The conversion of food waste and biological sludge into bio-based products: a pilot scale platform for urban waste management

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**Circular economy: from waste to resource**

New Circular Economy Action Plan 2020 (EC)

- New focus on **product design phase**

- 2.5 billion tonnes of waste generated each year in EU (EPRS, 2016)

- **Problematic disposal for most of categories** (esp. Sewage sludge and organic fraction of municipal solid waste in urban areas)

- Waste framework directive 2008/98/EC (old)

- Few technologies to recover resources applied as **isolated systems**
Biorefineries: transforming treatment plants into resource recovery facilities

**URBAN CONTEXT**

SOURCE SORTED WASTE = RENEWABLE SOURCE OF CARBON

MUNICIPAL WWTP

ADDITIONAL TREATMENT STAGES

VIRGIN MATERIALS FROM RECOVERED RESOURCES
e.g. Biofuels, biopolymers, etc.
Feed characteristics

OFMSW* (30-35% v/v) - SS mixture (65-70% v/v)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Jan-Jun 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS</td>
<td>gTS/kg</td>
<td>60 ± 5</td>
</tr>
<tr>
<td>TVS</td>
<td>gTVS/kg</td>
<td>49 ± 4</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>4.9 ± 0.3</td>
</tr>
<tr>
<td>COD\text{VFA}</td>
<td>gCOD/L</td>
<td>2.8 ± 0.5</td>
</tr>
<tr>
<td>COD\text{SOL}</td>
<td>gCOD/L</td>
<td>22.8 ± 0.4</td>
</tr>
<tr>
<td>TKN</td>
<td>gN/kgTS</td>
<td>29 ± 3</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>gP/kgTS</td>
<td>2.5 ± 0.6</td>
</tr>
<tr>
<td>N-NH$_4^+$</td>
<td>g/L</td>
<td>0.31 ± 0.02</td>
</tr>
<tr>
<td>P-PO$_4^{3-}$</td>
<td>g/L</td>
<td>0.20 ± 0.01</td>
</tr>
<tr>
<td>COD\text{SOL}:N:P</td>
<td>g</td>
<td>100 : 7.4 : 1.5</td>
</tr>
</tbody>
</table>

* Slurry after OFMSW squeezing
### Treviso (TV) WWTP ATS S.r.l.
(Alto Trevigiano Servizi – North East Italy)

#### Pilot plant platform experimental area

<table>
<thead>
<tr>
<th>OFMSW-Sludge Anaerobic Co-digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feed characteristics</strong></td>
</tr>
<tr>
<td>Flow, m³/d</td>
</tr>
<tr>
<td>TVS, %TS</td>
</tr>
<tr>
<td><strong>Operational parameters</strong></td>
</tr>
<tr>
<td>OLR, kgVS/m³d</td>
</tr>
<tr>
<td>HRT, d</td>
</tr>
<tr>
<td>Temperature, °C</td>
</tr>
<tr>
<td><strong>Yields</strong></td>
</tr>
<tr>
<td>Biogas, Nm³/d</td>
</tr>
<tr>
<td>Methane, %</td>
</tr>
<tr>
<td>SGP, Nm³/kg VS (% biowaste)</td>
</tr>
<tr>
<td>TS removal, %</td>
</tr>
<tr>
<td>VS removal, %</td>
</tr>
</tbody>
</table>
Process flowchart

Weekly collected in the WWTP facilities

Squeezed OFMSW
Thickened WAS

Acidogenic fermentation
Production of PHA-precursors (e.g. VFA)

Split of liquid and solid-rich streams

Inoculum

Biomass selection SBR
Selection/enrichment of a mixed consortium

PHA-rich biomass to downstream

Enriched MMC

PHA production
Maximization of PHA content (% wt)

Solid-rich streams

VFA-rich stream

Overflows valorisation and closure of the loop

ACoD

Biogas Bioenergy

Overflows

Weekly collected in the WWTP facilities

Squeezed OFMSW
Thickened WAS
Pilot Plant Biorefinery for PHA production

- Solid/liquid separation units
- Feedstock tank
- Permeate storage tank
- Acidogenic fermenter
- Aerobic reactors
Acidogenic fermentation
Fermenter operating conditions

