Fermentation Technology to Improve Biological Phosphorus Removal

Central States WEA

James L Barnard
Contents

- Need for fermentation
- Some fundamentals
- Types of fermenters
- Fermentation of mixed liquor
- Innovative approaches
Postulation of Theory
Variations of Phoredox Process

Construction Started October 1974
Flow Diagrams Published July 1975 as Phoredox
Renamed AO, A2O, April 1976
Earlier Plants
Goudkoppies plant completed - 1975

60th Birthday of the activated sludge process

85% N removal
90% P Removal

Anaerobic Zones added 1974
Palmetto BNR plant (First in the US)

- Total N < 3 mg/L
- Total P < 1 mg/L
- No primary tanks
- Septic wastewater

Photo by Eimco
View of Kelowna B.C.
"In the presence of acetate, \textit{Acinetobacter} can form PHB, a carbonaceous reserve material which can serve as a storage form for energy for the uptake of phosphorus."

As further developed by Comeau 1986 & Wentzel (1989)
First Primary Sludge Fermenter – Kelowna B.C. 1977

Studies by Oldham & Stevens, 1984

A. STATIC FERMENTER

Raw Influent

PST

VFA

Anaerobic Zone

Optional Recycle

Thickener

To Digesters

Diagram explaining the process of a static fermenter.
Anaerobic zone as fermenter
Bio-P Organisms Store PHB and Release P in the Anaerobic Zone

- **rbCOD**
- **Influent**

**Facultative heterotrophs**

- **Influent**
- **Volatile Fatty Acids**

- **Energy**

- **Poly-P**
- **Phosphate**

These are obligate aerobes. They can store but not process VFA from outside source.

**No dissolved oxygen or nitrates**

**VFA from outside source**
Importance of Anaerobic Zone

- Serves for contact of VFA and PAO but main contribution is for fermentation of rbCOD
- Thus no DO and no nitrates
- Plug-flow or at least 3 anaerobic zones
- No high energy mixing that would enhance surface entrainment of oxygen
- Chimneys for good contact of various inflowing streams
- Recommended energy input for top entry slow mixers (LT 25 rpm) < 2 W/m³ (0.1 hp/kcf)
Various Types of Mixers

- Top entry mixers >3 times as efficient as submersibles
Mixing influent streams and directing flow to bottom

At daily maximum flow 90% of flow passes through the holes near the floor, the remainder carry scum over the top.
Estimate of VFA and rbCOD Requirements for Phosphorus Removal

At this point all rbCOD is VFA

These plants are getting fantastic results

This line is used in BNR models
Substrate for Bio P removal

- COD:P > 36; BOD$_5$:P > 18
- RbCOD:P ratio > 15
- Good VFA’s – mostly acetic and propionic
- Flat sewers, high temperature wastewater and force mains

In absence of these, need carbon supplementation:

- 70:30 mixture of acetic:propionic most efficient
- 6-8 g acetic/g P removed
- 17 g BOD$_5$/g P removed
Fundamentals of Fermentation
Simplified anaerobic fermentation

Volatile Fatty Acids Are Fermentation End Products

Acetic Acid

Propionic Acid

Complex Waste

Other Intermediates

Methane

Acid Formation

15%

15%

15%

17%

17%

13%

20%

35%

72%

15%

65%
HYDROLYSIS

- Complex organic matter to low mol. weight compounds
- Mediation of exo-enzymes excreted by bacteria
- Proteins to amino acids, carbon-hydrates to soluble sugars, lipids to long chain VFA and glycerine
- In practice is the rate limiting process
ACIDOGENESIS

- Dissolved compounds generated by hydrolysis taken up
- Excreted as simple compounds such as VFA, alcohols, lactic acid and $\text{H}_2$, $\text{CO}_2$, $\text{NH}_3$, $\text{H}_2\text{S}$
- Diverse group of organisms mostly obligate anaerobes
- Some facultative bacteria can also metabolize compounds through oxidative pathway
ACETOGENESIS

- Products of acidogenesis converted to mainly acetate, propionate, hydrogen and \( \text{CO}_2 \)
- About 70% of degradable COD converted to acetic and propionic acids and the remainder to hydrogen
Methanogenesis

Don’t go there
How much VFA?

