THERMAL HYDROLYSIS AND ENERGY REDUCTION IN BIOSOLIDS PROCESSING

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SUSTAINABLE WATER AND ENERGY SOLUTIONS

RESIDUALS PROCESS SPECIALIST
WERF ENERGY NEUTRAL PROJECT ENER1C12
WERF ENER1C12 – ENERGY EFFICIENCY AND PRODUCTION

Objective:
Provide research ... that will allow wastewater treatment plants to be energy neutral, and thus able to operate solely on the energy embedded in the water and wastes they treat.

Co Principal Investigators:
Steve Tarallo           Black & Veatch
Ralph Eshborn           AECOM
SOURCES OF RENEWABLE ENERGY AT WATER RECLAMATION FACILITIES

- Chemical energy – caloric energy stored in organic compounds
  - May include embedded energy (nutrients)
- Hydraulic energy – potential and kinetic
- Thermal energy – heat energy due to specific heat of water
Base Case

Influent → Primary Sedimentation → Aerated Biological Treatment → Effluent

Solids Management (stabilization, thickening, drying)

Solids → Sidestream Return Flow

Biosolids Disposal or Beneficial Reuse
Best Practices

## OPTIMIZATION – BEST PRACTICES

<table>
<thead>
<tr>
<th>Process</th>
<th>Parameter</th>
<th>Units</th>
<th>Typical</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple</td>
<td>pump efficiency</td>
<td>%</td>
<td>60%</td>
<td>85%</td>
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<tr>
<td>Grit removal</td>
<td>energy use</td>
<td>hp</td>
<td>33.5</td>
<td>4.6</td>
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<tr>
<td>Primary clarifiers</td>
<td>removal efficiency</td>
<td>%</td>
<td>60%</td>
<td>70%</td>
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<tr>
<td>Biological reactor</td>
<td>fouling constant</td>
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<tr>
<td>Biological reactor</td>
<td>combined blower/motor efficiency</td>
<td>%</td>
<td>70%</td>
<td>80%</td>
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<tr>
<td>Gravity thickener</td>
<td>thickened sludge concentration</td>
<td>%TS</td>
<td>5%</td>
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<tr>
<td>Gravity thickener</td>
<td>removal efficiency</td>
<td>%</td>
<td>90%</td>
<td>92%</td>
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<td>Mechanical thickener</td>
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<td>%TS</td>
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<td>Mechanical thickener</td>
<td>removal efficiency</td>
<td>%</td>
<td>95%</td>
<td>98%</td>
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<tr>
<td>Anaerobic digester</td>
<td>mixing power use</td>
<td>hp</td>
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<td>6</td>
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<tr>
<td>CHP</td>
<td>electric efficiency</td>
<td>%</td>
<td>33%</td>
<td>40%</td>
</tr>
<tr>
<td>CHP</td>
<td>thermal efficiency</td>
<td>%</td>
<td>40%</td>
<td>45%</td>
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<tr>
<td>Dewatering</td>
<td>cake concentration</td>
<td>%TS</td>
<td>18%</td>
<td>23%</td>
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<tr>
<td>Dewatering</td>
<td>capture rate</td>
<td>%</td>
<td>90%</td>
<td>95%</td>
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</table>
Proven Energy Neutral Treatment Processes

Research Targets
- Enhanced primary
- More co-digestion and more efficient CHP
- Apply Demon at US plants (like in EU)
Future Energy Neutral Treatment Processes

- Heat pump
- Enhanced
  - Primary Sedimentation
  - New Anaerobic Biological Treatment
  - Solids Pretreatment
  - Solids Management (Stabilization, Thickening, Dewatering, or Thermal Conversion)

- Influent
- Co-digestion FOG/org. waste
- Anaerobic Digestion
  - Biogas
  - CHP/ Cogeneration Fuel cell/ Improved CHP
  - Research Targets
    - Apply heat pumps
    - Use solids pretreatment technologies (i.e., Cambi)
    - Apply thermal conversion processes (gasification, reformation, pyrolysis)
    - Develop new anaerobic biological processes (i.e., full scale Demon)

