

# Computational analysis of hydrodynamics and light distribution in algal photo-bioreactors

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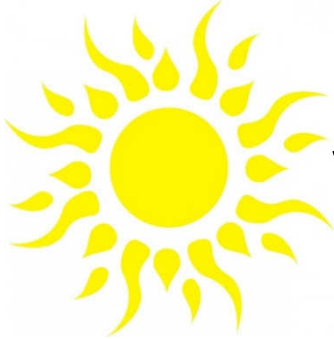
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- Motivation
- System description
- Results
  - Hydrodynamics
  - Particle tracing
  - Light intensity
  - Different shapes of reactor
- Outlook

# MOTIVATION

microalgae

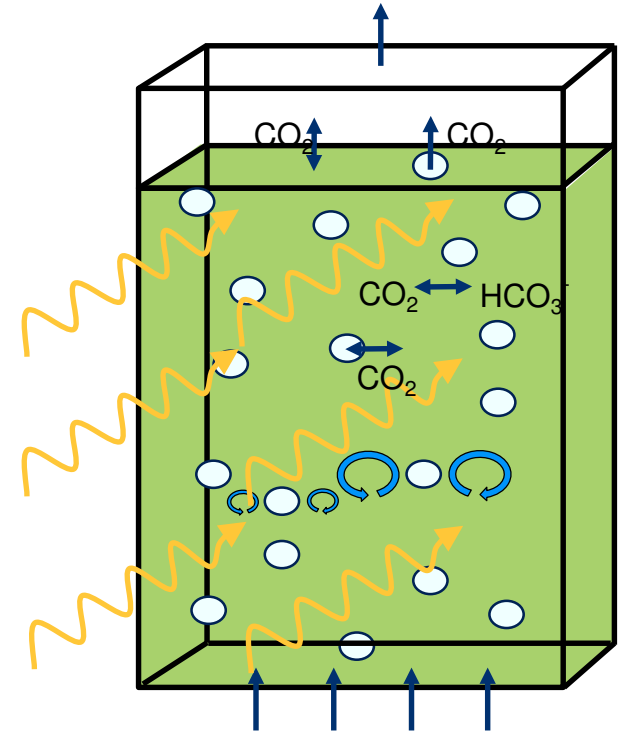


scale up

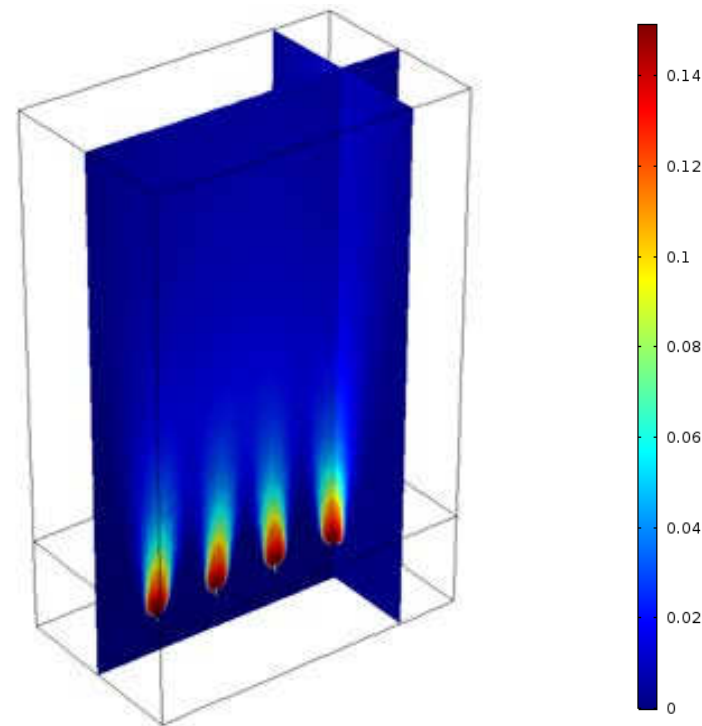
biofuel

# SYSTEM DESCRIPTION

- **Laboratory Photobioreactor (PBR)**  
Size is 10 x 6 x 21cm
- **Hydrodynamics:** The system is highly heterogeneous and requires the study of turbulence
- **Light Profile:** The distribution of light needs to be studied as light is scattered and absorbed by algae
- **Mass Transfer:** Amount of  $\text{CO}_2$  transferred from gas to liquid is studied
- **Reactor Shapes:** Different shapes of the reactor are studied to minimize dead zones