- SCVFA/VSS from primary sludge fermentation depends on the degree of fermentation that has already taken place in the collection system.

- Reported SCVFA/VSS ranges from 0.02 to 0.085 kg/kg applied.

- However, mostly rbCOD/VSS through fermentation of primary sludge is not reported but it is important since rbCOD can be further fermented in the anaerobic zone.
Worst case – needed up to 5 days fermentation to get enough VFA.
Potential sources of carbon...

- Internal from fermentation in sewers
- Industrial contributions to plant
- Industries that have the right stuff.
  - Soft drink bottlers
  - Breweries
  - Yeast factories
  - Fruit juice canneries
- Fermentation on site
Annual VFA production in sewer system - Eagle’s Point MN

Temperature and VFA Relationship

Temperature ºC or VFA mg/L

0 5 10 15 20 25

Dec-02 Mar-03 Jun-03 Oct-03 Jan-04 Apr-04 Aug-04 Nov-04 Feb-05 May-05

Months of the Year

Temp  VFA  Relationship
On-site Production

- In the anaerobic zone
- In the stripping tank - Phostrip
- Fermenting the primary sludge
- Fermenting the primary effluent
- Fermenting some of the activated sludge
Bonnybrook WWTP 100 ML/d BNR Expansion Fermenter Supernatant VFA Fractionation

- Acetic Acid: 56%
- Propionic Acid: 30%
- Butyric Acid: 7%
- Other: 7%

Barry Rabinowitz and James L. Barnard
Types of PST fermenters
Examples of acid fermentation of primary sludge.

Complete-mix fermenter
Hold sludge for 2 to 8 days

Accumulate sludge in primaries and ferment
Anaerobic zone
to digesters

Primary tank
VFA
anaerobic zone
to digesters
Two-stage Fermenter and Thickener

- You can add elutriation water
- Primary Tank
- VFA
- Anaerobic zone
- To digester
- Anoxic

Fermenter
Thickener

Train 4
Trains 2 and 3
Fermenter
Gravity Thickener
Static Fermenter

Primary tank

Anoxic

VFA to anaerobic zone

Oversized Thickener – retain sludge for 6 to 8 days

to digesters

Westbank BC

Grimstad Norway
Fermenters Operating in Series

- VFA-rich Supernatant to Anaerobic Zones
- Elutriation Water
- Primary Solids
- Thickened Solids
- Compressed Air
- Sparger
- Air
- Fermenter #1
- Fermenter #2
- Thickened Solids
Fermenters in Parallel

Primary Solids

Compressed Air Sparger

Fermenter #1

Elutriation Water

VFA-rich Supernatant to Anaerobic Zones

Fermenter #2

Thickened Solids

Air

Thickened Solids
Fermentation of Mixed liquor or RAS
Phosphorus removal observed with this configuration

At this stage design underway with JHB Goudkoppies plant
Acid fermentation of mixed liquor

- Note that there was no anaerobic zone
- Any VFA in the feed would go for denitrification in the anoxic zone
- The configuration could not be modelled by BioWin™
Model Based Analysis

Bardenpho Pilot Plant Barnard (1974)

Soluble PO4-P

Switching off Aerators - Disneyworld

Reedy Creek, Florida

Total P, mg/L

First Few Aerators Turned Off
Trial at Kelowna B.C. Canada

Liquid level

Sludge height
Phosphorus reduced from 9 mg/L to less than 0.5 mg/L, then with post chemical treatment to less than 0.03 mg/L. Overall molar ratio to Al:P is 0.5.
Examples of Fermentation of Secondary Sludge