- Effluent
- Heat Power Fuel
WERF ENER1C12 PROJECT ENERGY MODELING 10 MGD PLANT

• 50 Baseline energy models
  • Common WWTP configurations
    • 25 “un-optimized”
    • 25 “optimized” (best practices)

• 19 “pioneering” process modules
  • Potential for significant step towards energy neutrality
Activated Sludge – BNR – with Primary Treatment; WAS Mechanical Thickening, Anaerobic Digestion, and Dewatering
G1 OPT

Activated Sludge – BNR – with Primary Treatment; WAS Mechanical Thickening, Anaerobic Digestion, and Dewatering
4 December 2013

Total Plant Electricity Usage (kWh/MG)

- Conv. Act. Sludge w/ Pri. Treat., Co-thickening in Gravity Sludge Thickener,
- Conv. Act. Sludge w/ Pri. Treat., WAS Mech. Thickening, Anaerobic Digestion and...
- Conv. Act. Sludge w/ Pri. Treat., WAS Mech. Thickening, Anaerobic Digestion, Dewate...
- Trickling Filter w/ Pri. Treat., Co-thickening, Anaerobic Digestion and Dewatering
- Act. Sludge – nitrification – w/o Pri. Treat., WAS Aerobic Digestion and Dewatering
- Act. Sludge – nitrification – w/ Pri. Treat., WAS Aerobic Digestion and Dewatering
- Act. Sludge – BNR – w/ Pri. Treat., WAS Mech. Thickening, Anaerobic Digest. and...
- Act. Sludge – BNR – w/ Pri. Treat., WAS Mech. Thickening, Anaerobic Digest. and...
- Act. Sludge – BNR w/o Pri. Treat., WAS Aerobic Digestion and Dewatering
- Act. Sludge – BNR w/o Pri. Treat., WAS Dewatering and Class B Lime Stabilization
- MBR (aerobic) – BNR – w/ Pri. Treat., Co-thickening, Anaerobic Digestion and...
- MBR (aerobic) – BNR w/o carbon addition – w/ Pri. Treat., Co-thickening,...
- MBR (aerobic) – BNR w/o carbon addition – w/o Pri. Treat. WAS Aerobic Diges...
- MBR (aerobic) – BNR – w/o Pri. Treat. WAS Aerobic Digestion and Dewatering
- Pure Oxygen Act. Sludge w/ Pri. Treat., Co-thickening, Anaerobic Digestion and...
- Mainstream Two-Sludge (A/B) Act. Sludge (Two secondaries in series – each w/...
### "PIONEERING" PROCESS MODULES

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<td>Multiple Hearth Energy Recovery</td>
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CHEMICALLY ENHANCED PRIMARY CLARIFICATION

CEPT

15% Increase in Biogas
17% Decrease in aeration
THERMAL HYDROLYSIS

Biogas 18% increase
Biosolids 22% decrease
TAKE HOME MESSAGES

- Base energy use and optimized operation strongly dependent on specific configuration
- What technologies apply to you?
  - Optimize existing processes
  - Combined heat/power
  - Chemically enhanced primary treatment
  - Co-digestion
  - Thermal hydrolysis/pretreatment
  - Future treatment technologies
THERMAL HYDROLYSIS
**THE BASICS**

*Hydrolysis*

- Solubilisation of the cellular material

*Thermal*

- Done by applying heat — it’s just a pressure cooker!
THP INSTALLED CAPACITY
THERMAL HYDROLYSIS PROCESS (THP)

• Batch Heat Sterilization
  • Hold sludge for 30 min at 170 °C (340 °F), 6 bars
  • USEPA alternate 1 time/temp Class A batch – no reactivation

• Destruction of Extra Cellular Polymeric Substances
  • Sludge dewatering 10 percentage points increase
  • Lower viscosity – increased digester capacity

• Hydrolysis of insoluble COD
  • Rapid digestion, 10 days HRT, 60% VSR
TYPICAL CONFIGURATION

