Sludge Pre-Treatment for Enhanced Efficiency in Resource Recovery

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Acknowledgements

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  – Peiman Kianmehr
  – Gill Staples-Burger
  – Priyanka Joshi
Context

• Increasing interest in pretreatment processes to enhance digestibility of waste activated sludges
  ➢ Increased solids destruction
  ➢ Increased biogas production
  ➢ Pathogen reduction?
  ➢ Improved dewaterability?

• Enhancement in digestibility varies with:
  – Pretreatment technologies
  – Operating conditions of the activated sludge process from which the sludges are generated
Research Questions

• Are there simple test methods that can be employed to characterize the impact of pretreatment on sludges?
• Can we develop predictive models of sludge pretreatment?
• Can we take advantage of PT by integrating it with high rate digestion in Anaerobic Membrane Bioreactors?
Tools for Evaluating Sludge Pretreatment Technologies
BAP – BMP comparison

- **Biochemical Methane Potential (BMP) test:**
  - Long operation (50-70 days),
  - Complexity of gas measurements
  - Requires balance between rate of acidification and methanogenesis
  - Pretreated WAS: Higher hydrolysis rate $\rightarrow$ VFA accumulation $\rightarrow$ methanogenesis inhibition

- **Biochemical Acid Potential (BAP) test:**
  - Shorter test (5 – 15 days),
  - Simpler analyses
  - Less sensitive to inhibition
  - Describes early stages of digestion
Municipal Wastewater

SBR 1
SRT=1.95 day

SBR 2
SRT=7 day

SBR 3
SRT=15 day

Sonication
20 kH, Amp 250μm, 45°C

Physical

Particle size analysis
L.D.M

Biochemical

Solid Test
(Std)

COD test

TKN, STKN & Ammonia

Biological

Respirometry

Anaerobic Digestion

Active Fraction of Biomass

Aerobic Biodeg.

BAP Test

BMP Test

Modeling
Pretreatment apparatuses:

Ozonation

1-Ozone generator, flow meter and concentration monitor
2-Ozonation reactor
3-Magnetic stirrer
4-Foam destruction chamber
5-Ozone destruction column
6-Pump
Ultimate Methane vs VFA

\[ y = 0.5049x + 0.2234 \]

\[ R^2 = 0.9025 \]
Summary

• Both PTs increased rate of digestion but did not affect ultimate yield of methane
• Batch tests provide useful information on the impact of PT on sludge
• Short term BAP tests could be substituted for longer term BMP tests
Modeling COD transformations in WAS pretreatment
Approach

1. Generate Waste Activated Sludge (WAS) on a simple synthetic wastewater in the lab

2. Fractionate COD of WAS before and after Thermal Hydrolysis pretreatment

3. Develop COD-based pretreatment model and integrate into WWTP simulations
COD fractionation

TCOD

<table>
<thead>
<tr>
<th>Biodegradable COD</th>
<th>Non-biodegradable COD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readily biodeg. $S_S$</td>
<td>Sol. non-biodeg. $S_I$</td>
</tr>
<tr>
<td>Slowly biodeg. $X_S$</td>
<td>Part. non-biodeg. $X_I$</td>
</tr>
<tr>
<td>Complex $S_F$</td>
<td>endogenous decay products $X_E$</td>
</tr>
<tr>
<td>SCFA $S_A$</td>
<td></td>
</tr>
<tr>
<td>Colloidal $S_{COL}$</td>
<td></td>
</tr>
<tr>
<td>Particulate $X_{SP}$</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Methods for Wastewater Characterization in Activated Sludge Modeling by Melcer, Dold, Jones, et al. WERF, 2003
Overview

Development of a COD-based pretreatment model

Compare solubilization of different materials

Physical
- TSS, VSS

Biochemical
- TCOD, SCOD, ffCOD
- NO₃, NH₃, TKN, ON

Model fitting

Biological
- Online OUR
- Offline OUR
  - Rate & extent of aerobic degradation
  - Active fraction

Model fitting

Development of a COD-based pretreatment model
Reactors

Parr® 4563 Mini Pressure Reactor

- Maximum capacity: 400 mL

Aerobic Digester
10 d SRT

Biological Reactor
5 d SRT
Steady-state concentrations in process streams

TCOD
- BR WAS: 4170 mg/L
- PT BR WAS: 4142 mg/L
- AD WAS Phase 1: 2427 mg/L
- AD WAS Phase 2: 2098 mg/L

PCOD
- BR WAS: 4127 mg/L
- PT BR WAS: 4127 mg/L
- AD WAS Phase 1: 1773 mg/L
- AD WAS Phase 2: 2119 mg/L

ffCOD
- BR WAS: 53 mg/L
- PT BR WAS: 1725 mg/L
- AD WAS Phase 1: 190 mg/L
- AD WAS Phase 2: 177 mg/L