Truckee Meadows NV

Fermenting portion of RAS

Changed from Pho-strip to Phoredox
Switching off a mixer in the anaerobic zone resulted in In-plant Fermentation. Effluent ortho-phosphorus averaged 0.1 mg/ℓ
Surface appearance of Henderson Plant

Some hours after mixer off

During mixing
Configuration for achieving both nitrogen and phosphorus removal*

RAS Fermentation

Achieved TN 3 – 4 mg/L  
TP <0.3 mg/L

The main reactor consisted of channel systems for SND. 7% of the RAS was passed to a sidestream anaerobic zone with long retention. Note that VFA in the feed was lost for enhancing phosphorus removal.
BPR plant designed for fermenting mixed liquor
### SOME FULL-SCALE DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kelowna WWTP</th>
<th>Penticton WWTP</th>
<th>Kalispell WWTP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Flow (ADWF)</strong></td>
<td>22.5 ML/d</td>
<td>18 ML/d</td>
<td>12 ML/d</td>
</tr>
<tr>
<td><strong>Fermenter type</strong></td>
<td>Single-stage</td>
<td>Complete mix</td>
<td>2-Stage complete</td>
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<tr>
<td></td>
<td>fermenter/thickener</td>
<td></td>
<td>mix/thickener</td>
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<tr>
<td><strong>Complete mix volume</strong></td>
<td>n/a</td>
<td>700 m³</td>
<td>500 m³</td>
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<tr>
<td><strong>Thickener diameter</strong></td>
<td>15 m</td>
<td>n/a</td>
<td>12.4 m</td>
</tr>
<tr>
<td><strong>VFA discharge</strong></td>
<td>to anaerobic zone</td>
<td>to primary clarifiers</td>
<td>to anaerobic zone</td>
</tr>
<tr>
<td></td>
<td>5-6% of ADWF</td>
<td>6-8% of ADWF</td>
<td>7-8% of ADWF</td>
</tr>
<tr>
<td><strong>Fermenter inflow</strong></td>
<td>5-6% of ADWF</td>
<td>6-8% of ADWF</td>
<td>7-8% of ADWF</td>
</tr>
<tr>
<td><strong>HRT</strong></td>
<td>14 hrs</td>
<td>17 hrs</td>
<td>28 hrs</td>
</tr>
<tr>
<td><strong>SRT</strong></td>
<td>4 d</td>
<td>7 d</td>
<td>12 d</td>
</tr>
<tr>
<td><strong>Supernatant VFA</strong></td>
<td>370 mg/L</td>
<td>240 mg/L</td>
<td>390 mg/L</td>
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<tr>
<td><strong>Supernatant sol. COD</strong></td>
<td>550</td>
<td>500</td>
<td>n/a</td>
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<tr>
<td><strong>Equiv. plant inf. VFA</strong></td>
<td>21</td>
<td>17</td>
<td>30</td>
</tr>
<tr>
<td><strong>Plant inf. total-P</strong></td>
<td>5.5</td>
<td>7.1</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Plant effluent ortho-P</strong></td>
<td>0.10 mg/L</td>
<td>0.15 mg/L</td>
<td>0.29 mg/L</td>
</tr>
</tbody>
</table>
Key Design and Control Parameters

- **Solids retention time (SRT)**
  - Similar definition to the activated sludge process
  - Typically 3-5 days in summer; 4-8 days in winter

- **Hydraulic retention time (HRT)**
  - 6-12 hours when PS flow is 4-8% of plant flow

- **SCVFA Yield**
  - Should be between 0.05 and 0.3 g SCVFA/g VSS added
  - Well operated fermenter should produce 0.15 g SCVFA/g TSS added

- **Elutriation water flow**
  - Can use primary or secondary effluent
  - Typically 25 to 100 percent for PS pumping rate
  - Increase gravity thickener SOR to 5 to 10 m³/m²/d (120 to 240 gpd/sf)
DESIGN and control

- Modeling included in simulator packages such as BioWin
- Sparging with air for a few minutes per day to control methane production
- Control of retention time by the rate of primary sludge feed.
- Control of SRT by monitoring sludge blanket
- Centrifuge or linear belt as alternative for gravity thickener
Operation of Fermenters

