Development of a novel top-lit gas-lift bioreactor for algal cultivation and CO$_2$ mitigation of industrial off-gas

Nekoo Seyed Hosseini $^1$, Helen Shang $^1$, Gregory M Ross $^2$ and John A Scott $^{1,2}$

$^1$ Bharti School of Engineering, Laurentian University, Canada
$^2$ Northern Ontario School of Medicine, Canada
Microalgae: third generation biofuel & CO₂ mitigation

- Sunlight
- Initial microalgae + Nutrients (e.g., N, P)
- CO₂

Controlled stress (pH, temperature, nutrient limitation)

- Increased biomass (1.8 kg CO₂ = 1 kg biomass)
- Increased microalgal lipids
- Biodiesel

Industrial off-gas
Microalgae cultivation in open and closed systems

<table>
<thead>
<tr>
<th>Factors</th>
<th>Open System</th>
<th>Closed System</th>
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</thead>
<tbody>
<tr>
<td>Capital investments</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Required area</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Light utilization</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Mixing efficiency</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Gas transfer efficiency</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Major issues: open systems have limited productivity

Open raceway oval ponds -
the foremost outdoor
large-scale cultivation option

Limitations:

• Shallow operational depth (0.15-0.3 m)
• Large land space requirements
• CO$_2$ diffusion
• Mixing
• Maintaining required growth temperature (cold climates)
A solution: use a gas-lift system to enable deeper ponds

Gas-lift system – promising alternative
- Simple design
- Good mixing
- Low rate of shear stress
- Scale-up

Our core concept:
Use gas-lift systems with CO₂ rich industrial off-gas to provide a carbon source, agitation and heat
One-meter deep laboratory gas-lift bioreactors

(Right-hand column is uncovered for display purposes)
Advantages of the bioreactor

- Smaller footprint on industrial sites
- Larger operational volume
- Enhanced vertical mixing
- Increased CO$_2$ mass transfer rate from off-gas
- Increased heat transfer rate from off-gas
- Improved light utilization efficiency
- Low capital, maintenance and operation costs
Growth profiles with enhanced CO$_2$ levels

Error bars show the standard error of triplicate experiments.
Lipid content (%) & volumetric production (g_{lipid}/L)

- **Content:** Air (0.038% CO₂)
- **Content:** Air + 3% CO₂
- **Content:** Air + 6% CO₂

### Lipid content (%)

- **Content:** Air (0.038% CO₂)
- **Content:** Air + 3% CO₂
- **Content:** Air + 6% CO₂

### Volumetric production

- **Volumetric production:** Air (0.038% CO₂)
- **Volumetric production:** Air + 3% CO₂
- **Volumetric production:** Air + 6% CO₂

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**Day:** 0 | 7 | 15 | 21
---|---|---|---
**Lipid content (%)** | 15 | 15 | 15 | 15
**Volumetric production (g_{lipid}/L)** | 0.12 | 0.14 | 0.16 | 0.18

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**Legend:**
- Green, striped: Content: Air (0.038% CO₂)
- Dark green: Content: Air + 3% CO₂
- Orange: Content: Air + 6% CO₂
- Green, filled triangle: Volumetric production: Air (0.038% CO₂)
- Green, filled square: Volumetric production: Air + 3% CO₂
- Green, filled triangle: Volumetric production: Air + 6% CO₂
# Traditional raceways compared to the top-lit gas-lift bioreactor

<table>
<thead>
<tr>
<th></th>
<th>Traditional raceways</th>
<th>Gas-lift</th>
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</thead>
<tbody>
<tr>
<td><strong>Depth (cm)</strong></td>
<td>15-30</td>
<td>100</td>
</tr>
<tr>
<td><strong>Volumetric Productivity</strong> ( (g_{dw} \text{ L}^{-1} \text{ day}^{-1}) )</td>
<td>0.05-0.08</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Areal Productivity</strong> ( (g_{dw} \text{ m}^{-2} \text{ day}^{-1}) )</td>
<td>20-25</td>
<td>61.1</td>
</tr>
<tr>
<td><strong>CO}_2 \text{ Sequestration rate</strong> ( (g_{CO}_2 \text{ m}^{-2} \text{ day}^{-1}) )</td>
<td>35-40</td>
<td>109.8</td>
</tr>
<tr>
<td><strong>Lipid content (%)</strong></td>
<td>12-15</td>
<td>18-20</td>
</tr>
</tbody>
</table>
Effect of operational parameters

Three main parameters:

- Dispersion height (5-30 cm)
- CO$_2$ Concentration (0-6%)
- Gas flow rate (0.002-0.008 m/s)
Impact of CO$_2$ % & dispersion height on algae growth

Gas flow rate = 0.002 m/s

Dispersion height = 5 cm

Dispersion height = 30 cm
Statistical Analysis

• Dispersion height does not have a significant effect on biomass productivity
• Increasing \( \text{CO}_2 \) concentration enhances biomass and lipid productivity
• Lower gas flow rates result in higher productivity
Conclusions – top lit gas-lift bioreactors

- Same volumetric productivity as open raceway systems
  - But three times higher biomass productivity per unit area than open raceway systems

- Deeper tanks lead to a smaller footprint on an industrial site
  - Can be located close to an off-gas/CO₂ source which can be used to enhance lipid (biodiesel) productivity