 cfm
  - **Target Temperature:** Ambient Temp.~ AT-3. (**since Aug. 19th 2013**)
  - **No pH Control (since March 08th 2014)**
  - **~40 % Fill with Kaldnes K1 (since June 26th 2013)**

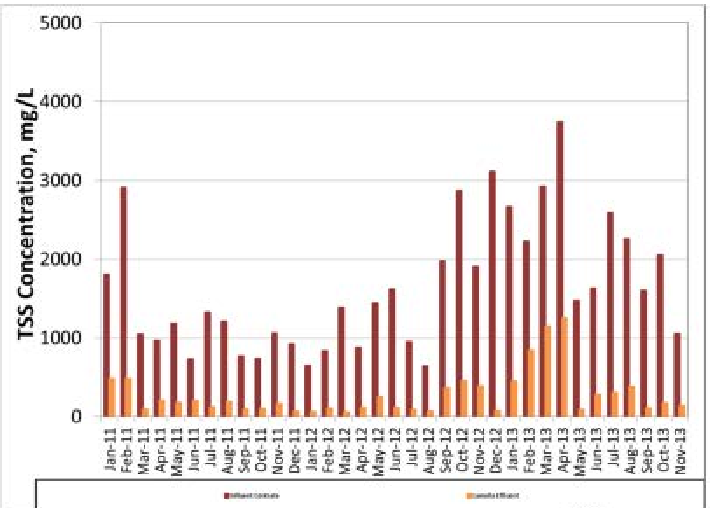
Note:

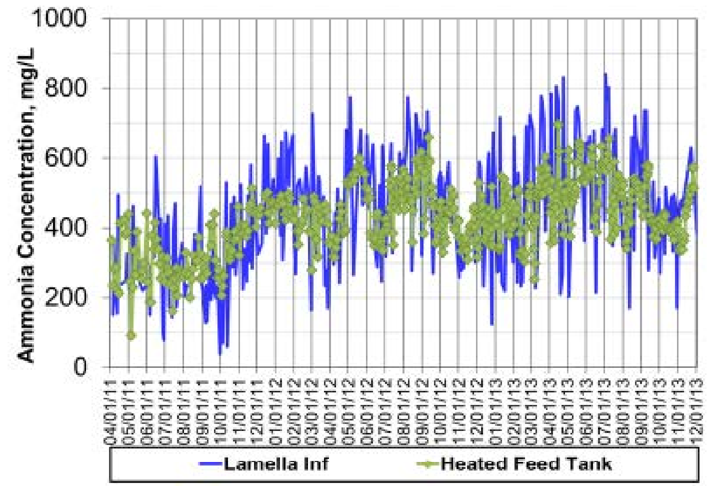
***Low Ammonia Set Point is adjusted based on daily Influent NH_3-N**

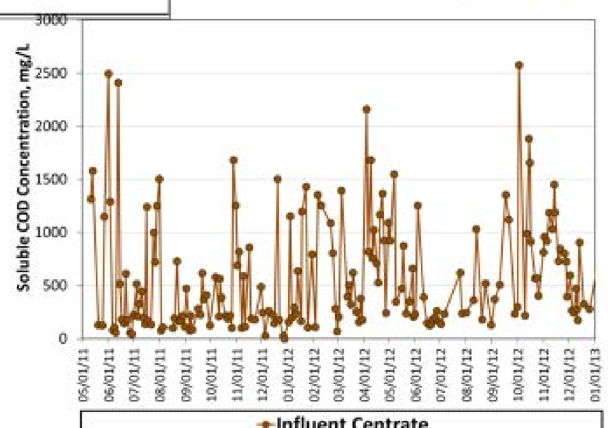
Lessons Learned

Pre-Treatment:

- **Solids Separation Unit Required: Plate Settler**
- **Flow Equalization may be considered**



