Production of bioplastics as by-products of waste treatment

Fernando Morgan, Anton Karlsson, Simon Bengtsson, Alan Werker, Steven Pratt*, Paul Lant*, Per Magnusson, Peter Johansson
AnoxKaldnes AB, Sweden

*Neptune Partners
Advanced Water Management Centre, The University of Queensland, Australia

Wastewater treatment - biorefinery for environmental protection

...An organic waste biorefinery for biodegradable polymers and biobased platform chemicals with energy production and low sludge production...

F Morgan-Sagastume et al. 2010. AnoxKaldnes AB
Content

- Objective
  - To present a promising vision in organic waste cycling

- Linear life of conventional plastics
- Polyhydroxyalkanoate (PHA) bioplastics

- Industrial wastewater treatment plants as biorefineries producing PHAs
- PHAs from wastewater and biosolids

Petroleum-based plastics

- Extensively used, but produced from a non-renewable resource

<table>
<thead>
<tr>
<th>Region / Country</th>
<th>Plastic waste (million tonnes / yr)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU 2005</td>
<td>30</td>
</tr>
<tr>
<td>USA 2007</td>
<td>31</td>
</tr>
<tr>
<td>OECD Countries 2005</td>
<td>70</td>
</tr>
</tbody>
</table>

OECD Environmental Data 2008; US EPA 2007

Plastics in municipal solid waste in USA

Municipal solid waste

Recovery

PET HDPE PVC LCPF PP OTHER

F Morgan-Sagastume et al. 2010. AnoxKaldnes AB
Plastics accumulate and impact ecosystems

Polyhydroxyalkanoate (PHA) bioplastics

- Microbial short-chain length (scl) polyesters: 3-5 C
- Intracellular storage compounds – energy and C source
  - G- and G+ bacteria: ~75 genera, 300 species
  - Pure and mixed cultures under growth-limiting conditions

Biologically produced from renewable resources
Biodegradable
Thermoplastic
Biocompatible

F Morgan-Sagastume et al. 2010. AnoxKaldnes AB
Production of commercial PHAs

Pure cultures and transgenic plants


F Morgan-Sagastume et al. 2010. AnoxKaldnes AB

PHA production with open, mixed microbial cultures

- Towards cost effectiveness
  - Recombinant organisms: bacteria, plants, yeasts
  - Other C sources: molasses, sucrose, lactose, glycerol, oils
  - Open, mixed cultures: no sterilization and cheaper C sources
    - Harnessing a selective pressure by dynamic conditions

- Substrate dynamics – Aerobic Dynamic Feeding or Feast-Famine
  - Volatile fatty acids (VFAs) used for culture enrichment

- Electron- acceptor (oxygen) dynamics – anaerobic/aerobic cycling


F Morgan-Sagastume et al. 2010. AnoxKaldnes AB
Mixed culture synergies and opportunities

Wastewater biotreatment \(\rightarrow\) PHA production

Aerobic \(\left(\text{O}_2\right)\) processes

Carbon (Wastewater) \(\rightarrow\) Waste biomass \(\rightarrow\) PHA production

Wastewater Biosolids \(\rightarrow\) Resources

Acidogenic fermentation

VFA spectrum depends on wastewater, pH and retention time

- Control of VFA and final PHA monomers in fermenters

- However, full VFA fermentation may not be required with readily degradable carbohydrates (Fruit cannery effluents; Gurieff, 2008)

Industrial wastewaters for PHA production

- VFA mixtures (acetate, propionate)
- Food waste
- Olive and palm oil mills effluents
- Sugar-cane molasses
- Diary effluent
- Paper mill effluents
- Fruit and tomato cannery effluents
- Brewery effluent
- Municipal wastewaters

