Opportunities for improved nutrient removal and recovery from municipal wastewater

Nutrient removal practice and developing trends

Damian J. Kruk, Tanner R. Devlin, Jan A. Oleszkiewicz

Webinar, October 22nd; 2015
1. Modified Ludzcak-Ettinger (MLE)
   - TN removal
   - Defined Aerobic and Anoxic zones
2. CAS Extended aeration

- E.g. oxidation ditch
- Only nitrification
- SRT > 10d
3. Carousel oxidation ditch

- Both processes occur in the same tank
  Simultaneous Nite/Denite
- Extended SRT required
Biological P removal
EBPR: PAO metabolism

PE → Anaerobic → Aerobic → Effluent
Biological P removal
EBPR: PAO metabolism

**Anaerobic**

**Aerobic**

$\text{PO}_4^-\text{P}$

**PE**

**Effluent**

October 22nd, 2015
Nutrient Removal and Recovery Webinar
Canadian Water Network
University of Manitoba
Biological P removal
EBPR: PAO metabolism

P removed in WAS
Biological P removal

EBPR: PAO metabolism

EBPR needs VFA!

P removed in WAS

Anaerobic

Aerobic

PE

Effluent

PO₄-P
BNR with EBPR
Simultaneous N and P removal

Influent → Ax → Aer → S.C. → Effluent

NOx recycle

RAS → WAS
BNR with EBPR

- Reduce ORP in Anaerobic zone

Influent → Ana → Ax → Aer → S.C. → Effluent

NOx recycle

RAS

NOx!!!

WAS (containing P)
BNR with EBPR

- Reduce ORP in Anaerobic zone

Influent

\[ \text{Ax} \quad \text{Ana} \quad \text{Ax} \quad \text{Aer} \]

NOx recycle

RAS

WAS (containing P)

Effluent
BNR with EBPR

- Reduce ORP in Anaerobic zone
- Provide sufficient VFA

Influent → Fermenter (VFA) → Ana → Ax → Aer → S.C. → Effluent

RAS → NOx recycle

WAS (containing P)
Chem. P removal: Coagulation

• Al and Fe salts: $\text{Al}^{3+}$; $\text{Fe}^{3+}$
• Small footprint
• Easy to retrofit
Chem. P removal: Coagulation

- Al and Fe salts: Al$^{3+}$; Fe$^{3+}$
- Small footprint
- Easy to retrofit

... but:
- Higher sludge production
- High chemical costs
- Prevents recovery from liquid phase
Ferric dose for P precipitation

Data Dr S Hermanowicz, UC Berkeley

Effluent P (mg/L)

Fe:P (mol:mol)

Lab data pH 6.5
Lab data pH 6.8
Lab data pH 7.2
Lab data pH 8
Full Scale data
Ferric dose for P precipitation

Target P < 0.1 mg/L

Ferric dose skyrockets
EBPR vs + Chem. P

Data Dr S Hermanowicz, UC Berkeley

Effluent P (mg/L)

Fe:P (mol:mol)

October 22nd, 2015 Nutrient Removal and Recovery Webinar
EBPR vs + Chem. P

Data Dr S Hermanowicz, UC Berkeley

EBPR to the limit of carbon + Chem. P for the reminder
Key issues of nutrient removal

1. Oxygen demand

- DN is advantageous
  - Reduction of oxygen demand
    - 1 kg NO$_3$-N removed = 2.9 kg O$_2$ saved
  - Recovers Alkalinity
Key issues of nutrient removal

1. Oxygen demand

- DN is advantageous
  - Reduction of oxygen demand
    - 1 kg NO₃-N removed = 2.9 kg O₂ saved
  - Recovers Alkalinity
- Sidestream PN/Anammox
Biological N removal

Nitrification
Autotrophic

NO$_3^-$

25% O$_2$

NO$_2^-$

75% O$_2$

NH$_4^+$

4.5 kg O$_2$/kg

40% carbon

NO$_2^-$

60% carbon

N$_2$

2.9 kg COD/kg

Denitrification
Heterotrophic
PN/Anammox

- $\text{NO}_3^-$
  - 25% $\text{O}_2$
  - 40% carbon

- $\text{NO}_2^-$
  - 40% carbon

- $\sim 60\% \text{ NO}_2^-$
  - 45% $\text{O}_2$

- $\text{NH}_4^+$
  - AOB

- $\text{N}_2$ and $\sim 10\% \text{ NO}_3^-$
  - AMX
NO₃⁻ - NO₂⁻ - 40% carbon

NH₄⁺ — 60% NO₂⁻

AOB

25% O₂

45% O₂

40% carbon

AMX

Savings:
• 55% O₂ demand
• 90% carbon demand

N₂ and ~10% NO₃⁻
Key issues of nutrient removal

2. Carbon demand

- Approx. requirements
  - 6 g bCOD/g N
  - 20 g bCOD/g P

<table>
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<tr>
<th>In</th>
<th>Out</th>
<th>Need: 280 mg bCOD/L</th>
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<td>35</td>
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<td>5.5</td>
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Missing: 33 mg bCOD/L

