MORE EFFICIENT MECHANISMS OF BIOLOGICAL PHOSPHORUS REMOVAL

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AGENDA

• History of EBPR
• Proposed mechanisms
• Alternative flowsheets
• Possible limitations of existing practices
• Problems with modeling alternative flow sheets
• Proposed remedies
SOME EARLY OBSERVATIONS

- Hi-rate no nitrification
- 30 to 40 h in Stripper
- Supernatant high in P treated with lime
- All primary effluent to aeration basin
- RAS thru deep anaerobic conditions

Phostrip Process

Levin et al (1975)
MIXED LIQUOR FERMENTER (MLF)

- Fermenter resulted from basin configuration and not deemed important
- Excellent phosphorus removal resulted
- Note orthophosphates profile through plant
- Performance could not be replicated in laboratory
- Barnard suggested organisms (PAO) should pass through anaerobic phase with low ORP which triggered EBPR
- Suggested Phoredox process by adding anaerobic zone up front
PHOREDOX (AKA AO) CONCEPT OF PASSING ALL PRIMARY EFFLUENT THROUGH ANAEROBIC ZONE

Construction Started October 1974
Flow Diagrams Published July 1975 as Phoredox
Renamed AO, A2O, April 1976
FUHS & CHEN (1975)

- Studied the Pho-strip process
- Suggested PAO take up P when aerobic, use that energy to take up VFA in anaerobic zone
- Identified PAO as Acinetobacter
- Mechanisms further developed by Comeau & Wentzel

Problem – not always sufficient VFA in primary effluent
VFA FROM FERMENTERS

A. STATIC FERMENTER
- Raw Influent
- PST
- VFA
- Anaerobic Zone
- Thickener
- Optional Recycle
- To Digesters

B. ACTIVATED PRIMARY
- Raw Influent
- VFA
- Anaerobic Zone
- To Digesters

C. FERMENTER THICKENER
- Raw Influent
- PST
- VFA
- Anaerobic Zone
- Fermenter
- Thickener
- To Digesters
VIEW OF KELOWNA B.C.

Anaerobic Zones

Fermenter

PST
FURTHER STUDIES IDENTIFIED CANDIDATUS ACCUMULIBACTER AS THE DOMINANT PAO

- “...it was incorrectly considered that PAOs were of the genus Acinetobacter.... or Tetrasphaera” by Fuhs & Chen and others*

- “More recently, culture-independent methods have shown Accumulibacter phosphatis ... is a PAO which can be grown in enriched cultures ...”*

- “For the purpose of design it will be considered that anoxic P uptake is not significant”*

*IWA – Biological Wastewater Treatment - Principles, Modeling and Design  Henze et al
Westside Kelowna BC (Westbank)

**TN** < 6 mg/ℓ
**BOD** < 5 mg/ℓ
**TSS** < 2 mg/ℓ
**TP** < 0.15 mg/ℓ
WESTBANK WWTP

Bioreactor Profile
Phosphorus by Zone

Tetrasphaera can denitrify

Note P uptake in Anoxic Zone
MIX OF ORGANISMS IN WESTSIDE PLANT

FISH Image from WR WWTP Sludge with EUB mix (all bacteria) Shown in Green, Tet2-174 (Tetrasphaera clade 2B) in Orange, and Tet3-654 (Tetrasphaera clade 3) in Red.

Dunlap et al 2015
PHOSPHORUS REMOVAL WITH SIDE-STREAM FERMENTATION

Iowa Hill CO plant – From Chris Maher


Effluent Ortho P mg/L

To FC

RAS
Aerobic not in use

AX

To FC

RAS
Aerobic

Sec Clr  BAF  Flash Mix  Rxn Chamber  Densadeg  Filtered
CAROUSEL PLANT HENDERSON NV
60 ML/D – UPGRADED TO BNR

Switching off a mixer in the anaerobic zone resulted in In-plant Fermentation

Ortho-P for May 2010

Phosphorus (mg/L)
POSSIBLE LIMITATIONS OF EXISTING CONFIGURATION

• Were we perhaps selecting mostly for species of *Accumulibacter* that needed a supply of acetic & propionic acid

• They could have prevailed in standard anaerobic zones since conditions were not ideal for fermenting species like *Tetrasphaera*

• *Tetrasphaera* can ferment glucose and amino acids and other higher carbon forms and store phosphorus – Nguyen et al

• They actually produce VFA that allow a population of *Accumulibacter* to grow alongside them

• They can denitrify under anoxic conditions

• Why did we not grow them – not deep enough anaerobic conditions
WHY DID WE MISS IT?

- It appears that we need an ORP of <-300 mV – most anaerobic zones struggle to get -150 mV
- Impossible to achieve with nitrates or DO anywhere
- Most plants were over-mixed with turbulent surfaces that entrained air which prevented deeper anaerobic conditions
- Standard mixing energy 0.6 hp/kcf – need 0.08 hp/kcf (huge saving in energy)
- Too much air entrained in primary effluent
- Too much primary effluent per se which may contain very little VFA thus diluting the content of the anaerobic zone and reducing the anaerobic SRT
ORP IN ANAEROBIC ZONES

Anaerobic Zone

Conventional Anaerobic Zone

Side-stream Fermenter

ORP (mV)

0

-100

-200

-300

Accumulibacter

Accumulibacter

Tetrasphaera

VFA

Glucose

Galco
MODIFIED WESTBANK PROCESS

Aim for 1 to 2 day SRT in anaerobic zone (12-18 h with fermentate)
WHEN NO PRIMARIES USE MIXED LIQUOR FERMENTER – OLATHE KS, SACRAMENTO CA

MLF mixed only once per day or less often
Guideline SRT of MLF approximately 2 days

And here I would like to thank Kevin Clark from Pinery Water for showing us the way
The Occurrence of Enhanced Biological Phosphorus Removal in a 200,000 m3/day Partial Nitration and Anammox Activated Sludge Process at the Changi Water Reclamation Plant, Singapore – Cao et al, 2016

- Step-feed nitrification/denitrification
- Achieve EBPR – Denite PAO
- Presence of Accumulibacter & Tetrasphaera
Process Modeling
**TETRASPHAERA IMPACTS MODEL BEHAVIOR**

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<th>Fermentation With Tetrasphaera</th>
<th>Anaerobic Process</th>
<th>Aerobic Processes</th>
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<tr>
<td></td>
<td>Tetrasphaera</td>
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<td>Poly-P</td>
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<td>COD</td>
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DRAWBACKS OF PARAMETER ADJUSTMENT

- Coarse parameter adjustment can offer insight into current model shortcomings but; the adjustment of many variables likely results in over adjustment & compensation, calibration is only possible if all relevant mechanisms are incorporated, and it will provide little predictive power when extrapolating beyond specific scenario.

- We are working with Northeastern University towards recommendations for better modeling sidestream EBPR as part WERF study

- Refer to WWTmod 2016 paper for more information;

  Rethinking EBPR: What do you do when the model will not fit real-world evidence?
CONCLUSIONS

• Shortcomings of design resulted in selection for limited variety of PAO, mainly those that need a supply of SCVFA

• Deeper anaerobic conditions are needed to cultivate fermenting PAO such as Tetrasphaera

• These organisms can also take up phosphorus under anoxic conditions

• Limit HRT in anaerobic zone by reduced primary effluent discharge and/or reduced RAS flow

• Wastewater characteristics irrelevant

• Modeling for alternative species of fermenting PAOs
Thank you all for coming
DISCUSSIONS