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Advances in Wastewater Treatment Technology

Nathan Cassity, Donohue
Presentation Agenda

- History of Activated Sludge Process
- Advancement & Current Status
- Future Challenges
- Innovative Technologies
- Hypothetical Case Study for West Chicago, IL
- Conclusions
Early Sanitation

➢ Once upon a time ...  
  ▪ Human waste & animal manure were simply returned to land to be used as fertilizers  

➢ Industrial revolution of 20th century...  
  ▪ Increased population growth and urbanization  
  ▪ ‘Cesspools’ were constructed to treat increased sewage  
  ▪ Rivers became septic producing H2S  
  ▪ The ‘Great Stink of 1858’: Thames River in London
Early Sanitation

- Interceptor sewers + ‘Sewage Farms’
- Development of processes to extract nutrients from sewage for irrigation
  - ABC Process (alum, blood, and clay)
  - Septic tanks
  - Travis ‘Colloider' or ‘Hydrolytic’ Tank
  - Imhoff Tank
- Obnoxious and imposed health hazards
- Aerobic conditions to avoid undesirable malodors
1914 – Origins of Activated Sludge

- In 1913 Dr. Fowler (University of Manchester)
  - ‘Lawrence Experimental Station’ in Massachusetts
  - Purification of sewage in 24 hours in aerated bottles
- Ardern & Lockett repeated wastewater aeration experiments back in Manchester
  - Sludge was left in the bottle & mixed with new batch
  - Active role of sludge formed during aeration
    - ‘Activated Sludge’
  - Published three papers which formed design basis
Activated Sludge - Principles

Retention of solids in aeration basin (RAS)
- Excess sludge wasting (WAS)
- Solids separation
- SRT

- BOD removal, nitrification
- MLSS
- Effluent
Activated Sludge – Process Advancement

- Activated Sludge
- Process Advancement
- Eutrophication
- Sludge Bulking
- Use of Selectors to Bio-select Microorganisms
- Increasing Process Complexities

<table>
<thead>
<tr>
<th>BOD Removal</th>
<th>BOD Removal + Nitrification</th>
<th>BOD Removal + Nitrification + Selectors</th>
<th>BOD Removal + Nitrification + TN &amp; TP Removal</th>
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</thead>
<tbody>
<tr>
<td>Nitrification – Unnecessary</td>
<td>Aquatic toxicity</td>
<td>Sludge Bulking</td>
<td>Eutrophication</td>
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<tr>
<td>High-rate systems with short SRTs</td>
<td>Systems with longer SRTs</td>
<td>Use of Selectors to Bio-select Microorganisms</td>
<td>Unaerated zones</td>
</tr>
</tbody>
</table>
## Existing Treatment Schemes

### Nitrification
- Conventional ASP
- Trickling Filters
- Oxidation Ditches
- SBRs
- BAF
- MBRs
- IFAS, MBBR
- Fluidized Beds

### TP Removal
- CPR
- A/O
- PhoStrip
- SBRs
- MBRs
- Deep Bed Sand Filters

### TN Removal
- MLE
- Bardenpho
- Oxidation Ditches
- SBRs
- Biological Filters
- MBRs
- IFAS, MBBR
- Deep Bed Sand Filters
- Upflow Fluidized Beds

### TN & TP Removal
- A2/O
- Modified Bardenpho
- UCT/ MUCT
- VIP
- Jo’burg
- SBRs
- PhoStrip
- MBRs
- IFAS, MBBR
- Deep Bed Sand Filters

### Site-specific Evaluation
- Lots of Variations
Challenges

More Stringent Effluent Limits

- Limits of Technology (LOT)
- More chemicals (ferric, alum, methanol, polymers, etc.)
- More energy consumption (carbon footprint, GHG emissions)
- More sludge production
- More land requirements

Resource Scarcity

- Increasing water demand but limited supply
- Utilize treated effluent, gray water
- Phosphorus is limited and irreplaceable
- 200 years supply at current consumption
- Increasing energy costs
- Renewable energy generation
Paradigm Shift

Next Generation Wastewater Resource Recovery Facility (WWRRF)

Influent

Lower Chemical Consumption

Treated Effluent Reuse

Renewable Energy Generation

Sludge Utilization

Nutrient Recovery
### Innovative Technologies

**Membrane Aerated Biofilm Reactors (MABR)** ✓
- Anaerobic Membrane Bioreactor
- Anaerobic Migrating Blanket Reactor
- ANAMMOX Bacteria ✓
- Aerobic Granular Sludge ✓
- Membrane Fuel Cells ✓
- Biomass Immobilization ✓
- Vacuum Rotation Membrane...

...and more
MABR  
(Membrane Aerated Biofilm Reactor)

- Oxygen diffusion through hollow fiber membrane
- Biofilm Development
  - Aerobic ... outside wall
  - Anoxic ... inside
- BOD along with SND
- ~ 95% reduction in energy
- 30%-50% reduction in sludge
MABR
(Membrane Aerated Biofilm Reactor)

Autotrophic nitrifying biofilm oxidizes nitrogen compounds to nitrate in the oxygen rich, low BOD layer.