Have: 380*0.65 = 247 mg bCOD/L
Key issues of nutrient removal

2. Carbon demand

Possible improvements:

- Fermentation of PS: + 34 mg bCOD/L (VFA)
- Sidestream PN/Anammox: + 47 mg bCOD/L
- Sidestream P recovery: + 80 mg bCOD/L
- Simultaneous Nite/Dinite
- Supplemental COD
- Chem. P removal
Key issues of nutrient removal

2. Carbon demand

Possible improvements:

- Fermentation of PS + 34 mg bCOD/L (VFA)
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In many cases fermentation is enough.
### Key issues of nutrient removal

#### 3. Limit of technology

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Key issues of nutrient removal

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rDON is the absolute TN limit (1 to 2 mg/L)
High costs of low limits

Total present worth for a 38 MLD WWTP

![Graph showing costs for different TN and TP limits.]

- No N, P
- The first 70 t P/a costs US $40 M
- TN 8 TP 0.1-03
- TN 4-8 TP 0.1-03
- TN 3 TP <0.1
- The last 1.1 t P/a costs US $100 M

from JB Neethling, HDR, 16 May, 2012, WERF CBP STAC Workshop

October 22nd, 2015
Opportunities for improved nutrient removal and recovery from municipal wastewater

Thank you
Opportunities for improved nutrient removal and recovery from municipal wastewater

Nutrient Recovery and Reuse: Practice and Developing Trends

Tanner R. Devlin, Damian J. Kruk, Jan A. Oleszkiewicz

Webinar, October 22nd, 2015
Recovery and reuse practice

Should we recover or reuse nutrients?

If

1. Recognized ROI; or
2. Mandated

Then yes!

Fluctuating market:

- Phosphorus = $0.75/kg P
- Ammonium = $0.20/kg N
- Dried biosolids = $0.15/kg DS

22/10/2015
Recovery and reuse practice

Cases

Saskatoon BNR facility (85 MLD)
- Crystallizer + P stripping from WAS
- 7 to 10 year payback

Miami-Dade HPO facility (541 + 426 MLD)
- Crystallizer on centrate (planned)
- $NPV_{(20y)} < 2x$ existing operations and ferric dosing!

New York 26th Ward Centrate facility (4.5 MLD)
- Ion-exchange based ammonium capture and extraction
- Promising, but lost bid in 2014 to anammox removal
Recovery and reuse practice

Nutrient targets – N

Remove or recover?

P.C. → BNR → S.C.

Gone 65%

100% 10%

Removal can be 2x less expensive than recovery

Anaerobic Digester

Dewatering

20% Sludge liquor

Biosolids 5%

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Recovery and reuse practice

Nutrient targets – P

Yields large P cache when EBPR

Biological sludge

Solids processing

Chemical sludge

P locked and unavailable?
Recovery and reuse practice

Nutrient targets – P

100% → P.C. → BNR → S.C. → 5%

45% Sludge liquor → Dewatering → Biosolids 50%

Low hanging fruit

Anaerobic Digester
Recovery and reuse practice

Nutrient targets – P in sludge liquor

Many processes:
- **Ostara Pearl**
- Multiform harvest
- PHOSNIX
- P-RoC
- Phospaq
- Crystalactor

![Diagram showing the process]

Struvite from Pearl
Recovery and reuse practice

Nutrient targets – P stripping sidestream

100% → P.C. → BNR → S.C. → WAS Stripping

50% → Biosolids

45% → VFA

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Recovery and reuse practice

Nutrient targets – P

100% → P.C. → BNR → S.C. → 5%

100% → P.C. → BNR → S.C. → 5%

45% → Anaerobic Digester → AirPrex → Dewatering

45% → Anaerobic Digester → AirPrex → Dewatering

Target P load before dewatering

45% → Anaerobic Digester → AirPrex → Dewatering

45% → Anaerobic Digester → AirPrex → Dewatering

22/10/2015
Recovery and reuse practice

Nutrient targets – P in digested sludge

1. Better solids dewaterability (> 4% improvement)
2. Reduced maintenance costs (up to 50%)
3. Reduced P recycle (up to 90%)
4. Increased revenue from fertilizer (up to 10%)

Benefits:

Digested sludge to dewatering

Air

Struvite

Digested sludge

Magnesium chloride

AirPrex

22/10/2015
Recovery and reuse practice

Nutrient targets – P

100% → P.C. → BNR or CAS+Chem → S.C. → Raw sludge incineration → Ash 95%

> 2x cost of P recovery from liquor

But largest source of P!