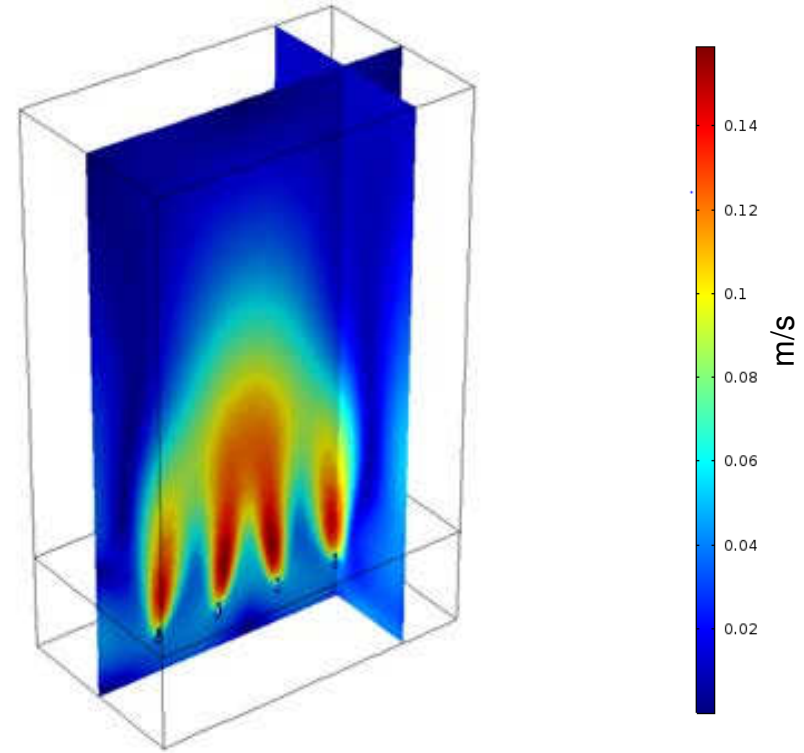


- Turbulent Bubbly Flow module was used to solve the Navier–Stokes equations
- $k$ - $\varepsilon$  model was implemented to include the effect of turbulence
- Inlet pipe was removed to speed up the simulations
- Bubble diameter is assumed constant



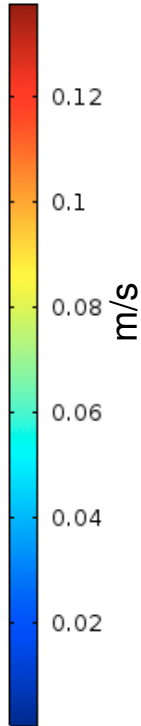
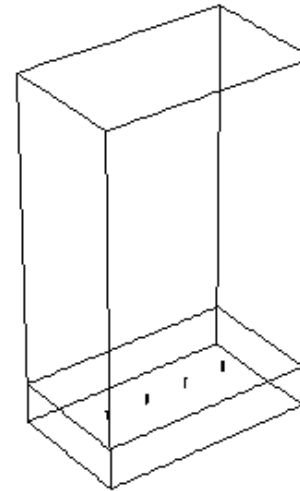
Gas phase volume fraction profile along 2 perpendicular planes

- Time dependent simulations were performed and their results used as input for stationary simulations
- 1<sup>st</sup> order discretization was implemented for both velocity and pressure
- Direct solvers were used to solve the discretized equations



