Integrated process for PHA production from lignocellulosic waste: A new anaerobic biorefinery

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THESSALONIKI 2021
Lignocellulosic waste

The upcycling of waste biomass into high-added value products can be an attractive route for attaining the circular bio-economy as well as environmental sustainability.

1. Most abundant natural renewable resource
2. Agricultural, forest, and municipal waste
3. Does not compete with food production
Photo-biorefinary

Lignocellulosic Waste\n
Thermal Pretreatment\n
Centrifuge\n
Photo-heterotrophic process by PPBs\n
PHA\n
Bio-H$_2$\n
Proteins\n
Anaerobic digestion\n
Biogas\n
CHP\n
Renewable Electricity\n
Energy recovery
Material and methods

Lab-scale proof of concept

Pruning waste

120 – 150 – 180 °C
1:5 water to SV ratio

Severity factor:

\[ Ro = \int_0^t \exp \left( \frac{T(t) - T_{Ref}}{14.75} \right) dt \]

\( R_o: 2.1 – 3.1 – 3.9 \)

Specific Phototrophic Activity Test (SPA)

Conditions:
45 W m\(^{-2}\) IR Light
1 g DQO L\(^{-1}\)
PPB inoculum

Standard BMP test
Results

Thermal hydrolysis

Figure 1: FTIR spectra of the three hydrothermal pretreatments, 120(pink), 150 (black) and 180 °C (green) and initial (blue) solid phases.

- Solid destruction: 13-29%
- COD solubilization: 9-24%
- DQO/N/P: 100/3/0.5

Figure 2: Comparison of DRX spectra of the raw waste (blue) and the hydrothermal pretreatments solid phases were 120 (pink), 150 (black) and 180 °C (green).

- Crystallinity increase ($CR_I$)

Results

Anaerobic digestion

Figure 3: BMP results and 95% confidence regions for the first-order kinetic parameters.

No elimination of liquid fraction

Elimination of liquid fraction

Control
120ºC
150ºC
180ºC

Potential presence of inhibitory compounds above 180 ºC.

## Results

### Energy integration balance

Table: Energy integration balance. Results were simulated for a combined heat and power (CHP) system for electricity and thermal energy production.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Total Energy biogas kWh t⁻¹</th>
<th>Thermal Output kWh t⁻¹</th>
<th>Electrical Output kWh t⁻¹</th>
<th>Thermal energy required kWh t⁻¹</th>
<th>Electrical balance kWh t⁻¹</th>
<th>Thermal energy balance kWh t⁻¹</th>
<th>Electric output Euro t⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>1343</td>
<td>739</td>
<td>443</td>
<td></td>
<td>428</td>
<td>739</td>
<td>64</td>
</tr>
<tr>
<td>TH-120°C</td>
<td>1343</td>
<td>739</td>
<td>443</td>
<td>154</td>
<td>408</td>
<td>585</td>
<td>61</td>
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<tr>
<td>TH-150°C</td>
<td>1398</td>
<td>769</td>
<td>461</td>
<td>177</td>
<td>426</td>
<td>592</td>
<td>64</td>
</tr>
<tr>
<td>TH-180°C</td>
<td>1693</td>
<td>931</td>
<td>559</td>
<td>210</td>
<td>524</td>
<td>721</td>
<td>79</td>
</tr>
</tbody>
</table>

Positive electrical and thermal balances
Results

Photoheterotrophic process

Figure 4: Comparison of biomass growth (a) and SCOD consumption (b) in the SPA tests using the liquid fraction

Figure 5: Comparison of biomass yield (YX/S) (columns) with specific phototrophic activity (kM x 10) (open squares) and PHA production yield (YPHA) (black circles) in SPA tests

- 37-60% COD consumption
- Nitrogen limitation
- 15-20% PHA in dry mass
Discussion

Prospects and industrial implications

- Current industrial PHA cost: \(\approx 4-8 \text{ € t}^{-1}\)

- The theoretical maximum PHA production yield reported by PPBs is 0.9 \(\text{mol}_{\text{PHA}}\text{mol}_{\text{Acetate}}^{-1}\).* This is vastly higher than any aerobic processes

Conclusions

Key findings

- High temperatures in the thermal pre-treatment lead to better solubilizations, but may produce inhibitory products.
- Up to 180 LCH\(_4\) Kg VS\(^{-1}\) produce in BMP test after removal of liquid fraction
- An energetically sustainable process is achieved.
- Up to 20% PHA in dry mass is accumulated by PPB
- The PPB integrated biorefinery concept offers potential for the reduction of PHA production costs, inviting for future research
Thank you!

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THESSALONIKI2021