Feedstock: OFMSW-WAS
(30-40% - 70-60% v/v)

Working Volume = 380 L

Thermal pre-treatment
70°C, 48 h

CSTR
HRT = 6 days
T = 37°C
pH = uncontrolled
Best performances
(heat pretr. + mesophilic fermentation)

- VFA = 30.1 ± 0.4 g COD/L
- VFA/COD$_{SOL}$ = 0.86 ± 0.05
- COD$_{VFA}$ : N : P = 100 : 3.3 : 0.9
OVERFLOWS - Suitable for anaerobic codigestion after dilution with WAS

Acidogenic fermentation effluent → Solid-rich stream (23% TS)

VFA-rich liquid stream + WAS → Anaerobic co-digestion

Solid stream (2% TS) → PHA aerobic line
Anaerobic co-digestion (AcoD)
Operating conditions

Feedstock mixture
1) Thickened WAS
2) Centrifuge solid fraction (cake)
3) Membrane retained phase

Working Volume = 230 L

CSTR
HRT = 15-20 d
OLR = 2.0-3.5 kg VS/m$^3$d
T = 37°C - 55°C
Energy Balance

- Thermally sustainable under mesophilic T (37°C)
- SGP = 0.44 m³/kg VS

Valentino et al., J Cleaner Prod. (2019)
Aerobic PHA line
Sequencing Batch Reactor (SBR) + fed-batch accumulation reactor

Working Volume = 120 L

SBR (biomass production)
HRT = SRT = 2 d
Cycle length = 12 h
OLR = 4.0 kg COD$_{SOL}$/m$^3$ d
T = 25°C - 28°C

Graph showing substrate, PHA, and biomass over time after pulse feeding.

Key:
- Famine
- Feast
- Famine

Biomass
Carbon source
**PHA accumulation and microbial community**

![Graph showing DO, pH, and PHA levels over time](graph.png)

<table>
<thead>
<tr>
<th>Fed-batch accumulation reactor</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum PHA content (g PHA/g VSS)</td>
<td>0.42 - 0.62</td>
</tr>
<tr>
<td>Storage Yield (g PHA/g VFA)$_{COD}$</td>
<td>0.49 - 0.52</td>
</tr>
<tr>
<td>PHA composition (g HB/g HV)</td>
<td>(80-91)/(9-20)</td>
</tr>
</tbody>
</table>

**FISH image**

- green: Bacteria (EUB mix probe)
- orange: *Hydrogenophaga* cells (HYD208 probe)
- 80% of total bacteria
- Scale bar = 10 µm
Mass Balance

- $Y_{Xa/VFA}^{SBR} = 0.55 \frac{COD_{Xa}}{COD_{VFA}}$
- $Y_{P/VFA}^{batch} = 0.61 \frac{COD_{PHA}}{COD_{VFA}}$
- 30% v/v reduction in the S/L separation stage
- 11% OVERALL YIELD kg PHA/kg VS

Moretto et al., ACS Sust Chem & Eng (2020)
Main achievements (1)

Extruder

PBS: Biomer 75:25
PBS: PHA 90:10
PBS: PHA 75:25

stress (Pa)
strain

MD
A

Mechanical tests
Film
Blow molding

PHA (granules)

PHB
F.I.
Extruder

SABIMATERIALS

PBS-PH (granules)

FilmMachanical tests Blow molding

PHB (granules)

SAPIENZA
UNIVERSITÀ DI ROMA

mi-plast
bio-company
Main achievements (2)

- PHA compound in pellet (>90% PHA)
- Prototypes for mechanical tests
- Flexible handle

PHBV compounds with fibers collected from green biowastes

Viretto et al. Waste Management
https://doi.org/10.1016/j.wasman.2020.10.018
Main achievements (3)

Electrospinning

- Multi-layers film for permeability assessment
- Nanoparticles incorporation for properties improvement (active packaging, es. antimicrobial)
- Application as adhesive in substitution of fossil-origin products
Many thanks for your attention

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