Liquid phase velocity profile along 2 perpendicular planes

- Using the liquid phase velocity data from the hydrodynamic simulations, the paths of algae cells were traced using COMSOL's Particle Tracing Module
- Drag force is the only force affecting the movement of the algae cells
- A random turbulent dispersion was added to the velocity from the hydrodynamic data to account for the randomness because of turbulence



Radiative Transfer Equation:

$$\frac{\partial I(s, \lambda)}{\partial s} = \underbrace{-\kappa I(s, \lambda)}_{\text{Absorption}} \underbrace{-\sigma I(s, \lambda)}_{\text{Out-Scattering}} + \underbrace{\frac{\sigma}{4\pi} \int_{4\pi} I(\hat{s}', \lambda) \varphi(\hat{s}, \hat{s}') d\Omega}_{\text{In-Scattering}}$$

- Light intensity is homogeneously incident on one surface of the reactor
- Absorption and out-scattering reduce the intensity from direction  $s$
- In-scattering term accounts for the light that is removed from other directions and is added to the current direction  $s$

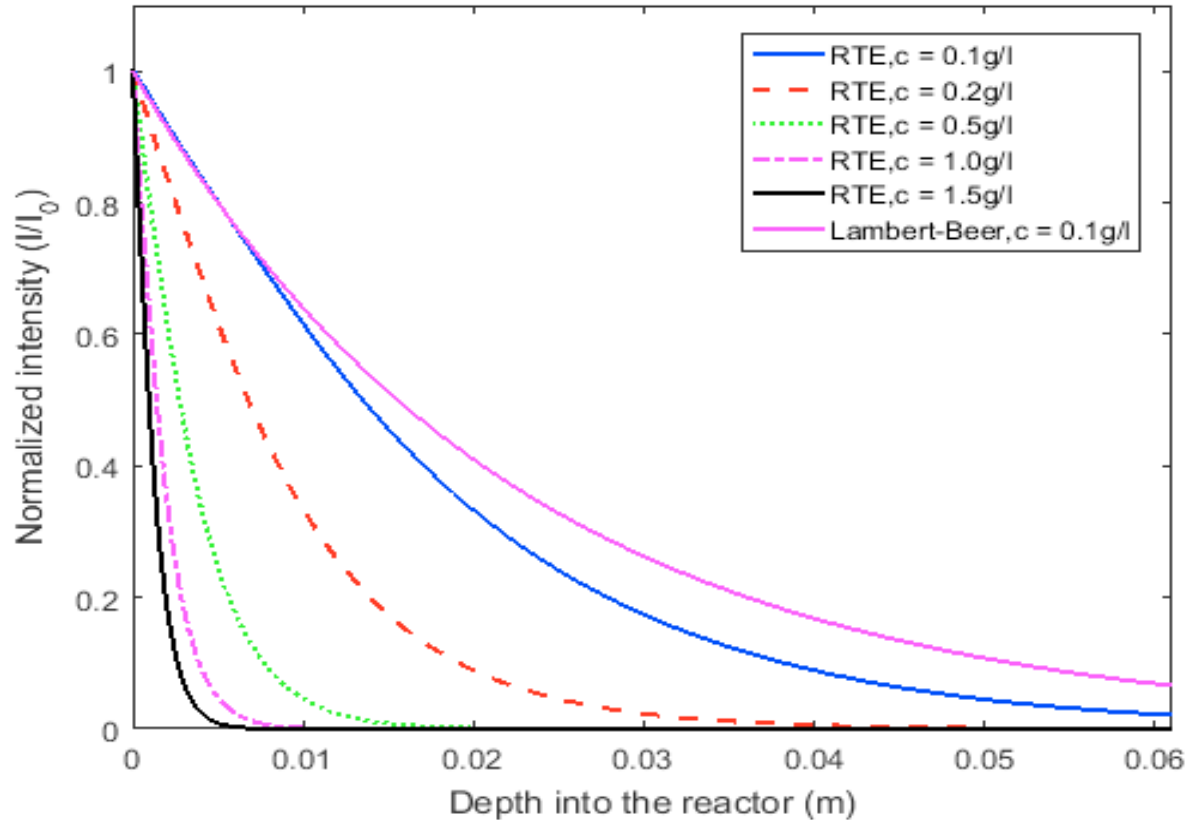


Radiative Transfer Equation:

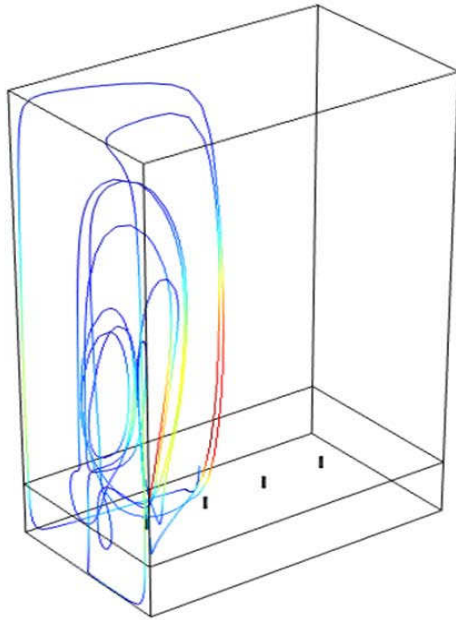
$$\frac{\partial I(s, \lambda)}{\partial s} = -\kappa I(s, \lambda) - \sigma I(s, \lambda) + \frac{\sigma}{4\pi} \int_{4\pi} I(\hat{s}', \lambda) \underbrace{\varphi(\hat{s}, \hat{s}')}_{\text{phase function}} d\Omega$$

- COMSOL's RTE solver (Heat Transfer Module) does not contain the phase function needed in this specific case
- A MATLAB code was written to calculate the intensity at each discretized points in the PBR.