Acidogenic fermentation

VFA production from Carbohydrate-rich effluents

F Morgan-Sagastume et al. 2010. AnoxKaldnes AB

PHAs production from wastewater at lab scale

**Fermentation → Enrichment → Accumulation → DSP**

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Enrichment reactor</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar cane molasses</td>
<td>SBR</td>
<td>Albuquerque et al., 2007</td>
</tr>
<tr>
<td>Paper mill</td>
<td>Activated sludge</td>
<td>Bengtsson et al., 2008</td>
</tr>
<tr>
<td>1° sludge or cannery</td>
<td>SBR</td>
<td>Gurieff, 2008</td>
</tr>
</tbody>
</table>

**Diary effluent**

*F Morgan-Sagastume et al. 2010, AnoxKaldnes AB*

**Production of polyhydroxyalkanoates by activated sludge treating a paper mill wastewater**

*Simulation model analysis made by Ralf Kötter, University of Stuttgart, Germany, January 2008*

**Sequencing batch reactors (SBRs) enriching for PHA-accumulating organisms**

**PHA accumulation in fed batch**

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Batch PHA production (g PHA / g dry biomass)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar cane molasses</td>
<td>0.30</td>
<td>Albuquerque et al., 2007</td>
</tr>
<tr>
<td>Paper mill</td>
<td>0.48</td>
<td>Bengtsson et al., 2008</td>
</tr>
<tr>
<td>1° sludge or cannery</td>
<td>0.32-0.39</td>
<td>Gurieff, 2008</td>
</tr>
</tbody>
</table>

*Westerberg, Werker, Linden (2008),*  

- Yields of 50% polymer in biomass accumulation attainable  
- Overall yields: 0.10 to 0.20 g PHA/g COD influent

*F Morgan-Sagastume et al. 2010, AnoxKaldnes AB*
PHA from biosolids

- Biosolids – major operating costs in WWTPs
- Waste activated sludge and 1st solids pretreated with high-pressure thermal hydrolysis (solubilised sludge)

**Fermentation into VFAs**
- VFA levels = 20 g VFA\textsubscript{COD}/L
- Yield 50% (g VFA\textsubscript{COD}/gCOD\textsubscript{sol} in)

**Enrichment in SBRs**
- At high organic loadings 6 g COD/Ld
- High N and P levels
- Non-VFA COD

**Batch PHA accumulation**
- 0.25 g PHA/g dry biomass
- 0.33-0.46 PHA Cmol/VFA Cmol
- Under high N and P levels

**Downstream processing to final product**
- Most costly stage in PHA production and critical
- Optimise for lower PHA content and other matter

**Pretreatment** → **Extraction** → **Purification**
- 40% → 60% → 90% → 100%

**Polymer properties by a suite of techniques**
- Content / composition
- GCMS and FTIR
- Molecular weight
- SEC
- Thermal properties
- DSC
- TGA
- Viscoelasticity
- Melt rheology

**Final product**
- PHB-PHV with flexible processing potential
- High molecular weights: 500,000 – 1,000,000 g/mol
- High thermal stability

F Morgan-Sagastume et al. 2010. AnoxKaldnes AB
Concluding remarks

- Wastewater treatment can be coupled to the production of PHA bioplastics taking advantage of the existing open, mixed cultures and renewable resources
  - Reduction of waste sludge, aeration and nutrient costs complementing energy and mineral recovery - biorefinery
Acknowledgements

• Truke Smoor, Kristina Hedren, Adrian Ho, Karen Westerberg, Petter Lind, Kristina Berglund, Elise Blanchet, Mariana Voltolini, Sara Johansson, Lamija Karabegovic.

• Frans Maurer and Patric Jannasch (Lund University). Stéphane Déléris, Pierre-Alain Hoffmann, Dores Cirne, Emmanuel Trouvé (Veolia Environnement). Nicholas Gurieff (Kruger AS). Maria Reis and Paulo Lemos (FCT/Universidade Nova de Lisboa).

• This study was partly supported by the EU Neptune project (Contract No 036845, SUSTDEV-2005-3.II.3.2), which was financially supported by grants obtained from the EU Commission within the Energy, Global Change and Ecosystems Program of the Sixth Framework (FP6-2005-Global-4)