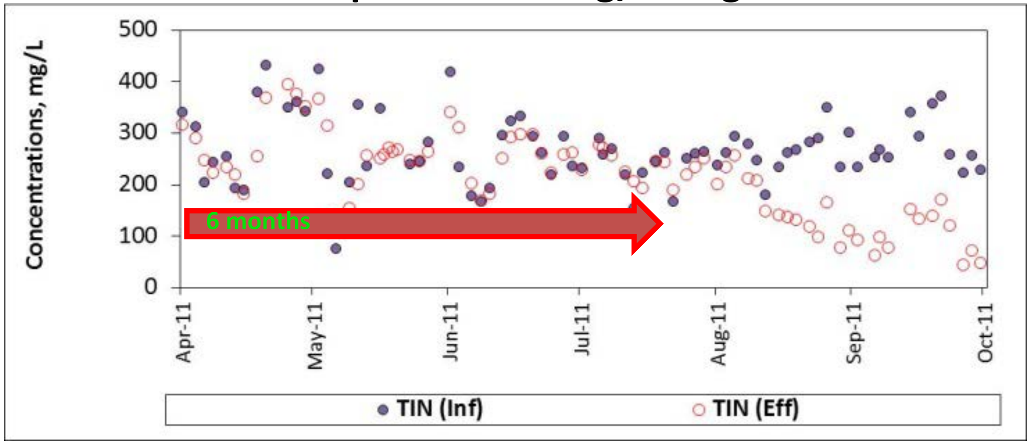




Lessons Learned

Start-up:

- **The pilot took 6 months to establish anammox activity without anammox seeding**
  - **Immediate effort was to initiate biofilm attachment on carriers by growth of AOB**
  - **Subsequently, increase load to stimulate rapid growth of a thick film which will support the anammox bacteria in the inner layers**
  - **Alternate Option: Seed reactors with carriers with established biofilm of AOB and Anammox bacteria**
- **Nitrite inhibition of anammox bacteria is not as restrictive as initially reported in the literature – "growth phase" at the pilot was evident at nitrite concentrations up to 90-100 mg/L range in the MBBR reactor**

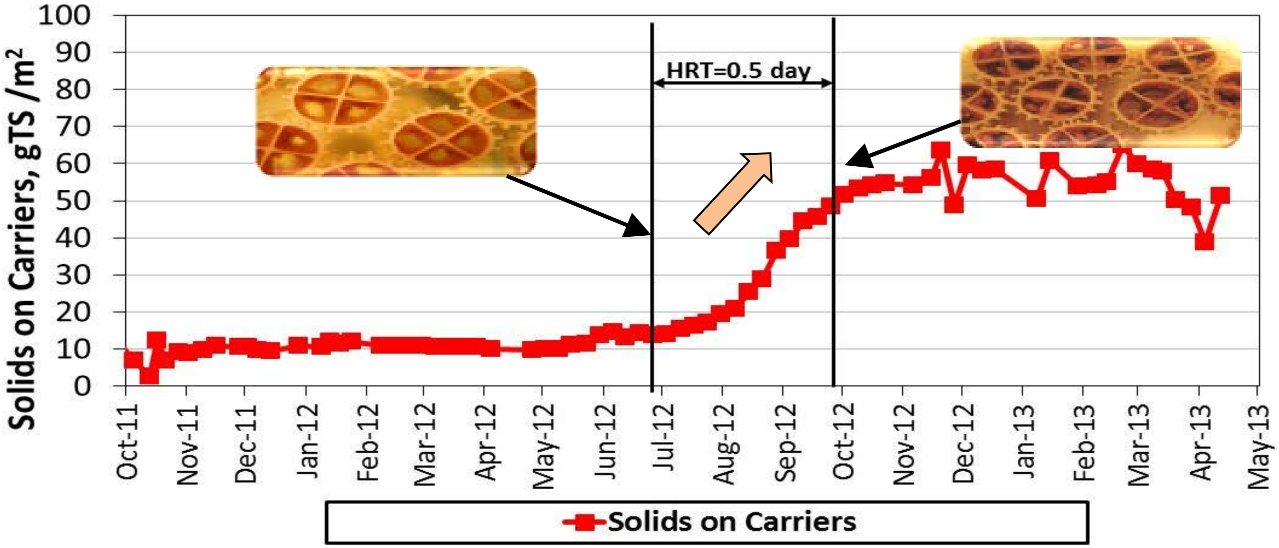


Lessons Learned

Start-up:

Once AOB activity on the biofilm is established, an aggressive operating mode is recommended (low HRT)

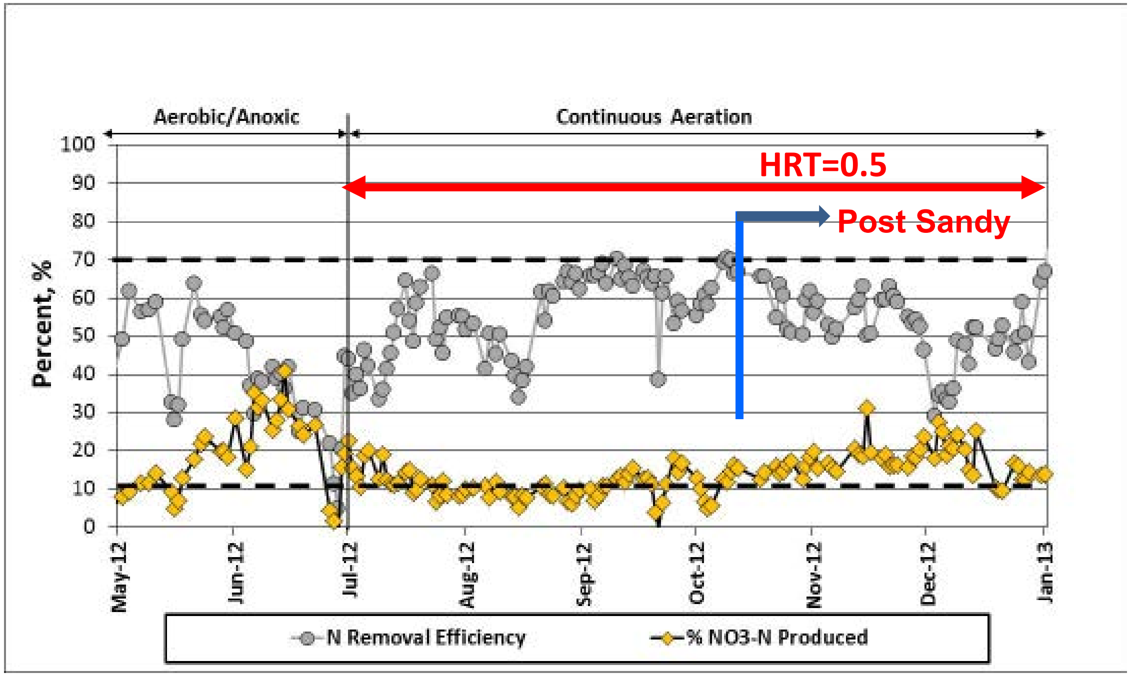
- **Wash out of suspended growth promotes a thick biofilm**
- **Oxygen consumption rate localized at biofilm**
- **Establishes anammox dominance**
- **Control of NOB activity becomes achievable**



Lessons Learned

Process Optimization:

The maximum nitrogen removal is limited by the amount of alkalinity in the centrate.
Adjusting only the temperature to the optimum of 33°C, the maximum nitrogen removal achieved was between 60 -70%.
Once a thick biofilm was established on the carriers, continuous aeration was practiced to maintain a DO concentration of 1-2 mg/L.
Higher nitrogen removals would require alkalinity addition.

