Sludge Minimization
A Paradigm Shift in Sludge Management

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Our Profession Will Continue to be Fueled by Paradigm Shifts

Dr. John Snow

Broad Street Pump
Broad Street Pump Today
Presentation Outline

• Key Drivers
• Background
• Sludge Minimization at the Source
• Sludge Minimization ‘After the Fact’
• Sustainability Perspective
• Summary
Presentation Outline

• **Key Drivers**
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Key Drivers for Sludge Minimization

- Steadily increasing sludge production (500-800 lb dry weight per million gallons treated)
- Sludge operations represent >50% of a plant’s O&M cost
Key Drivers for Sludge Minimization

• Three primary disposal alternatives
  – Land application (51%)
  – Landfilling (38%)
  – Incineration (11%)

• All three face varying degrees of pressures
  – Land application costs are escalating
  – Landfill availability is rapidly declining
  – Regulatory controls are increasing
  – Closer public scrutiny (NIMBY)
It is clear that we cannot keep doing the same thing and expect a different answer.
Benefits of Sludge Reduction

• Reduce costs (capital and O&M) in sludge processing and ultimate disposal/reuse.
• Optimize energy use
• Reduce carbon footprint
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Sources of Sludge

Primary Sludge

Primary Clarifier

Return Activated Sludge (RAS)

Biological Reactor

Handling and Processing

Disposal

Waste Activated Sludge (WAS)

Final Clarifier
What’s in Your WAS?

- **MLSS/WAS**
  - **Organic Solids (VSS)**
    - Organic Cell Debris
    - Active Biomass (Bugs)
    - Non-Biodegradable Influent VSS
  - **Inorganic Solids**
    - Influent Inert Solids
    - Chemical Solids
    - Inorganic Cell Debris
Sludge is the ‘Undesired’ End Product of the Biological Process

Soluble Substrate

Energy

Catabolism

Oxygen, Nitrate

ATP

ADP

Maintenance

Biomass Growth (Y)

Net Growth (Y_{net})

Decay, Predation, Lysis

Biodegradable Substrate

Debris
Net or Observed Growth (Yield) (Sludge Production)

\[ Y_{\text{net}} = \frac{Y}{K_d \times SRT} + \text{(Cell Debris)} + \text{(Inert solids)} + \ldots \]

- Actual growth
- Endogenous Decay Coefficient
- Solids Retention Time
- Biomass or Bugs
Sludge Reduction Technologies

Marketplace is actively responding to the paradigm shift. Available technologies can be classified based on:

• Location
  – At the source
  – After the fact
  – Enhanced digestion

• Process mechanism
  – Biological
  – Chemical
  – Physical
Based on Location

At the Source

After the Fact

Enhanced Digestion

Headworks

Primary Treatment

Activated Sludge

Secondary Treatment

Plant Influent

PS

WAS

Anaerobic Digester

Dewatering/Disposal

Plant Effluent

Plant Influent
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Sludge Reduction at the Source

- Primary Clarifier
- Biological
- Final Clarifier

RAS

- Sludge Minimization Technology
  - Extended Aeration
  - Cannibal
  - Ozonation

WAS
Extended Aeration

\[ Y_{net} = \frac{Y}{K_d \times SRT} \]

Net Yield, lb VSS/lb COD

SRT, d

Yield graph with points for Plug Flow, Oxidation Ditches, and Flow.
Cannibal™ Process

• Been in operation since 1998
• Siemens licensed the technology in 2003
• In operation: 10 plants. Largest: 16 mgd
• Entails 2 mechanisms:
  • Physical separation of inert materials and grit
  • Biological process
Typical Cannibal™ Process Flow Scheme

Influent → Aeration Basin → Final Clarifier → Effluent

- SRT = 8-15 days
- Fine Screen (250 micron) and Hydrocyclone
  - Trash, grit and inerts to landfill
    - 0.2 to 0.3 lb TSS/lb BOD
    - Dewaters to 30 – 40% solids
    - 90% VSS

RAS → Interchange Reactor → WAS

- SRT = 10-12 days
- MLSS = 10,000 mg/L
- Low/no DO conditions
- 0.1 lb TSS/lb BOD
Cannibal Process – Biological Step

- Builds on the extended aeration concept
- Interchange Reactor operated on the cusp of anaerobic/anoxic conditions
- Several biological processes act in combination to reduce sludge production
  - Cycling between aerobic & low/no DO conditions selects organisms with low yield
  - Long SRT
  - Predation
  - Decay and lysis

\[ Y_{\text{net}} = \frac{Y}{K_d \times SRT} \]
Anabolism and catabolism are closely coupled during aerobic metabolism.