WHAT IS THERMAL HYDROLYSIS?
HEAT TREATMENT DENATURES EXTRACELLULAR PROTEINS

- 1 gram ECP binds 5 gram water

Barjenbruch and Kopplow, University of Rostok, 2003
The effect of different treatments on the extra cellular polymer content of activated sludge
- THP sludge behaves differently to conventional sludges

Rheogram to compare 12% Hydrolysed sludge with digested sludges of 7 to 8% DS

- Hydrolysed
- 8% DS digested sludge
- 7.6% DS digested sludge
Dewatered 15-18%  
Cambi hydrolyzed sludge at 12-13% (pre-dilution)  
Digested sludge 6% DS  
Dewatered biosolids cake at 30-35%DS
EFFECT OF THERMAL PRETREATMENT DIGESTION OF WASTE ACTIVATED SLUDGE

## SUMMARY – DIFFERENCES BETWEEN CONVENTIONAL AND POST THP DIGESTERS

<table>
<thead>
<tr>
<th>Control parameters</th>
<th>&quot;Cambi&quot; digester</th>
<th>Conventional digester</th>
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<tbody>
<tr>
<td>Retention time</td>
<td>10-15 days</td>
<td>15-20 days</td>
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<tr>
<td>Digester Volume</td>
<td>&lt; ½ of conventional</td>
<td>1</td>
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<tr>
<td>DS feed</td>
<td>9 – 12%</td>
<td>4 – 6%</td>
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<tr>
<td>VS load</td>
<td>5-7kg/m(^3)/day (300-400 lb/1000 cuft)</td>
<td>2-3 kg/m(^3)/day(100-200 lb/1000 cuft)</td>
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<tr>
<td>pH</td>
<td>7.5-8</td>
<td>6.8-7.5</td>
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<tr>
<td>Temperature</td>
<td>38-42(^\circ)C (100-108F)</td>
<td>35-37(^\circ)C</td>
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<tr>
<td>VFA / Total alkalinity</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>Ammonium</td>
<td>2000-3000 mg/l</td>
<td>600-1000 mg/l</td>
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<tr>
<td>Gas quality</td>
<td>65-68% CH(_4), H(_2)S low</td>
<td>60-65% CH(_4), H(_2)S high</td>
</tr>
<tr>
<td>Foaming bacteria</td>
<td>None</td>
<td>Nocardia, Microthrix</td>
</tr>
</tbody>
</table>
WHAT IS THERMAL HYDROLYSIS?

**CAMBI**

**PULPER**

- **SLUDGE FEED (CONTINUOUS)**
- **16% DS**

**REACTORS (2 TO 6)**

- **320 °F**
- **90 PSI**
- **HOLD FOR 30 MIN**

**FLASH TANK**

- **DEPRESSURISE TO 45 PSI**
- **DEPRESSURISE TO JUST ABOVE ATMOSPHERIC PRESSURE**
- **SLUDGE DISCHARGE (CONTINUOUS)**
- **225 °F**
- **14% DS**

**RECIRCULATION**

Heat (Steam)
WHAT IS THERMAL HYDROLYSIS?

VEOLIA EXELYS

SLUDGE FEED (CONTINUOUS) >22% DS

Steam

PLUG FLOW REACTOR

REACT @ 320 °F, 90 PSI

PRE HEAT BOILER FEED

HEAT RECOVERY

SLUDGE 140–220°F

DILUTION WATER

10-12% DS
WHAT IS THERMAL HYDROLYSIS?

