Harvesting of Microalgae by bio- and autoflocculation

Sina Salim, Marian Vermuë & René Wijffels
Why harvesting?

• A major bottleneck in algal biodiesel production

• Alternative for centrifugation is needed
  – Only suitable for high value products
  – High energy input & costly
    • 30% of total production costs!*

Harvesting

Integrated sustainable harvest methods

• **Pre-concentration**
  Flocculation combined with flotation/sedimentation

• **Post-concentration**
  Dewatering by centrifugation/filtration
Harvesting of microalgae by bio-flocculation

- Technique
- Preliminary kinetics

Addition of bio-flocculant to non-flocculating microalgae:
- Initial sedimentation rate ↑
- Recovery percentage ↑
- Both marine & fresh water microalgae as bio-flocculant

Bio-flocculation: an energy-efficient harvesting technique for microalgae

• Effect of ratio ($R_{fnf}$)
  – Sedimentation kinetics
  – Recovery efficiency

• Reduction in energy
  – Raceway ponds cultivation system (100 ha)

Morphological analysis

E. texensis
C. vulgaris

A. falcatus
C. vulgaris

S. obliquus
C. vulgaris

T. suecica
N. oleobundans

ABO Conference 2013, Orlando, Florida
Sedimentation kinetics at various $R_{fnf}$

- Ettlia texensis
- Ankistrodesmus falcatus
- Scenedesmus obliquus
- Tetraselmis suecica

Initial sedimentation rate (% recovery h$^{-1}$)

$R_{fnf}$

OD$_{750nm}$

Harvesting efficiency %

$OD_{750(t_0)} - OD_{750(t)}$ \( \times 100\% \)

ABO Conference 2013, Orlando, Florida
Recovery at various $R_{\text{fnf}}$

OD$_{750\text{nm}}$ over time for different species:

- **Ettlia texensis**
- **Ankistrodesmus falcatus**
- **Scenedesmus obliquus**
- **Tetraselmis suecica**

Recovery after 180 min (%):
Bio-flocculation: mechanism

Ettlia texensis

Chlorella vulgaris
Bio-flocculation: mechanism

C. vulgaris

E. texensis

C. vulgaris
Bio-flocculation: mechanism

Proteins and carbohydrates in the EPS

EPS extracted from the cell surface and in supernatant
- E. texensis
- C. vulgaris

<table>
<thead>
<tr>
<th>EPS concentration (mg·gDW⁻¹)</th>
<th>Proteins extracted</th>
<th>Proteins supernatant</th>
<th>Carbohydrates extracted</th>
<th>Carbohydrates supernatant</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. texensis</td>
<td>233 (+/- 8)</td>
<td>N.D.*</td>
<td>96 (+/- 10)</td>
<td>35 (+/- 1)</td>
</tr>
<tr>
<td>C. vulgaris</td>
<td>17 (+/- 3)</td>
<td>N.D.*</td>
<td>22 (+/- 3)</td>
<td>50 (+/- 8)</td>
</tr>
</tbody>
</table>

EPS involved in flocculation mechanism
Energy requirement for harvesting

Single step harvesting

<table>
<thead>
<tr>
<th>Device</th>
<th>Energy requirement (MJ.kgDW$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk stack centrifuge</td>
<td>8-16</td>
</tr>
<tr>
<td>Decanter</td>
<td>97</td>
</tr>
<tr>
<td>Evodos centrifuge</td>
<td>7</td>
</tr>
<tr>
<td>Belt filter</td>
<td>5</td>
</tr>
<tr>
<td>Vacuum drum filter</td>
<td>71</td>
</tr>
<tr>
<td>Filter press</td>
<td>11</td>
</tr>
<tr>
<td>Tangential flow membrane filter</td>
<td>37-120</td>
</tr>
</tbody>
</table>

Type of microalgae: Low initial concentration

Pahl SL et al. 2013
Energy requirement for harvesting

Initial cell concentration 0.6 g/L

<table>
<thead>
<tr>
<th>Harvesting technique</th>
<th>Harvesting energy (MJ·kgDW⁻¹)</th>
<th>Energy needed for added flocculant (MJ·kgDW⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single step (centrifugation)</td>
<td>13.8</td>
<td>0</td>
</tr>
<tr>
<td>Two steps (bio-flocculation and sedimentation with centrifugation)</td>
<td>0.24</td>
<td>1.78</td>
</tr>
<tr>
<td>Two steps (chemical flocculation and sedimentation with centrifugation)</td>
<td>8.85</td>
<td>N/D*</td>
</tr>
</tbody>
</table>
Energy requirement for harvesting

Initial cell concentration 5 g /L

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<th>Harvesting technique</th>
<th>Harvesting energy (MJ·kgDW⁻¹)</th>
<th>Energy needed for added flocculant (MJ·kgDW⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single step (centrifugation)</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>Two steps (bio-flocculation and sedimentation with centrifugation)</td>
<td>0.04</td>
<td>1.78</td>
</tr>
</tbody>
</table>
Conclusions

- $R_{\text{f}} \uparrow \rightarrow$ initial sedimentation rate $\uparrow$ until a max was reached

- $R_{\text{f}} \uparrow \rightarrow$ harvesting efficiency $\uparrow$
  - *E. texensis*: highest improvement of harvesting efficiency

- Extra polymeric substances are involved in bioflocculation

- Reduction in total energy for harvesting only significant at low initial cell concentrations
  - Low cell concentration from 13.8 to 2 MJ·kgDW$^{-1}$
  - High cell concentration from 2.2 to 1.8 MJ·kgDW$^{-1}$