VSS
- BR WAS: 3342 mg/L
- PT BR WAS: 1518 mg/L
- AD WAS Phase 1: 1667 mg/L
- AD WAS Phase 2: 1557 mg/L

ISS
- BR WAS: 489 mg/L
- PT BR WAS: 412 mg/L
- AD WAS Phase 1: 980 mg/L
- AD WAS Phase 2: 528 mg/L
Offline respirometry results

- Pretreatment increased rate of aerobic digestion
COD fractionation of process streams

COD Fractions
- Readily biodegradable
- Slowly biodegradable
- Storage products
- Active biomass
- Decay products
Pretreatment model

- Pretreatment model integrated into WWTP simulator

<table>
<thead>
<tr>
<th>Process</th>
<th>$S_S$</th>
<th>$X_S$</th>
<th>$X_H$</th>
<th>$X_{STO}$</th>
<th>Kinetic Rate Expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mg COD/L</td>
</tr>
<tr>
<td>Conversion of $X_H$</td>
<td>$f_S$</td>
<td>1-$f_S$</td>
<td>-1</td>
<td></td>
<td>$k_{d-}X_H \times X_H$</td>
</tr>
<tr>
<td>Release of $X_{STO}$</td>
<td>1</td>
<td></td>
<td>-1</td>
<td></td>
<td>$k_{d-}X_{STO} \times X_{STO}$</td>
</tr>
</tbody>
</table>
Measured and simulated OUR from Offline Respirometry on pretreated WAS
Biowin Implementation
Significance

• Thermal pretreatment increased rate but not extent of biodegradation of WAS
• A COD-based pretreatment model was developed and calibrated
• Model was able to predict steady state and dynamic responses
• Approach and pretreatment model can be used to compare different pretreatment doses and technologies
Pre-treatment and Digestion in Anaerobic Membrane Bioreactors
Context

• Traditional digestion does not take complete advantage of increased rates of digestion after PT

• AnMBR advantages:
  – No biomass washout
  – SRT decoupled from HRT
    • reduced digester volumes
  – Permeate is solids-free
Membrane Fouling?

• Fouling can increase capital and operating costs of AnMBRs

• Potential challenges with operation of AnMBRs on PT WAS:
  – Operation with elevated MLSS
  – Potential for elevated colloidal concentrations from PT
Approach

Preliminary analysis to compare two peroxide-sonication PTs

Biodegradation analysis via AnMBR on both PTs

Membrane Fouling analysis – critical flux determination, fouling minimizing system analysis, solids and colloids impact.
# Pre-Treatment Conditions

<table>
<thead>
<tr>
<th>Pre-treatment</th>
<th>Sonication Duration (minutes)</th>
<th>Hydrogen Peroxide Dose (gH₂O₂/kg TS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT20</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>PT60</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>
Operation of AnMBR

WAS from Waterloo WWTP → AnMBR 4.5 L, SRT 20d, HRT 3d → Physico-chemical and biodegradation characterization

P1

P2

50 gH₂O₂/kg TS + 20 mins US

P3

50 gH₂O₂/kg TS + 60 mins US
AnMBR Setup
Solublization of COD through PT

![Bar graph showing the solublization of COD through PT. The graph compares the percentage of soluble COD (ffCOD/TCOD) and colloidal COD (cCOD/TCOD) after 20 minutes and 60 minutes of AOP treatment.]

- After 20 minutes AOP:
  - ffCOD/TCOD: 11%
  - cCOD/TCOD: 21%

- After 60 minutes AOP:
  - ffCOD/TCOD: 22%
  - cCOD/TCOD: 25%
COD Destruction in PT- AnMBR

 Phase 1 | Phase 2 | Phase 3
 COD Destruction (%) | AnMBR COD removal (%) | PT COD removal (%)

49% | 52% | 59%
6% | 4% |
AnMBR COD Fractions

- **cCOD**: 2018, 2936, 3598
- **ffCOD**: 340, 680, 386
- **SCOD**: 2404, 3276, 4278
- **pCOD**: 15486, 16344, 19269
- **TCOD**: 17890, 19620, 23547

**Phase 1**, **Phase 2**, **Phase 3**

**mg COD/L**

-WATERLOO ENGINEERING-
Critical Flux Determination

![Graph showing TMP (kPa) vs Flux (LMH) with data points indicating exponential increase and critical flux range.]

- Phase 2
- Phase 3

Exponential Increase – Critical Flux Range
Significance

• Increased PT duration resulted in higher COD and VSS solubilisation

• PT+AnMBR system enhanced the biodegradation of WAS.

• No apparent impact of PT on membrane fouling
Questions?