LYSOTHERM

THERMAL OIL
HEATED FROM CHP
EXHAUST

PRE-HEATING WITH WATER TO SLUDGE HX
USING DOWNSTREAM HEAT RECOVERY

SLUDGE FEED
(CONTINUOUS)

<7%DS

REACT @ 320°F, 90 PSI
PLUG FLOW REACTOR
30 - 60 MINUTE RETENTION

SLUDGE DISCHARGE

Black & Veatch  4 December 2013
BATCH THERMAL HYDROLYSIS PROCESS SCHEMATIC

- Foul Gas Control
  - Pulper
  - Reactors
  - Flash Tank
  - Steam Exchanger
  - Anaerobic Digestion Complex
  - Digested Sludge EQ Tank

16% Solids
14% Solids 95°C 1 bar
14% Solids 170°C 6 bar 30 min
7% Solids 40°C 1 bar
11% Solids 85°C 1 bar
14% Solids 105°C 1.1 bar
STEAM CONTROL

Steam Valve Open Control for Single Cambi Reactor

- Period 1: Sludge filling, valve at "Min" position
- Period 2: Valve open ramps up from "Min" to "Max"
- Period 3: Valve at "Max" position
- Period 4: Valve at "Int" position
- Period 5: Valve under PID control
- Period 6: Valve closes down
STEAM DEMAND – MATCH BOILER OUTPUT
• 275 ton DS/d
• Doubling capacity of existing 8 x 2Mgal digesters
• 4x5 reactor Cambi THP
• 10 MW electricity
• Pasteurized product
• High dry solids final product
• Maximized VS reduction
• 10 megawatts of electricity
MAJOR IMPACTS

- Less digester volume required
- Higher VS conversion in digesters
- More biogas
- Less dry solids for disposal
- Better dewaterability
- Pathogen free product for land application
- Reduced digester foaming
CHALLENGES

• Requires high pressure steam
• Requires pre-screening and pre-dewatering (Cambi and Exelys)
• Increases sidestream loads of P and N
• Odors prior to digestion.
THANK YOU!

QUESTIONS?
Building a world of difference.

Together

BLACK & VEATCH
EFFECT OF THERMAL HYDROLYSIS NOT ZIMPRO

![Graph showing the effect of thermal hydrolysis on dewaterability and digestibility at different temperatures for Autoclave, Cambi, and Zimpro.](image)

- **Dewaterability**
- **Digestibility**
DEWATERABILITY AFTER DIGESTION OF WAS ONLY HYDROLYSED SLUDGE IN ADMIXTURE WITH PRIMARY SLUDGE

36% improvement in dewaterability
## SOURCES OF RENEWABLE ENERGY AT WATER RECLAMATION FACILITIES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (MMBtu/MG)</th>
<th>Equivalent Electrical Energy (KWh/MG)</th>
</tr>
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<tbody>
<tr>
<td>Thermal energy</td>
<td>75</td>
<td>22,000</td>
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<tr>
<td>Chemical energy</td>
<td>17</td>
<td>5,100</td>
</tr>
<tr>
<td>Hydraulic energy</td>
<td>0.033</td>
<td>10</td>
</tr>
</tbody>
</table>

### Assumptions
- Influent COD 358 mg/L (ENER1C12 models)
- Chemical energy 5,971 Btu/lb COD (ENER1C12 models)
- Heat energy $\Delta T=5$ °C
- Hydraulic energy of 3 feet head

### Notes
1. Assumes 100% conversion
Electricity Requirements for Activated Sludge Wastewater

Derived from data from the Water Environment Energy Conservation Task Force *Energy Conservation in Wastewater Treatment*

## BASELINE

<table>
<thead>
<tr>
<th>Source</th>
<th>Value kWh/MG</th>
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<tr>
<td>MOP32, 2009</td>
<td>1,203</td>
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<tr>
<td>Wisconsin Study (SAIC, 2006)</td>
<td>2,300</td>
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<tr>
<td>WERF Fact Sheet (WERF, 2011)</td>
<td>1,107 – 1,741</td>
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</tbody>
</table>
ENERGY BALANCES
1. Dewatered 15-18% DS

Digested sludge 6% DS

Mix of digested sludge (3/4) and hydrolyzed sludge (1/4) to digester. 7-8% DS

Cambi hydrolyzed sludge at 12-13% DS (pre-dilution)

Dewatered biosolids cake at 30-35% DS
CAMBI - HOW DOES IT WORK?