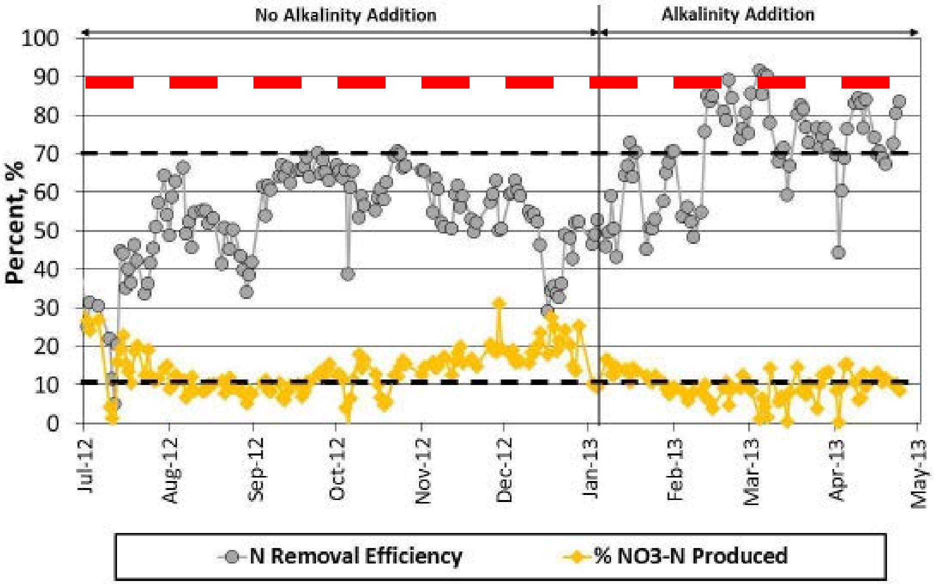


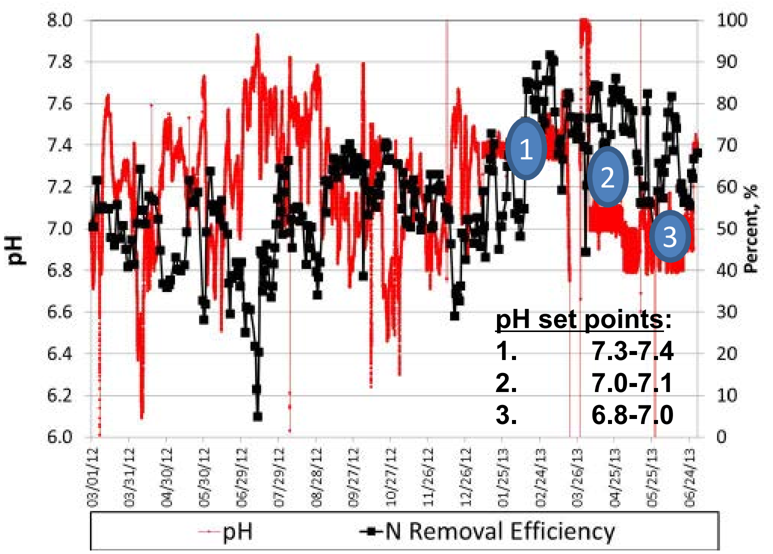
Lessons Learned

Process Optimization:

To improve nitrogen removal close to the maximum stoichiometric value of 88%, continue operation at the optimum temperature but adjust operation by:

- **Supplementing the alkalinity available**
- **Controlling the pH within a narrow band**
- **Maintain a surface loading within 1 to 3.5 gN/m^2-d**





Lessons Learned

Process Optimization:

Note:

A = pH set point : 7.3 (low) and 7.4 (high)

B = pH set point : 7.0 (low) and 7.1 (high)

