Emerging Knowledge and Understanding of Sidestream BioP Processes

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Definitions

• These are not quite unified:
  – (Enhanced) Biological Phosphorus Removal (EBPR) or Bio-P or BioP
  – SSEBPR or SSR or S2EBPR or SBPR etc: Different names for sidestream BioP configurations
• PAO: (Poly)Phosphate Accumulating Organism
• GAO: Glycogen Accumulating Organism
• dPAO and dGAO: denitrifying PAO and GAO
BioP Process Fundamentals
Gly: Glycogen
PHA: Polyhydroxyalkanoate
PP: Polynosphosphate
OP: Orthophosphate

BioP Process Configurations

Mainstream BioP

Johannesburg

University of Cape Town
(Similar to VIP)

Zones:  
- Anaerobic
- Anoxic
- Aerobic

Sidestream BioP

MLE with RAS Fermentation

Westbank

Slide courtesy of Patrick Dunlap
This paper traces the history of EBPR from first observations in plants not specifically designed for it and not having specific anaerobic zones to flowsheets where the anaerobic zone up front became enshrined in the culture. However, presently overwhelming evidence point to coincidences that led to a narrow interpretation of only those results that fitted the perceived optimal design of having an anaerobic zone with all the primary effluent passing through it and ignoring other observations of plants removing phosphorus even without a specified anaerobic zone. This led to the revaluation of all options in scientifically sound way and to the research which is presently being carried out at Northeastern University under WERF Project U1R13.
Rethinking the Mechanisms of Biological Phosphorus Removal

Figure 2 Pilot plant at Daspoort Pretoria WWTP where BPR was observed in 1972
Rethinking the Mechanisms of Biological Phosphorus Removal

Flow scheme for the Westbank (now Westside) plant in BC, Canada
Sidestream BioP Configurations

Rethinking the Mechanisms of Biological Phosphorus Removal: Main Conclusions

1. PAOs must pass through a truly anaerobic zone with very low ORP (around -300 mV). Most conventional plants do not achieve this because:
   a. Overmixing
   b. Excessive primary effluent
   c. Lack of plug flow

2. Anaerobic zone should be designed with flexibility

3. Possibility to select for *Tetrasphaera*

Accumulibacter vs. Tetrasphaera

• Unlike Accumulibacter, all known Tetrasphaera have the ability to denitrify nitrite and/or nitrate
• Tetrasphaera can ferment complex organic molecules
• Tetrasphaera may benefit from deeper anaerobic conditions and longer retention times

Accumulibacter vs. Tetrasphaera

• Conventional BioP may have selected for Accumulibacter because of readily available VFA
• In sidestream configurations, Tetrasphaera and Accumulibacter may co-exist
• More diverse population may lead to better process stability
• Maybe lead to more dPAO activity
PAO GAO Competition

- Glycogen Accumulating Organisms (GAOs)
  - Compete for VFA in the anaerobic zone
  - Do not uptake phosphorus in aerobic zone
- Can predominate over PAOs
  - High temperature
  - Long SRT
  - Low pH
  - VFA in excess of what is utilized by PAO
Selection of PAO over GAO

PAO will outcompete GAO in the sidestream reactor, seems to be due to PAO lower decay rates than GAO under extended anaerobic conditions.
Advances in BioP modeling

• Current models do not properly predict the performance of sidestream BioP processes
  – i.e. Full-scale processes have excellent performance, when the model shows it should not

• New models include:
  – PAO/GAO competition for substrate
  – Ability for PAO to ferment (aka Tetrasphaera)

In part because nitrification (aerobic zone) is typically the limiting factor for design, the size of the anaerobic zone has traditionally been too small.

Small anaerobic zone leads to incomplete rbCOD fermentation.

