Process Development for Hydrothermal Liquefaction of Algae

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Overview

- HTL of various algae species in plug flow reactor
- Conversion of HTL Water Organics
- Recovery of nutrient from HTL Water
- Process to recycle HTL Water nutrients

**Flue Gas**

**Wastewater**

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**HTL Reactor**

250-374 °C
40-220 bar

15-30% algae

**HTL water**

**Cleaning/Reforming**

**HTL water**

**Algal Crude**

**Upgrading Facility**
### Algal-crude yields and properties

<table>
<thead>
<tr>
<th></th>
<th>Nannochloropisis CCMP525 (Marine)</th>
<th>Chlorella sp.</th>
<th>Chlorella vulgaris</th>
<th>Chlorella sorokiniana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry wt, %</td>
<td>18</td>
<td>20</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>Feed, L/h</td>
<td>1.2</td>
<td>1.0</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>C, wt %</td>
<td>69.07 ± 0.25</td>
<td>75.1 ± 0.59</td>
<td>74.36 ± 0.13</td>
<td>73.73 ± 0.1</td>
</tr>
<tr>
<td>H</td>
<td>10.66 ± 0.05</td>
<td>10.7 ± 0.15</td>
<td>11.43 ± 0.26</td>
<td>12.04 ± 0.05</td>
</tr>
<tr>
<td>N</td>
<td>4.55 ± 0.02</td>
<td>6.2 ± 0.12</td>
<td>4.58 ± 0.39</td>
<td>3.83 ± 0.01</td>
</tr>
<tr>
<td>S</td>
<td>0.69 ± 0.12</td>
<td>1.1 ± 0.05</td>
<td>0.64 ± 0.06</td>
<td>0.7 ± 0.01</td>
</tr>
<tr>
<td>O</td>
<td>14.69 ± 0.11</td>
<td>6.7 ± 0.5</td>
<td>8.79 ± 0.30</td>
<td>9.3 ± 0.12</td>
</tr>
<tr>
<td>HHV, MJ/Kg</td>
<td>36.0 ± 0.42</td>
<td>39.6</td>
<td>40.0 ± 0.35</td>
<td>40.52 ± 0.11</td>
</tr>
<tr>
<td>Ash, wt %</td>
<td>0.44</td>
<td>0.24</td>
<td>0.2</td>
<td>0.36</td>
</tr>
<tr>
<td>Algal-crude yields, wt %</td>
<td>40.4</td>
<td>40.7</td>
<td>43</td>
<td>39</td>
</tr>
</tbody>
</table>

- Nannochloropisis CCMP525 (Marine) data obtained from NRC’s Ketch Harbor Facility.
- Chlorella sp., Chlorella vulgaris, and Chlorella sorokiniana data obtained from NRC’s Ketch Harbor Facility.
Similar product profiles were observed irrespective of algae species.
Overall Process: Integration into wastewater sources, nutrient recovery and recycle

- **Harvesting and Conc.**
  - Algae paste: 1/200-1/250
  - Water: > 99%

- **Algae Growth**
  - Flue gas
  - Municipal/Industrial Wastewater (Source of N, P)

- **HTL**
  - HTL Water: N, P, Organics
  - N, P: > ~80%

- **Partial recycle/recovery**
  - Struvite \( \text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O} \)

- **Other products**
  - Fertilizer

- **Algal-crude**
  - Algal-crude
Conversion of HTL Water Organics to Gaseous Products

Conversion: 25-40% at 350 C, 1 hr

C Conversion: 25-40 %
350 C, 1 hr

Pd-Alumina
Ru-Alumina
Ru-Carbon
Conversion of HTL Water Organics to Liquid Products

MoS based catalysts, $H_2$
350 C, 1 hr

Time, min
Conversion of HTL Water Organics to Liquid Products

MoS based catalysts, $H_2$
350 C, 1 hr

Time, min
Struvite as potential by-product

Maximum phosphate recovery from HTL Water: 75%
Nutrient Recycle Process

Scenedesmus sp-AMDD growth

Higher HTL concentrations detrimental for algae growth

<table>
<thead>
<tr>
<th>HTL Concentration</th>
<th>Biomass, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>1583</td>
</tr>
<tr>
<td>WW-1% HTL</td>
<td>135</td>
</tr>
<tr>
<td>WW-0.5% HTL</td>
<td>1387</td>
</tr>
<tr>
<td>WW-0.25% HTL</td>
<td>1530</td>
</tr>
<tr>
<td>WW-0.13% HTL</td>
<td>1407</td>
</tr>
</tbody>
</table>
HTL water at low concentrations could help boost yields of algae.
HTL water with appropriate processing to reduce contaminants increased algae yields by > 60%
Decoupling nutrient recycle from HTL Water using struvite ppt. and NH$_3$ stripping

![Diagram showing the process of decoupling nutrient recycle from HTL Water using struvite ppt. and NH$_3$ stripping.](image)

- **Air**: Red dots.
- **Simulated Flue Gas**: Black dots.

**Graph**:
- **Y-axis**: NH$_4$, mg L$^{-1}$
- **X-axis**: Time, hr

**Legend**:
- **PBR**: Process bio-reactor.
- **HTL Water**: High-temperature loop water.
- **Struvite**: Struvite precipitation.

**Notes**:
- The graph shows the concentration of NH$_4$ over time for both Air and Simulated Flue Gas conditions.
- The process involves the use of struvite precipitation and NH$_3$ stripping to decouple nutrient recycle from HTL Water.
Conclusions and Future Work

- Various species of marine and freshwater algae strains showed similar yields, properties and product composition.

- Around 75% of P in HTL water could be recovered as struvite.

- Nutrient recycle process that would minimize collapse and increase biomass yields using HTL water was developed.

- Potential to produce liquid HC’s from HTL aqueous phase.
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