- Low/no DO interchange tank acts like a ‘speed bump’
  - Shock and starvation conditions – no oxygen, no substrate
  - ATP (energy reserve) consumed
  - Catabolism and anabolism are uncoupled

- In the aeration tank, substrate used to restock ATP and less used for growth
  - Low DO - High DO sequencing selects organisms with low yield
Cannibal System

- Proven technology—several full scale applications
- Relatively large interchange tank needed – may not be cost effective for large facilities
- Issues with phosphorus mass balance remain unresolved
- May not be compatible with biological phosphorus removal
Ozonation

- Mechanisms involved
  - Solubilization of sludge solids and cell lysis cause an increase in the rate of degradation
  - Renders the non-degradable organic fraction degradable, thereby increasing the extent of degradation

- Solids that would otherwise contribute to sludge production are degraded resulting in sludge reduction
Cell Lysis Caused by Ozonation

Bacterial cell to be ozonated

Ozone contacts cell wall

Ozone penetrates cell wall

Ozone oxidizes cell wall causing lysis

Cell with lysis ‘pockets’ after contact with ozone

Weakened cell wall ruptures in aeration basin

Praxair Technology
Ozonation

- Biological Reactor
- Final Clarifier
- Ozone Contactor
- Ozone Generator

- Contact time = 15 min
- Solids inventory cycled through the contactor every 3-4 days
- Ozone dose: 0.05 – 0.4 g O₃/g TS red
Ozonation

• Solids reduction reported: 30-70%
• Side benefits
  – Filament control - avoid bulking and foaming
  – Lower SVIs - improved settleability
• Higher oxygen demand in aeration basin
• Require on-site ozone generation
• May not be compatible with biological phosphorus removal
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‘After the Fact’ Approaches

- Primary Clarifier
- RAS
- Final Clarifier
- WAS
- Primary Sludge
- Thickening
- Anaerobic Digester
- Dewatering and Offsite Disposal
- Sludge Minimization
- Thermal hydrolysis
- Ultrasound
- MicroSludge
- Pulsed Electric Field
The Goal is to Increase WAS Biodegradability

• WAS is slowly biodegradable during anaerobic digestion
  – Cell wall is like a walnut shell
  – The initial hydrolysis process (shell rupture) is rate limiting

• WAS biodegradability can be increased by pretreating digester feed

• Increased biodegradability means:
  – Increased VSS reduction
  – Increased methane production
  – Reduced biosolids to offsite disposal
Thermal Hydrolysis (Cambi)

**FEED SLUDGE**
15-20% TS

**PULPER**

**HIGH PRESSURE PUMP**

**REACTOR**
- **170-180°C; 120 psi; 20 min**
- **Organics solubilized**

**FLASH TANK**
- **Rapid decrease in pressure (60 psi)**
- **Flashing ruptures cells**

**DIGESTER**
- **40°C**

**HOT WATER**

**STEAM INJECTION**

**DEWATERING**

- **90°C; 45 psi**
- **Sludge preheated and homogenized**
Thermal Hydrolysis (Cambi)

• Several full scale operations in Europe
• Smaller digester volume:
  – Homogenized feed - lower viscosity. Higher solids concentration in digester (15%).
  – Higher volumetric loading rate
• VS reduction: 55 – 65%
• Class A biosolids
• Dewatered cake: 30 – 35% TS
Ultrasound

- Sound frequency: 20 – 40 kHz
- Human threshold: 18 kHz
- Mechanism:
  - Formation, growth and collapse of microbubbles
    - Hot spots created
    - $4,700^\circ$C; 7,250 psi
    - Jet stream velocities of 250 mph.
  - Causes cell rupture
Ultrasound – How it works

Refraction forms cavitation bubbles

Compression

Sonic Wave

Bulk Sludge

Bubbles implode creating ‘hot spots’

Refraction forms cavitation bubbles

Adapted from Tiehm, et al.
Ultrasound

- Small footprint
- Sludge reduction claimed: 20-50%
- Filament control achieved
- Improved SVI and settleability
- Improved dewaterability

Sonico Ultrasound Horn

WAS → Reactor → Digester

Ultrasound Waves

High Voltage

Transducer
MicroSludge Process

Chemical/Physical Treatment
• pH: 9-10
• Weaken cell wall
• Mechanical sheer

High Pressure Homogenizer
• 12,000 psi
• Cell rupture

WAS → Chemical/Physical Treatment → High Pressure Homogenizer → Digester
Impact of MicroSludge Pretreatment
Pulsed Electric Field

• Sludge is exposed to electric pulses:
  • High voltage and high frequency microbursts of conditioned electricity

• Application of electrical energy results in breaching of the cell membrane leading to:
  • Cell inactivation
  • Cell lysis
  • Release of intracellular material
Pulsed Electric Field – How it Works

Diagram showing the movement of positively and negatively charged particles through a conductor under the influence of pulsed electric fields, with labeled parameters for pulse frequency and pulse width.

Graph showing voltage over time, illustrating the waveform of the pulsed electric field with a focus on pulse frequency and pulse width.
Full-Scale Installation at Mesa, AZ

Performance data:
- Greater than 10% increase in VS reduction
- Increase in methane by 55-60%
- Sludge treated with pulsed electric field is a potential carbon source for denitrification

Operating data:
- Plant flow: 10-12 MGD
- Thickened PS/WAs mixture 50,000 - 60,000 gpd
- Solids content: 4 - 6%
- In operation since Sept. 2007
Enhanced Digestion

- Thermophilic
- Acid/Gas Phase
- Anaerobic-Aerobic
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Life Cycle Analysis
Holistic Approach to Achieve Net Environmental Benefit

No Sludge Reduction → Larger Sludge Quantity

With Sludge Reduction → Reduced Sludge Quantity

Energy and Materials

Wastes and Emissions
Summary

• Sludge minimization provides O&M cost savings and net environmental benefit.
• WAS provides the greatest opportunity to implement sludge minimization.
• A wide range of technologies both emerging & proven are available.
• Process selection should be based on a Triple Bottom Line analysis
• Water Environment Research Foundation study outlines a methodology for evaluating candidate technologies
Questions?