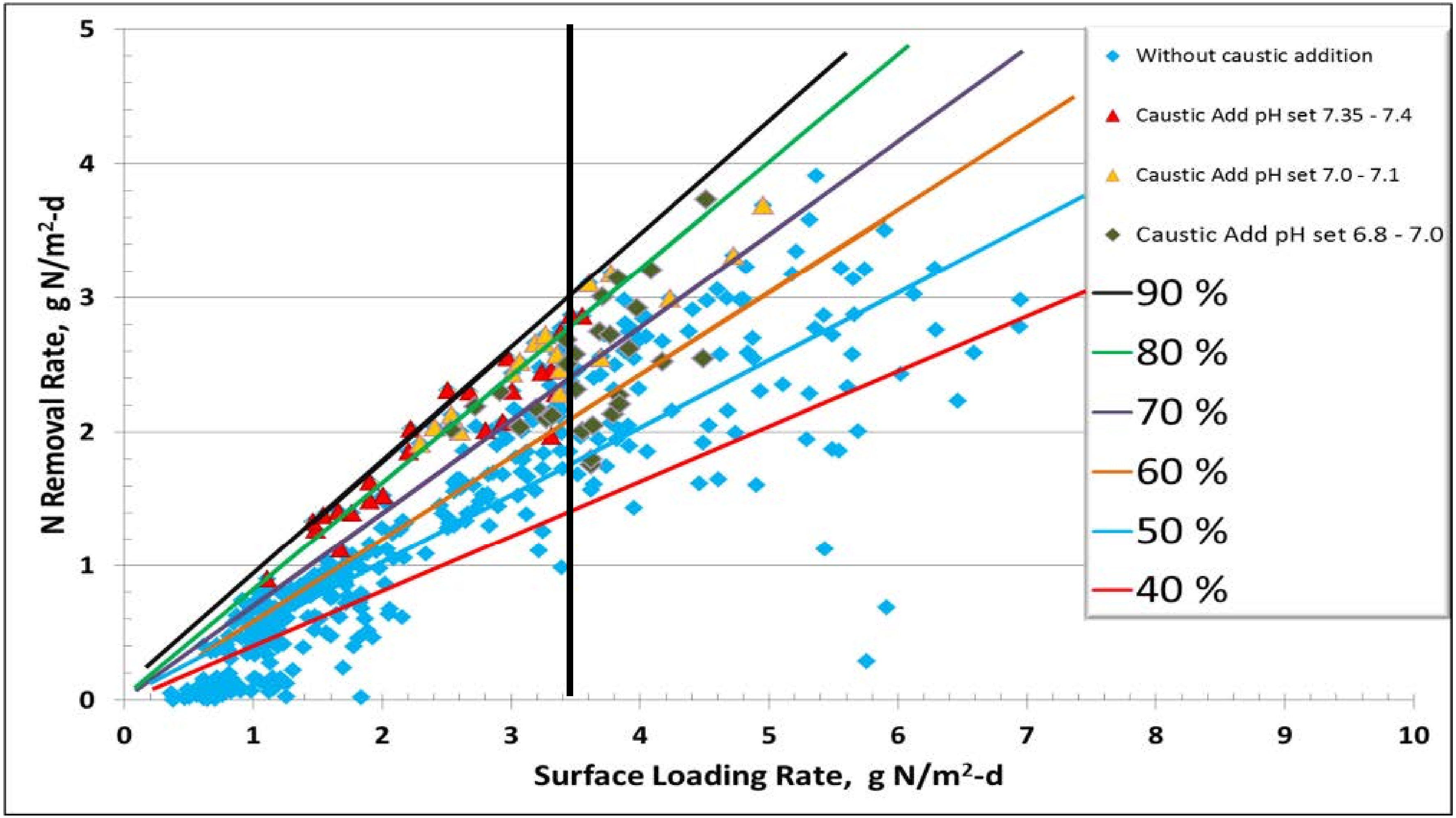
C = pH set point : 6.8 (low) and 7.0 (high)

D = pH set point : 6.9 (low) and 7.0 (high)

Online Reactor pH: Jan. 2013 – Dec. 2013

Lessons Learned

Process Optimization:

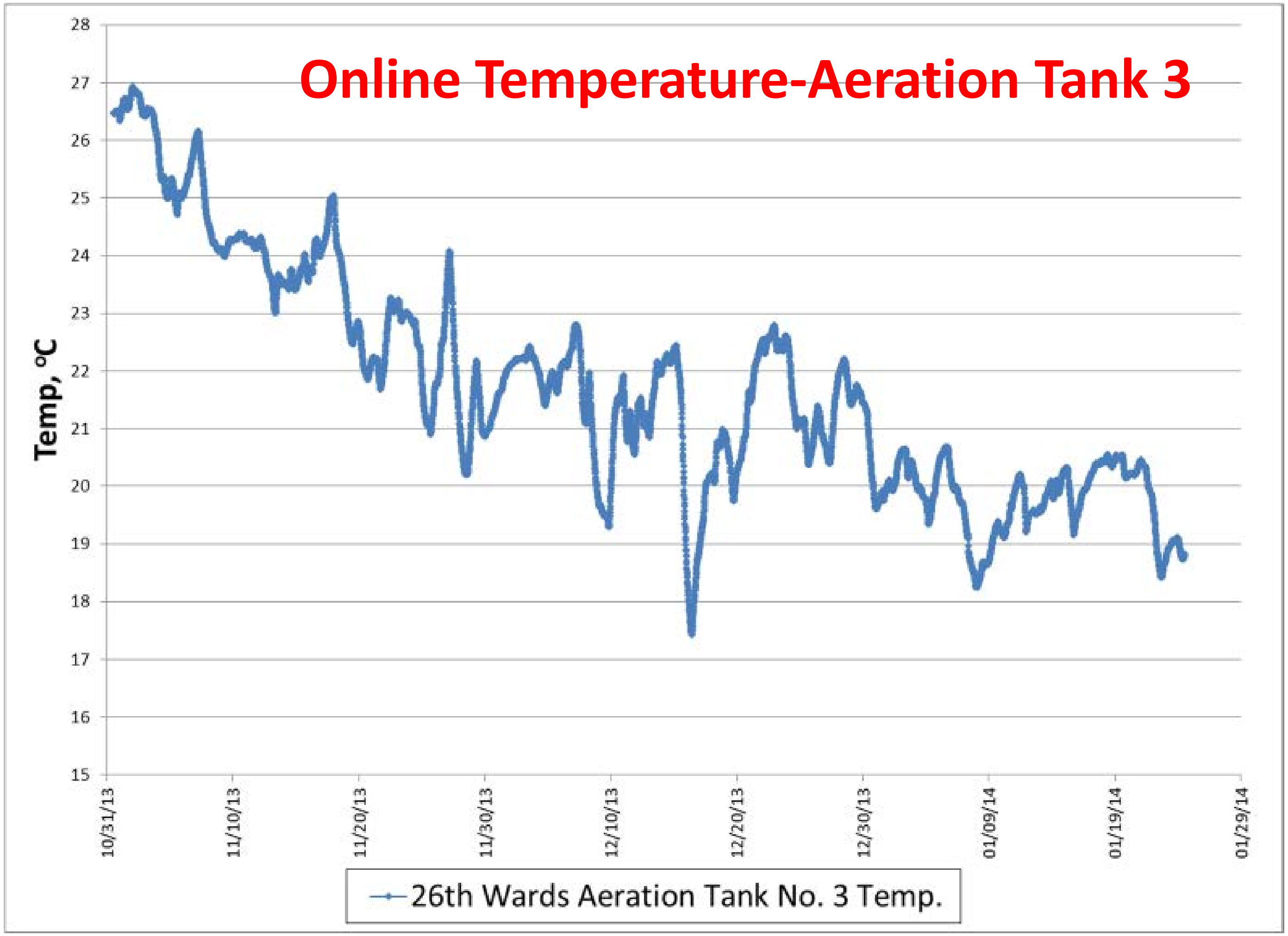


Sept 2011 – June 2013

Surface Loading vs. Removal Rates

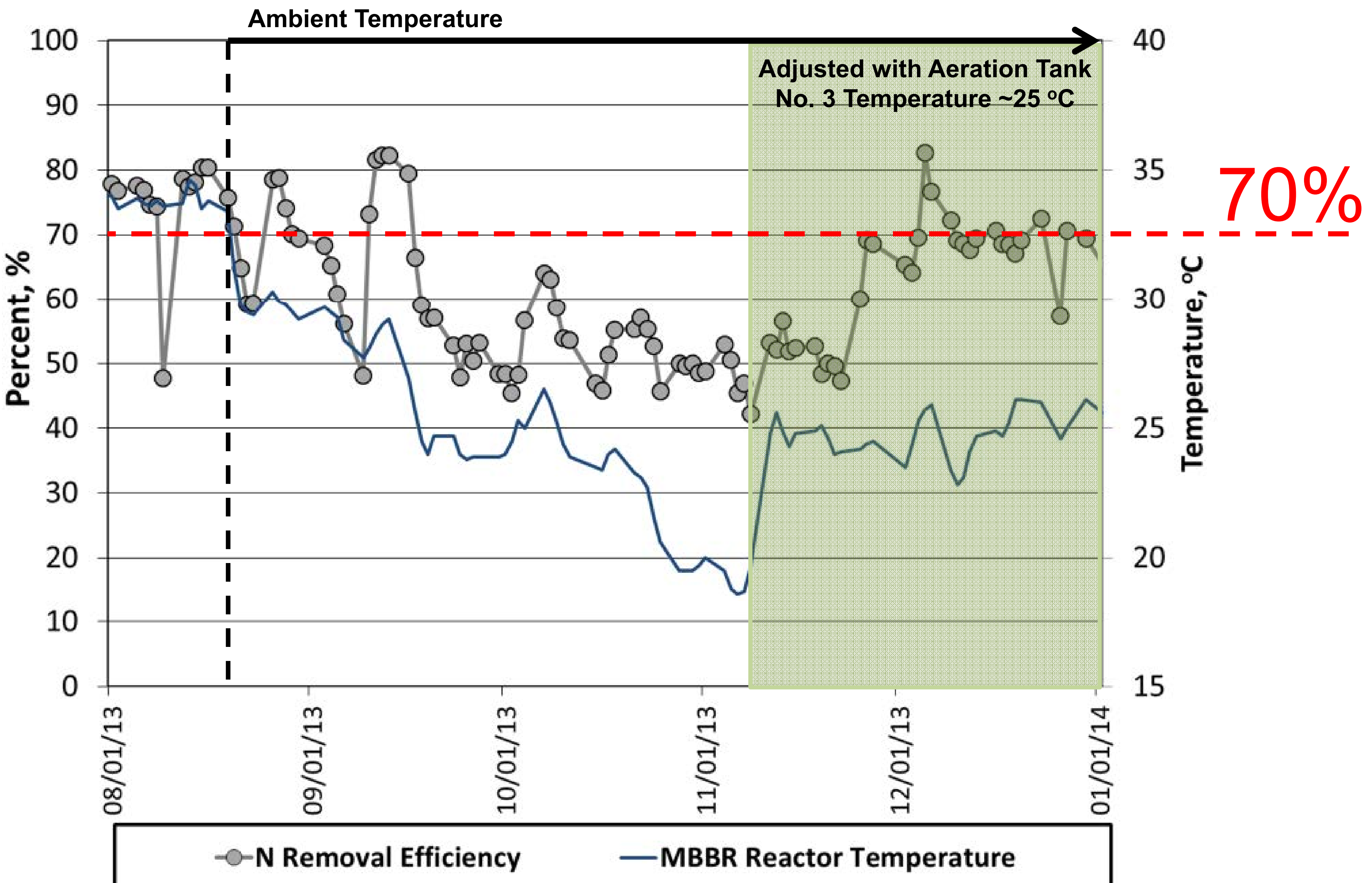
Lessons Learned

Process Optimization:



Lessons Learned

Process Optimization:



Lessons Learned

Some Additional Issues:

- To have provisions in design for NO-FLOW situation
- To be able to withstand occasional polymer overdoses
- Aeration System design to include capabilities to handle periodical COD $_{Solub}$
- Anammox bacteria once es resilient

In Conclusion

- **Anammox is a very viable, cost – effective and robust process- 100+ installations worldwide**
- **Substantial savings:**
  - **0% external organic carbon required**
  - **60% reduction in aeration requirements**
  - **90% reduction in sludge production**
  - **50% reduction in alkalinity**
- **Major entities making anammox available in the US:**
  - **World Water Works: Demon® -SBR Technology**
  - **Kruger-Anox Kaldnes: Anita Mox®- MBBR Technology**
  - **Clear Green (Degremont): SBR Technology**