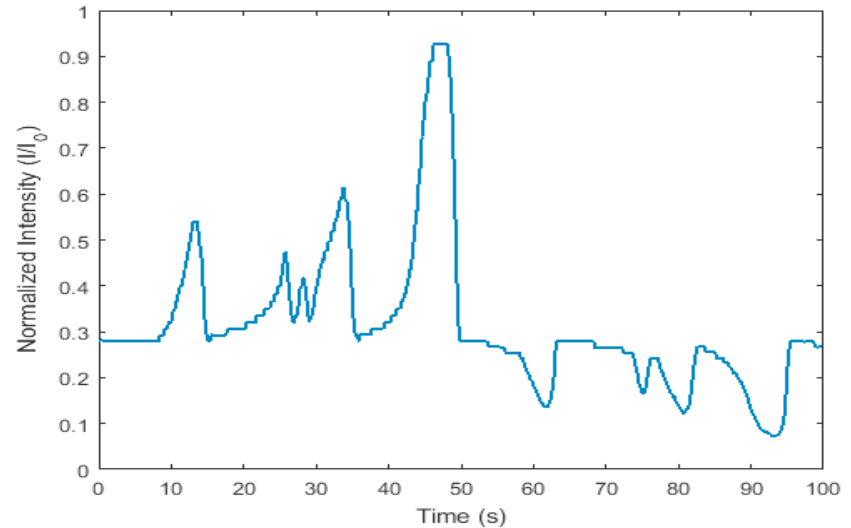
# LIGHT INTENSITY SIMULATION



# COMBINING LIGHT INTENSITY AND PARTICLE TRACING

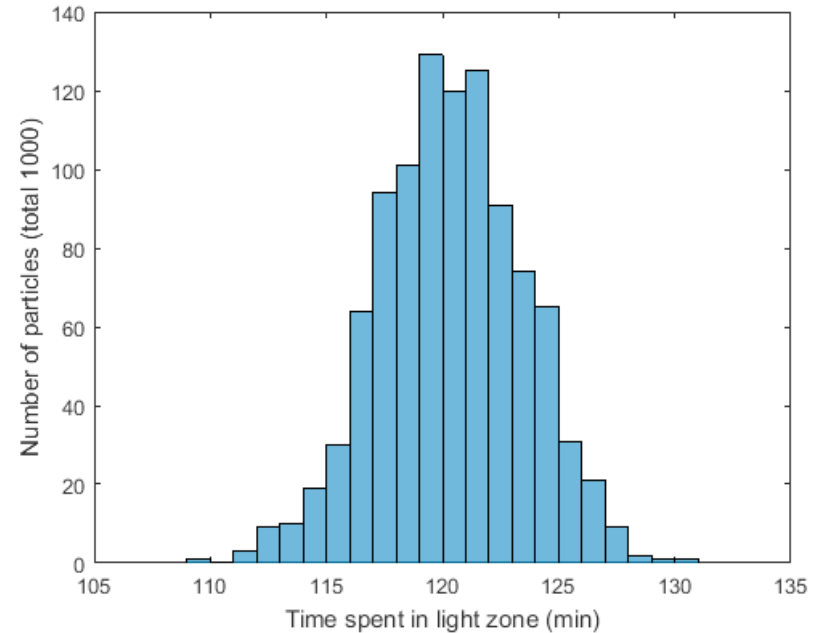
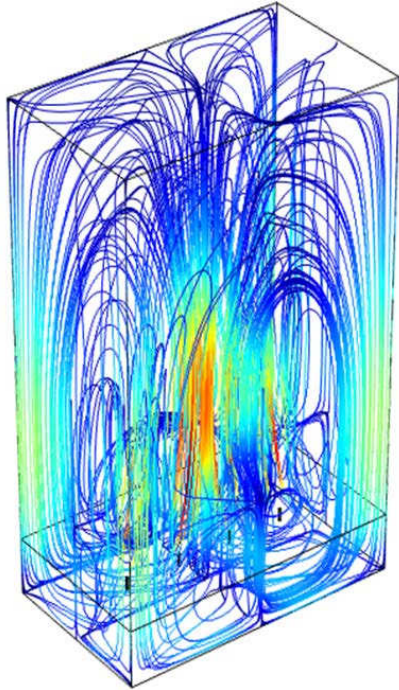


Path of a single algae cell from a given starting position



Normalized light intensity received by the algae cell over time

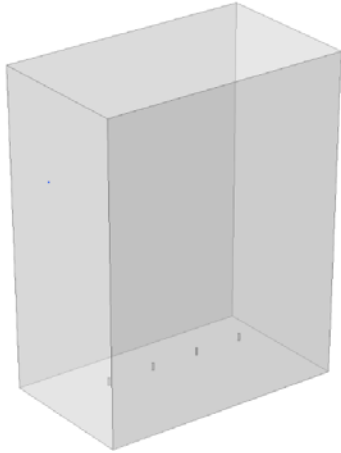
# COMBINING LIGHT INTENSITY AND PARTICLE TRACING



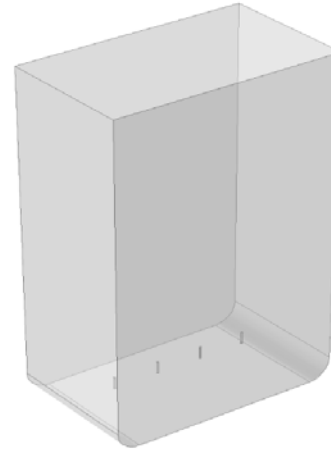
Path for many algae cells from a given starting position

Time spent by algae cells in light zone ( $I/I_0 > 0.1$ ) for total time 150 min and concentration  $0.1 \text{ kg/m}^3$