Heterotrophic biofilm breaks down BOD in the water side.

Heterotrophic denitrifying biofilm breaks down nitrate & remaining BOD.

Spiral Aerobic Biofilm Reactor (SABRE)

Courtesy: Emefcy
MABR
(Membrane Aerated Biofilm Reactor)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Valve</th>
<th>Units</th>
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<tbody>
<tr>
<td>Design Temperature</td>
<td>18 (64)</td>
<td>°C (°F)</td>
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<tr>
<td>Wastewater Flow</td>
<td>1000 (0.26)</td>
<td>m³/d (MGD)</td>
</tr>
<tr>
<td>Influent Filtered BOD</td>
<td>150</td>
<td>mg/l</td>
</tr>
<tr>
<td>Influent TKN</td>
<td>52</td>
<td>mg/l</td>
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<tr>
<td>Effluent BOD</td>
<td>8</td>
<td>mg/l</td>
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<tr>
<td>Effluent NH-3 Req.</td>
<td>1.0</td>
<td>mg/l</td>
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## MABR
(Membrane Aerated Biofilm Reactor)

<table>
<thead>
<tr>
<th>Process</th>
<th>SABRE</th>
<th>Activated Sludge</th>
<th>Units</th>
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<tbody>
<tr>
<td>Power Consumption</td>
<td>1.2</td>
<td>13</td>
<td>kW</td>
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<tr>
<td>Normalized Energy</td>
<td>0.06</td>
<td>1.10</td>
<td>kWh/kg BOD (kWh/lb BOD)</td>
</tr>
<tr>
<td>(0.03)</td>
<td></td>
<td>(0.5)</td>
<td></td>
</tr>
<tr>
<td>Normalized Energy</td>
<td>0.02</td>
<td>0.31</td>
<td>kWh/m³ (kWh/1000 gal)</td>
</tr>
<tr>
<td>(0.06)</td>
<td></td>
<td>(1.18)</td>
<td></td>
</tr>
</tbody>
</table>

Power consumption reduction 95%
SABRE wastewater treatment plant 50 m³/d (13,000G/d)
MABR (Membrane Aerated Biofilm Reactor)

Figure 1: MABR operation principle

Figure 2: Scanning electron microscope image of ZeeLung cord
MABR
(Membrane Aerated Biofilm Reactor)

Figure 4: ZeeLung MABR process flow diagram
MABR
(Membrane Aerated Biofilm Reactor)
Microbial Fuel Cells

- High-throughput treatment compared to anaerobic digestion
- 700 kWh energy recovery potential per 1000 kg BOD removed
- Reduced cost through automated process control
- Small, enclosed modular design for customer facility compatibility
- BOD treatment range 1,000 - 10,000 mg/L influent
- Excellent way for customer to bolster green marketing initiatives
Scaled-up Design Concept
Biomass Immobilization

Biofilms – Attached Growth
- Current form immobilized biomass
- Sand, gravel, Plastic, etc.
- Trickling filter, MBBR, IFAS

Biocatalyst
- Capture pure cultures of microorganisms in activated sludge in gel pellets
- Use entrapped bacteria for wastewater treatment
Biocatalysts

- **Activated Sludge**
  - Nitrification
    - Longer SRT → Tank Volume
    - High Oxygen demand
    - High sensitive demand to pH, temperature
  - Denitrification
    - High carbon demand

- **Conventional Design**
  - Mixed bacteria population
  - Heterotrophs predominant
  - Only ~ 4% nitrifiers (AOB, NOBs)
  - Traditional Denitrification
    - 2 step process w/ carbon

- **Pure Cultures**
  - High reaction rates
    - Nitrification ... ~ 16 times
    - Denitrification ... ~ 3 times
  - Increased process stability
    - No washout of nitrifiers
  - Low sludge production
  - Low carbon source need
Biocatalyst Operation

