Laboratory of
Computational
Systems
Biotechnology

Oxygen uptake bioreactors

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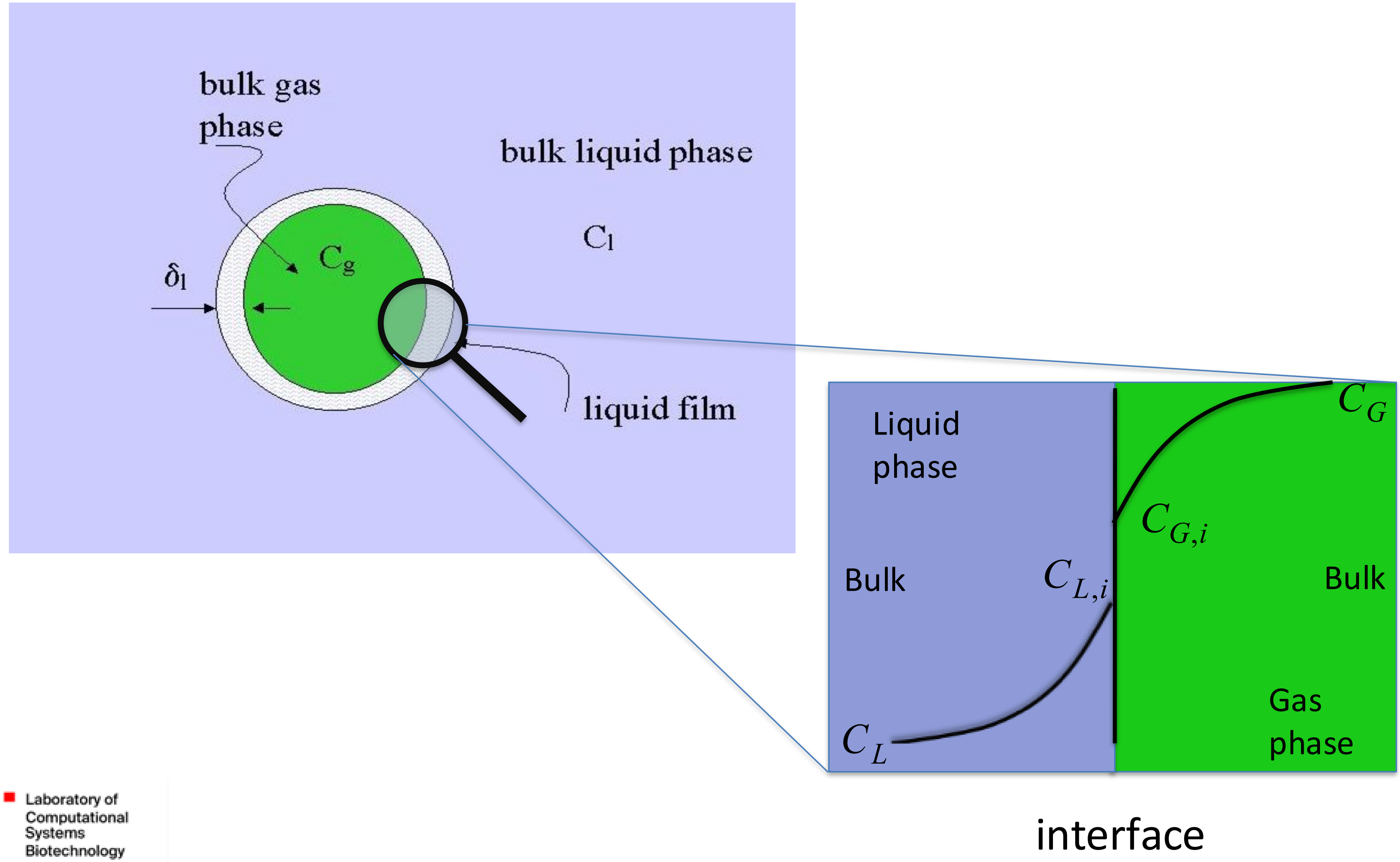
Gas transfer

Aeration of bioreactor have a direct impact on the system due to gas transfer from gas phase to liquid phase.