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Recovery and reuse practice

Nutrient targets – P in ash

- Ash
- Dried solids
- Digested and dewatered solids
- Digested, dewatered and lime treated solids
- Digested liquid solids
Recovery and reuse practice

Nutrient targets – P in ash

- Ash
- Hydrochloric acid
- Extractant conditioning
- Liquid/liquid extraction
- Calcium phosphate
- Centrifuge
- Lime
- Solid residue

PASH

22/10/2015
Recovery and reuse practice

Nutrient targets – N & P in biosolids

100% N & P

P.C. → BNR → S.C.

Want N:P 6:1 w/w!

Class A:
N:P from 1:1 to 3:1 w/w

Anaerobic Digester

Dewatering

Biosolids

5% N
50% P

22/10/2015
Recovery and reuse practice

Nutrient targets – N & P in biosolids

Source of nitrogen!
Recovery and reuse practice

Summary:

• N recovery is usually not economical
  o Cheaper to remove and produce N

• Many P recovery technologies, but…
  o Need recognized ROI
  o Recovery from liquor dominates
  o Recovery from ash pros and cons?

• Decision = f(ROI & Regulations)
Opportunities for improved nutrient removal and recovery from municipal wastewater

Thank you!
Emerging issues and research needs.

Improvement of current performance

Jan Oleszkiewicz, Damian Kruk, Tanner Devlin
Lowering ammonia load by sludge liquor treatment with decreased energy demand

- Full scale application of one-stage anammox processes in high-ammonia side-stream treatment (100 installations, none in Canada)
- $\text{NH}_3 \rightarrow \text{NO}_2$ nitrifiers
- $\text{NO}_2 + \text{NH}_3 \rightarrow \text{N}_2$ anammox
- Bioaugmentation and retention of granules or media in tank
Lowering ammonia load by sludge liquor treatment: bioaugmentation and RAS reaeration

Oleszkiewicz CIVL7930, University of Manitoba
Retrofit nutrient removal (NR) into existing systems

• Fit aerobic granular sludge (AGS) for removal of N, P into existing bioreactors

• Apply AGS to continuous flow

T Devlin, University of Manitoba 2015

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University of Manitoba

22.X. 2015 • 4
Retrofit NR into an existing system

- Biomass retention and concentration is the key
- Possible immediate CAS EA process upgrades to a BNR enabling P recovery

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Kruk & Oleszkiewicz, 2015
Retrofit NR into existing systems

Extended aeration 8 h HRT 12°C

MLE system 8 h HRT 12°C

Continuous re-oxidation of ammonia

Aerobic

NH₃-N = 2
NO₃-N = 30

Anoxic

NH₃-N = 2
NO₃-N = 12

25% less energy
Retrofit NR into existing systems

Conventional Activated Sludge; 6 h HRT

MLE 6 h HRT

Aerobic
MLSS 3 g/L

NH₃-N = 10
NO₃-N = 23

15% less energy

Vacuum degasification

MLE     6 h HRT
Final clarifier

Anoxic
Aerobic
MLSS 7 g/L

NH₃-N = 8
NO₃-N = 12

X = 7 g/L

Oleszkiewicz CIVL7930, University of Manitoba
Retrofit NR into existing systems: lagoon’s effluent

- Commercially available technologies to remove TN and TP at 1°C
Research: Chemical versus biological P removal

- There is too much P in biosolids but not enough N
- Unsure fate of P from Chem. P biosolids
  - Full scale field research needed
Principled nutrient management

• Demonstrate cost-effectiveness of nutrient recovery and nutrient trading in watershed partnerships where agricultural stakeholders would be recipients of the recovered nutrients

• Example: Great Miami River Watershed Water Quality Trading Program (2015 NACWA)
  o WWTP point sources: remove $11/kg P through BNR
  o Nonpoint source: $0.5/kg P removed through agricultural management e.g. change of farmer’s practices: conservation tillage, grassed waterways, cover crops
Research: pre-commercialization technologies

- Affordable P recovery from ash
- Reliable P removal to 0.01 mg TP/L
- Retrofit technologies for internal generation of carbon for biological P removal and denitrification.
- Improved removal of emerging substances of concern in biological nutrient removal processes
Research on pre-commercialization technology: P removal/recovery in conventional activated sludge (CAS)

- Process upgrades to promote release of P from WAS biomass stream, ahead of sludge processing.
Research: Phosphorus removal/recovery in CAS

- Application of a PhoStrip process on RAS ahead of solids treatment
Research: Pre-commercialization technology

Energy neutral facility

- PE
- HR AS
- PN/Anammox
- WAS thickening
- Sludge digester
- CHP
- Electric power and heat
- C and P removal
- N removal
- N removal
- N and P Fertilizer
- Biosolids
- PN/Amx
Thank you