**BOD Oxidation**
Paracoccus sp., Pseudomonas sp.

**Nitrification**
Nitrosomonas europaea, Nitrobacter and Nitrospira sp.

**Denitrification**
Paracoccus sp., Pseudomonas denitrificans

Courtesy: Lentikats Biotechnology
Biocatalysts
Biocatalysts
<table>
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<tr>
<th>Project</th>
<th>Process</th>
<th>Tonnage</th>
<th>Year</th>
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<tr>
<td>WWTP Baxter</td>
<td>Denitrification (tertiary treatment)</td>
<td>5.4</td>
<td>2009</td>
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<tr>
<td>WWTP Litomerice</td>
<td>Nitrification (reject water)</td>
<td>1.5</td>
<td>2010</td>
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<tr>
<td>Tona</td>
<td>Denitrification (tertiary treatment)</td>
<td>0.5</td>
<td>2010</td>
</tr>
<tr>
<td>WWTP Ostrov u M.</td>
<td>Denitrification (tertiary treatment)</td>
<td>0.5</td>
<td>2011</td>
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<tr>
<td>Kyocera</td>
<td>BOD removal</td>
<td>5.5</td>
<td>2012</td>
</tr>
<tr>
<td>Coral-shop</td>
<td>Nitrogen removal (inoculation)</td>
<td>0.1</td>
<td>2012</td>
</tr>
<tr>
<td>BASF</td>
<td>Nitrogen removal</td>
<td>testing</td>
<td>2014</td>
</tr>
<tr>
<td>Dairy production</td>
<td>BOD removal</td>
<td>testing</td>
<td>2014</td>
</tr>
</tbody>
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Biocatalysts

500 kg LB
Volume: 3 m³
Qₐ: 130 m³/day
\[ c(\text{N-NO}_3^-) \text{ influent} = 15 \text{ mg/l} \]
\[ c(\text{N-NO}_3^-) \text{ effluent} = 2 \text{ mg/l} \]
Biocatalyst Usage

- **Nitrification**
  - Immobilized bacteria strains *Nitrosomonas europaea, Nitrobacter and Nitrospira sp.*
  - Operation in oxic conditions

- **Denitrification**
  - Immobilized bacteria strains *Paracoccus sp. or Pseudomonas denitrificans*

- **BOD Removal**
  - Immobilized bacteria strains *Paracoccus sp., Pseudomonas sp.*
  - Operation in oxic conditions

- **Selective biodegradation**
  - R&D – immobilized bacteria strains, fungi or enzymes
Biocatalysts

Reference – Baxter Bioscience

5400 kg LB

V: 40 m³

Qd: 300 m³/day

c(N-NO₃⁻) influent - 30 mg/l
c(N-NO₃⁻) effluent - 5 mg/l
Biocatalysts

Benefits of Lentikats Biotechnology biocatalysts

- Pure cultures = smaller tank volumes
- Lower energy consumption
- Lower carbon need for denitrification
- Lower sludge production
- Better process stability – fluctuating influent
- Resistant to toxic conditions (NH4 ~ 4,000 mg/l)
- Industrial WW w/ nutrient deficiencies
Granular Activated Sludge

- Granules - dense & compact biomass
  - No support media
- Excellent settling properties
  - High MLSS (up to 15,000 mg/l)
  - ~ 75% smaller footprint
  - No bulking sludge
- >25-35% energy savings
  - Efficient aeration
  - Lower pumping
- Lower construction, O&M costs
  - Utilize existing tanks
  - No chemicals for nutrient removal
  - Low sludge production
Granular Biomass

- Oxygen gradient in granule
  - Diffusion controlled
  - Simultaneous BOD, N and P removal

FISH analysis of a sliced granule:
- NSO: nitrifying organisms
- EUB: heterotrophs
- PAO: phosphate accumulating organisms

Anoxic / Anaerobic Zone:
- Nitrate reduction to nitrogen gas
- Phosphate level

Aerobic Zone:
- Biological oxidation
- Ammonium oxidation to nitrate
Aerobic Granular Sludge

- Min. diameter 0.212 mm (0.0083 inch)
  \[ SVI_5 \] of granular sludge
  \[ SVI30 \] of activated sludge

- High setting rates
  - 25 – 40 ft/hr ... granules
  - 1.5 – 5 ft/hr ... activated sludge
Nereda

- Four basins operated in series
- One basin in sedimentation mode
- One basin in fill/decant
- Continuous flow
- No moving decanter
- No mixers

Granule Sequencing Batch Reactor (GSBR)
Nereda Installations

- **UK**
  - Dalmarnock, Daldowie, Davyhulme

- **Poland**
  - Ryki

- **South Africa**
  - Gaansbai

- **Ireland**
  - Clonakitty & Carrigtohill

- **Netherlands**
  - Rotterdam
  - Dinxperlo
  - Oosterwolde
  - Epe
  - Vroomshope

- **Australia**
  - Kingaroy

- **Brazil**
  - Jardim São Paulo
  - Jaboatão
  - Rio de Janeiro
  - São Laurenço Tatu
  - Rio Claro
Conclusions

- Stricter limits
- Energy neutrality
- Sludge minimization
- Resource recovery
- CAPEX/OPEX reduction
- Beneficial reclaimed water re-use
- Driving technological innovation
References

- “History of Activated Sludge”
  http://www.iwa100as.org/history.php
- J. L. Barnard and D. H. Stensel, "The Activated Sludge Process in Service of Humanity"
- US EPA “Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management”
- Lentikats - http://www.lentikats.eu/cs/
- Emefcy - http://www.emefcy.com/
- Arbsource - http://www.arbsource.us/
Questions

Nathan Cassity | (920) 803-7370
ncassity@donohue-associates.com