# DIFFERENT SHAPES OF REACTOR

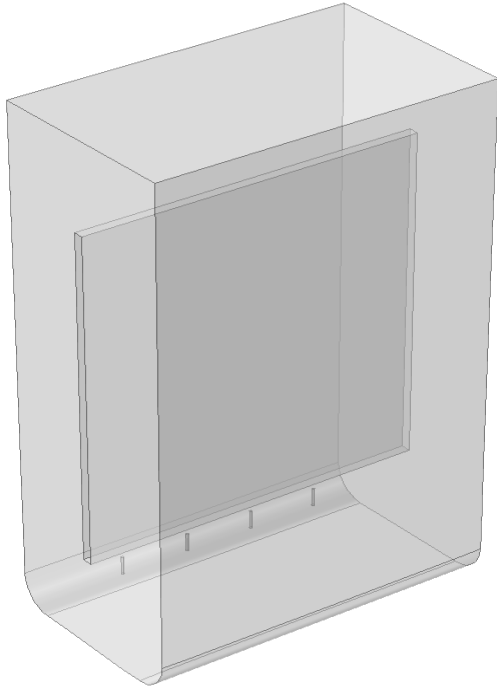


Actual shape of the PBR



Corners smoothed

- Smoothened corners improve the liquid flow profile and mixing in the system
- This also reduces the possibility of dead zones mainly at the corners of the PBR

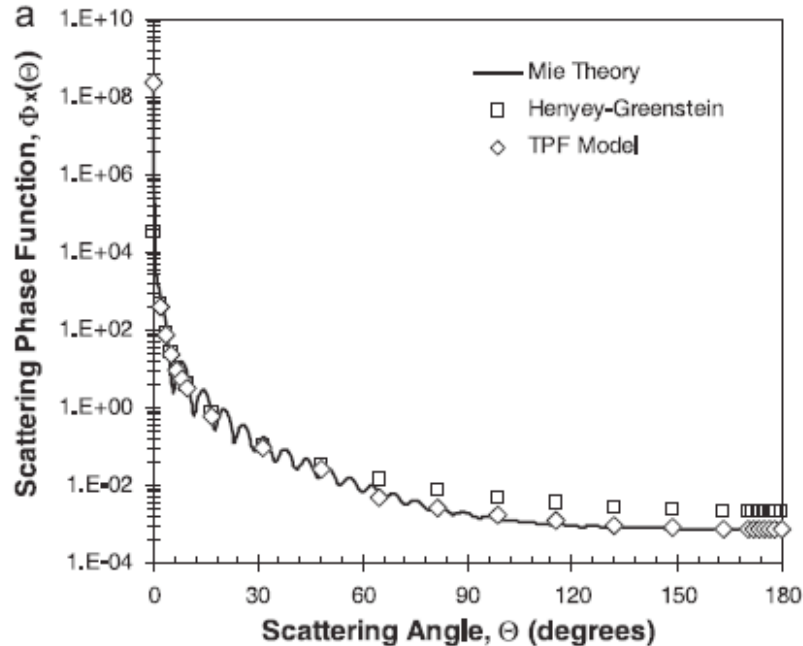


- Making it an Airlift reactor
- The plate divides the reactor into two regions
  - Riser
  - Downcomer
- The flow is highly turbulent in the riser region while laminar in the downcomer region
- Opens options to improve growth rate by combining the light exposure (light/dark cycles) and fluid flow patterns as the flow is more ordered than other designs

- CFD and particle tracing results combined with the light intensity simulations provide a quantification of the instantaneous light experienced by the particles.
- As next step, mass transfer of  $\text{CO}_2$  from the gas phase to the liquid phase will be calculated and combined with CFD and particle tracing.
- All these results will be combined with an algae growth model in order to optimize algae growth depending on reactor shape, gas input, illumination and algae concentration.

**Thank you  
for your attention!**





- The Henyey-Greenstein function is a good trade off between fast calculation and good approximation

$$\varphi(\hat{s}, \hat{s}') = \frac{1 - g^2}{(1 + g^2 - 2g\cos\theta)^{1.5}}$$

where  $g$  is the asymmetric parameter (deciding whether the scattering is forward, backward or isotropic in nature and  $\theta$  is the angle between incoming ( $\hat{s}$ ) and outgoing ( $\hat{s}'$ ) direction