- Fill
- Heat
- Hold (170°C 20 to 30 min)
- Let down
- Blow down

Dewatered sludge feed → Pulper (97°C) → Reactor (170°C) → Flash tank (102°C) → To digester

Process gas

Steam

Re-used
INTRODUCTION

Advanced digestion drivers:

- Pathogen reduction
- Better sludge product
- Improved dewaterability
- Increased biogas production
- Improved digestion efficiency
  - Thicker sludge
  - Control of foaming
  - Less (or re-use) of digestion infrastructure

Dublin Bay STC, Ireland
CONCLUSIONS

- Advanced digestion technique = Thermal hydrolysis
- Pre-treatment stage to digestion
- Physical/mechanical process due to cell destruction.

Advantages include increase of VSD, biogas production, product quality, as well as decrease in digester capacity requirement.
Biogas Treatment and Combined Heat and Power (CHP)

Pre-Dewatering → Thermal Hydrolysis → Mesophilic Anaerobic Digestion

Final Dewatering → Class A Loadout

Emissions → Biogas → Steam

Recycling/Processing

Biosolids Imports
Energy Balance
Digestion
Post Digestion Dewatering
Dewatering Liquors

Centrate Recycle
CAMBI THP AT DUBLIN'S RINGSEND SEWAGE TREATMENT WORKS
LYSOTHERM

Diagram showing a process involving thermal oil, plug flow reactor, preheating, reactor, cooling, and hydrolysate to digester.
THERMAL HYDROLYSIS PROCESS (THP)

- Lysis – breaking apart
- Hydro – with water (solubilization)
- Thermal – with heat
CONVENTIONAL ANAEROBIC DIGESTION

- Hydrolysis / acidogenesis is achieved by bacteria
- Conversion of organics is limited by access to COD contained in extracellular polymeric substances (EPS) and cells
- Dewaterability is limited by EPS and cell water
- Pathogens are reduced but not eliminated
WITH THERMAL HYDROLYSIS

- Thermal hydrolysis breaks open cells and solubilizes EPS
- Cell and EPS COD is made available for digestion
- High temperature kills bacteria and pathogens
- Water contained in cells is freed for dewatering
Batch THP

- Fill
- Heat
- Hold
- Empty

Energy Recovery

Biosolids → Heat (Steam) → Hold (320°F, 90 psi) → Empty → Output

e.g. Cambi, Kruger / Veolia Biothelys
CONTINUOUS THP

Energy Recovery

Biosolids

HX

Heat

Hold

320°F 90 PSI

HX

Output

Heat (Steam)

e.g. Kruger / Veolia Exelys SH+E Lysotherm
## “PIONEERING” PROCESS MODULES

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WHAT IS THERMAL HYDROLYSIS?

BATCH VERSUS CONTINUOUS

• BATCH
  • Established technology
  • Variable heat demand
  • Clear ‘lock in’ for time & temperature
  • More complex?

• CONTINUOUS
  • Emerging technology
  • Constant heat demand
  • Relies on plug flow for time & temperature
  • Less complex?
# AMMONIA CONCENTRATION IN DIGESTERS

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<th>VS DESTRUCTION</th>
<th>50%</th>
<th>51%</th>
<th>52%</th>
<th>53%</th>
<th>54%</th>
<th>55%</th>
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<th>58%</th>
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**CONVENTIONAL**

**THP**
Conventional Activated Sludge with Primary Treatment; WAS
Mechanical Thickening, Anaerobic Digestion, Dewatering, and CHP
Configuration CEPT - Plant Energy Balance

Legend
- COD [MJ/d]
- Electricity [kWh/d]
- Fuel [MJ/d]
- Heat [MJ/d]

Energy Flow Line Thicknesses are Equivalent:
1 kWh/d = 3.6 MJ/d = 142.2 BTU/hr

4 December 2013
FIN / FAN COOLER

When the outside air temperature is high, a hot day, water is sprayed onto fins and evaporates to add cooling effect.

Normally fans pull air across the fins and cool the water/glycol mix.