A larger anaerobic zone will promote hydrolysis of influent sbCOD.
• RAS fermentation offers several advantages
  1. protection from temperature shocks and reduced anaerobic retention time during wet weather
  2. possible GAO suppression
  3. possible decoupling of competition of PAOs and denitrifiers for influent rbCOD

• **BUT** lose benefit of influent VFA if anaerobic zone is bypassed

**Importance of anaerobic SRT**
Summary

Although there is some disagreement on how to achieve BioP stability, all parties agree that:

Biological phosphorus removal is not an inherently unstable process, there is just more to learn.
(aka we are doing it wrong)
Side-Stream Enhanced Biological Phosphorus Removal As A Sustainable And Stable Approach For Removing Phosphorus From Wastewater

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Sidestream BioP Configurations

In response to low influent VFA, nearly 30 Danish plants have implemented sidestream RAS fermentation (Vollertsen et al., 2006)


Recent Research

TITLE: OPTIMIZATION AND DESIGN OF SIDE-STREAM EBPR PROCESS AS A SUSTAINABLE APPROACH FOR ACHIEVING STABLE AND EFFICIENT PHOSPHORUS REMOVAL

Northwestern University and Cornell
Varun N. Srinivasan, Guangyu Li, Dongqi Wang, Nicholas B. Tooker, Zihan Dai, Annalisa Onnis-Hayden, April Z. Gu


Northwestern University
Paul Roots, Fabrizio Sabba, George Wells
Recent Research
HRSD BNR Pilot

A-stage HRAS

Influent

Air

RAS WAS

A-stage WAS Fermentation

Sidestream Bio-P Rector

RAS Split

Partial Denitrification/ Anammmox MBBR

Acetate Addition

Effluent

B-stage Nitrogen Removal

Anaerobic Zone

CSTR 1 CSTR 2 CSTR 3 CSTR 4

Air

RAS WAS
Motivations for Sidestream Bio-P with Shortcut Nitrogen Removal

- Achieve bio-P with low influent rbCOD
  - Shortcut N removal dictates low influent COD
  - A/B process - little to no VFA from A-stage
- Possible selection for dPAO
  - Couple denitrification and phosphorus removal
dPAO and Shortcut Nitrogen Removal

- Get P and N removal together with the same carbon
- Possibility for nitrite accumulation
  - Partial nitrification: dPAO provide nitrite sink
  - Partial denitrification: some dPAO and dGAO may reduce nitrate to nitrite
- Are dGAO good or bad
dPAO and dGAO Working Together

Enhanced post-denitrification without addition of an external carbon source in membrane bioreactors

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Stored glycogen was possibly used as an internal carbon source for denitrification in a post-denitrification system when combined with bioP.
Post-anoxic denitrification driven by PHA and glycogen within enhanced biological phosphorus removal

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Advancing post-anoxic denitrification for biological nutrient removal

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Partial Denitrification/
Anammox MBBR

A-stage HRAS

Influent

Air

RAS WAS

A-stage WAS Fermentation

Sidestream Bio-P Reactor

RAS Split

CSTR 1 CSTR 2 CSTR 3 CSTR 4

Air

RAS WAS

Effluent

Acetate Addition

HRSD BNR Pilot
High effluent nitrite associated with sidestream BioP operation
Nitrite accumulation during air off times

1 hour intermittent aeration cycle
Utilizing noticeably less supplemental carbon per N removal than should be theoretically required.
VIP 2\textsuperscript{nd} Anoxic Profile Data provided further observation of lower than expected methanol demand.

COD/N Ratio (g COD/g N)

\[ \text{MeOH C:N Ratio 4.8} \]

\[ \text{NOx Removal (mg NOx-N/L)} \]

- End. Denite from increase in NH4
- Methanol Assoc. Denitisation at 4.8
- "Mysterious" Denitisation

(d) PAO/GAO Activity Test

- **Anaerobic**
  - OP (mg P/L)
  - COD (mg/L)

- **Aerobic**
  - NO2-N
  - NO3-N
  - NH4-N
  - DO

- **Anoxic**
  - filtered-COD (mg/L)

Graph showing changes over time (min):
- OP (mg P/L)
- COD (mg/L)
- NO2-N
- NO3-N
- NH4-N
- DO
Summary

• Benefits of Sidestream BioP Processes
  o Increases reliability of Bio-P when influent VFA is low
  o Combines hydrolysis, fermentation, and enrichment of PAO
  o Selection of PAO over GAO
  o Possibly enrichment of *Tetrasphaera* over *Accumulibacter*

• Although biological phosphorus removal and RAS fermentation are not new processes, there is still a lot to learn
Questions

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