- Static Fermenter - Oversized Thickener
- Direct Supernatant to anaerobic zones - flow split if necessary
- Closed for Odor Control
- Remove floatables – Mechanically or by sprays
- Ports for inspection
Monitor Sludge Blanket and calculate the solids inventory

Calculate the sludge removed in the primaries per day - X ppd

Multiply by the desired SRT - say 5 days

The solids inventory in the fermenter should be 5X ppd

Adjust wastage
FERMENTER PROBLEMS

- Methane formation if SRT too long
- Odor and corrosion - mostly enclosing is sufficient plus corrosion protection
- Blockages could be eliminated by screening recycles
- Scum blanket formation - have a good scum removal system
Key Monitoring and Control Parameters

- VFA concentration in fermenter supernatant
- Readily biodegradable COD (ffCOD) concentration in fermenter supernatant
- PS, FS, and TFS MLSS
  - Grab samples, on-line analyzer
- Gravity thickener sludge blanket height
  - Can be difficult to measure
- ORP
  - Best measured in thickener overflow
- pH
  - Grab samples, on-line analyzer
Primary Sludge Fermenters in Canada

- Kelowna WWTP: One single-stage fermenter-thickener.
- Westbank WWTP: Two single-stage fermenter-thickeners.
- Penticton WWTP: Two intermittently mixed fermenters with sludge return to the PCs.
- Summerland WWTP: One activated primary sedimentation tank.
- Lake Country WWTP: One single-stage fermenter-thickener.
- Whistler WWTP: One single-stage fermenter-thickener.
- OK Falls WWTP: One activated primary sedimentation tank.
- Bonnybrook WWTP Plant C: Two 2-stage complete mix/gravity thickener fermenters.
- Bonnybrook WWTP Plants A&B: Two 2-stage complete mix/gravity thickener fermenters.
- Pine Creek WWTP: Two single-stage fermenter-thickeners.
- Gold Bar WWTP: Four single-stage fermenter-thickeners.
- Alberta Capital Region WWTP: Two single-stage fermenter-thickeners.
- Banff WWTP: Two single-stage fermenter-thickeners.
- Red Deer WWTP: One 2-stage complete mix/gravity thickener fermenter.
- Fort McMurray WWTP: Two single-stage fermenters-thickeners.
- Saskatoon WWTP: Two intermittently mixed fermenters with sludge return to the PCs.
Key Design and Operating Challenges

- Odor due to sulfides, reduced sulfur compounds, ammonia and amines
- Corrosion due to sulfides and reduced sulfur compounds in headspace
- Mixing intensity
- Thickener mechanism torque
- Roping
- Debris accumulation
- Grit accumulation
- Stable scum layers on surfaces and in launders
Phosphorus limits achievable with fermentation

City of Kalispell
WWTP Yearly Phosphorus Loading
to Flathead Lake

From Joni Emrick
Conclusions

- Most importantly the anaerobic zone should be designed as a fermenter.
- Primary sludge fermentation is a cost-effective way of augmenting the supply of readily biodegradable COD in biological N and P removal processes.
- Fermentation is particularly effective in temperate climates, in plants treating low strength wastewaters, and in plants required to meet stringent N&P limits.
- Most commonly applied primary sludge fermenter configuration is the single-stage fermenter/thickener.
- Other configurations have made use of retrofitted existing unit processes (digesters, thickeners, etc.).
Conclusions (cont.)

- Fermenter operation should be optimized to maximize VFA production and minimize odour, corrosion and other operating problems.
- Principal fermenter control parameters include MLSS concentrations, sludge blanket height, sludge pumping and elutriation water flow rates; there are limited opportunities for automated control of fermenter operation.
- Solutions to operating problems include:
  - Foul air containment and scrubbing
  - Fine screening and maceration
  - Elutriation water
  - Stainless steel mechanisms and concrete liners
If you are still awake
Thank you for coming