Bioreactor Design

Daniel Egger, 08.11.2013
Agenda

What is «Bioreactor Design»?

Why are different bioreactor designs needed?

Specific bioreactor designs
What is a bioreactor?

A device or system that:

supports a biologically active environment.

What is bioreactor design?
What is bioreactor design?

Functionality: depending on application and area of use.
Bioreactor applications

- Microbial
- Cell culture
- Biofuel (2nd generation)
- Biofuel (3rd generation)
- Syngas
Bioreactor applications

- Microbial
- Cell culture
- Biofuel 2nd generation
- Biofuel 3rd generation
- Syngas
Extract of specific requirements

<table>
<thead>
<tr>
<th></th>
<th>Bacteria</th>
<th>Cell culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doubling time</td>
<td>~ 30 min</td>
<td>~ 12 to 48 h</td>
</tr>
<tr>
<td>OUR (oxygen uptake rate)</td>
<td>~ 0.2·10^{-9} mmol Cell(^{-1}) h(^{-1})</td>
<td>~ 4.2·10^{-9} mmol Bact.(^{-1}) h(^{-1})</td>
</tr>
<tr>
<td>Sensitivity (shear...)</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Microbial fermentation: agitation

- Baffles
- Rushton blades
- Smaller bubbles = higher $K_L\alpha$
- Sparger
### Extract of specific functions: agitator

<table>
<thead>
<tr>
<th></th>
<th>Bacteria fermentation</th>
<th>Cell culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even nutrient &amp; temp. distribution</td>
<td>Yes</td>
<td>Main function</td>
</tr>
<tr>
<td>High oxygen transfer ($K_L a$)</td>
<td>Main function</td>
<td>Low</td>
</tr>
<tr>
<td>Energy input</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Bioreactor applications

- Microbial
- Cell culture
- Biofuel 2nd generation
- Biofuel 3rd generation
- Syngas
Biofuel

Fuel that contains energy from geologically recent carbon fixation, produced from living organisms.

## Biofuel

<table>
<thead>
<tr>
<th>1(^{st}) generation</th>
<th>2(^{nd}) generation</th>
<th>3(^{rd}) generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioethanol, Biodiesel from food crops</td>
<td>Bioethanol from lignocellulosic and cellulosic biomass</td>
<td>Biodiesel/Bioethanol from Microalgae</td>
</tr>
<tr>
<td>(corn, sugarcane, raps, soybean…)</td>
<td>(straw, wood, grass…)</td>
<td>(CO(_2))</td>
</tr>
</tbody>
</table>
Cellulosic Ethanol with strong growth

Ethanol demand by region (billion gallons)

- **North America**
  - 2006: 4.1 billion gallons
  - 2020: 30.0 billion gallons

- **Europe**
  - 2006: 0.7 billion gallons
  - 2020: 9.9 billion gallons

- **Brazil**
  - 2006: 4.3 billion gallons
  - 2020: 16.0 billion gallons

- **China**
  - 2006: 0.4 billion gallons
  - 2020: 7.0 billion gallons

- **ROW**
  - 2006: 0.8 billion gallons
  - 2020: 10.0 billion gallons

**Almost half the growth will come from cellulosics**

Note: Mandated demand split by technology according to either mandate or available information on raw material capacity plans for wave 1
Source: RFA; Unica (Brazil); European Commission; FO Licht; Press; McKinsey analysis
Biofuel 2nd generation

- Corn Stover
- Bagasse
- Milled Pine
- Switchgrass
- Poplar
- Ponderosa Pine
Process

Milling → Pretreatment pH ~ 1, > 160°C → Enzymatic Process → Fermentation

- Original 90% DW
- Original milled 90% DW
- After pretreatment 25% DW
- After liquification 12% DW
2 Step process

Cellulose → Enzymatic process → Fermentable sugars → Fermentation → Bio ethanol
1 Step process: simultaneous saccharification & ferm. (SSF)
SSF with a standard microbial fermenter
Solid & liquid agitation
Wheat straw. 31.6% dry matter. Provided by Lund University, Department of Chemical Engineering, G. Zacchi / M. Galbe
pH control
Temperature control

2 Measuring points

Eucalyptus chips. 24.4% dry matter. Provided by Lund University, Department of Chemical Engineering, G. Zacchi / M. Galbe
Extract of specific functions: agitator

<table>
<thead>
<tr>
<th></th>
<th>Solid Phase</th>
<th>Anaerobe fermentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy input</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Even nutrient, Enzyme &amp; temp. distribution</td>
<td>Main function</td>
<td>Low requirement but main funktion</td>
</tr>
</tbody>
</table>
Bioreactor applications

- Microbial
- Cell culture
- Biofuel 2nd generation
- Biofuel 3rd generation
- Syngas
Microalgea
Microalgea

Photoautotrophic organisms

→ complex organic compounds from simple substances: (carbohydrates, fats, and proteins)
Algae products
Biofuel 3rd generation

Challenges and reactor concepts

- Open pond
- Tubular reactors horizontal/vertical
- Flat panel reactors horizontal/vertical
Open ponds

- Extremely simple
- Low energy input
- High evaporation
- Need a lot of space
- Low algae concentration
Key target: high algae concentration

→ Only with tubular or flat panel reactor concept
Tubular reactors

- Medium/high volumetric productivity
- Scale-up possible
- High energy input
- High investment costs
Flat panel reactors

- High volumetric efficiency
- Low energy input
- Medium investment costs
- Scale-up possible
The air lift principle

Assymetric head space
→ Reduction of foam

Baffle

Sparger
→ Sterility & PAT for reproducible high quality data
Laboratory scale photosynthesis

Stirred tank

Flat panel
Stirred tank

- Traditional technology, well established
- Used by many scientists
- Plenty of reference data
- Less light in the center

→ Scale-up difficult
Why two different vessels?

Stirred tank

Pilot scale

1 m
Light intensity

How much light is needed in the lab?

Max. light intensity at noon

- 2000 µmol/m²s → light inhibition
- 1400 µmol/m²s → often optimum
- 800 µmol/m²s → enough for growth

Matthias Loster, 2006

Σ ≈ 18 TWe
## Typical agitator functions (photo bioreactors)

<table>
<thead>
<tr>
<th></th>
<th>Open pond</th>
<th>Tubular bioreactor</th>
<th>Flat panel bioreactor</th>
<th>Stirred tank bioreactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even nutrient</td>
<td>By water wheel</td>
<td>By pump</td>
<td>By gassing</td>
<td>Stirrer</td>
</tr>
<tr>
<td>distribution</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bioreactor applications

- Microbial
- Cell culture
- Biofuel 2nd generation
- Biofuel 3rd generation
- Syngas
Syngas fermentation

Very specific requirements

- Toxic
- ATEX
- Low CO transfer into water
- Complex control strategies
- Very slow co-substrate feeding

→ Solutions on the way
Thank you!