It is used for:

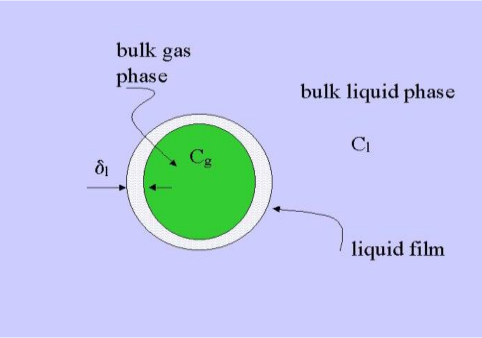
- Oxygen transfer to biological processes
- Stripping of volatile toxic organics (solvents)
- CO_2 exchange as it relates to pH control
- Ammonia removal by stripping
- Odor removal – volatile sulfur compounds
- Chlorination, ozonation for disinfection and odor control.

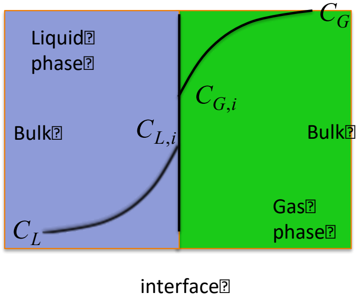
How is it transferred?



Dissolved oxygen uptake rate

- The rate of oxygen mass transfer from the gas phase (air bubbles) to the liquid phase (water) can be described by the equation:





$$\frac{dC_L}{dt} = k_L a \cdot (C_L^* - C_L)$$

C_L : dissolved oxygen concentration in the bulk liquid phase

C_L^* : saturated dissolved oxygen concentration in the liquid phase

$k_L a$: volumetric oxygen transfer coefficient [=] hr^{-1}

k_L : oxygen mass transfer coefficient [=] cm/hr

a : gas-liquid interfacial area [=] $\text{cm}^2 / \text{cm}^3$

Note: $\frac{dC_L}{dt} = k_L a \cdot (C_L^* - C_L) - Y_{O/S} \cdot r_S$

to allow for conversion of substrate with oxygen by the cells

Phase equilibrium assumption

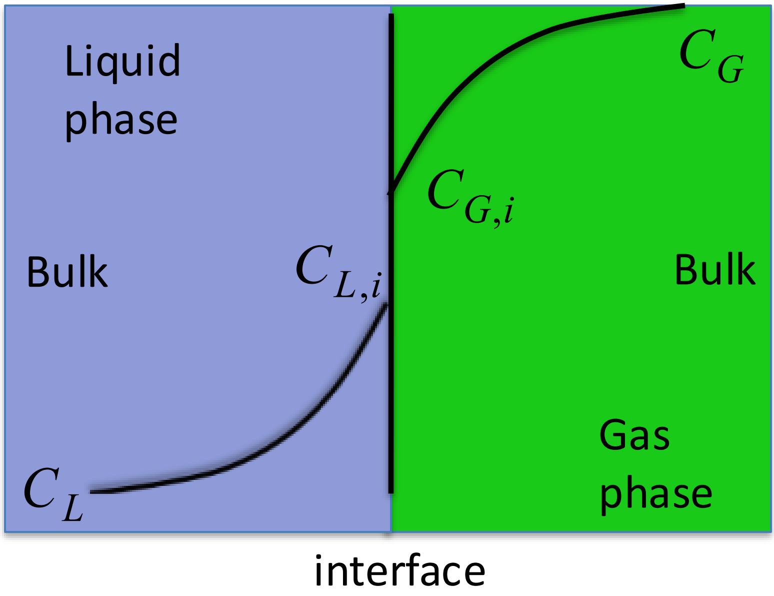
Rate of O_2 mass transfer in gas phase:

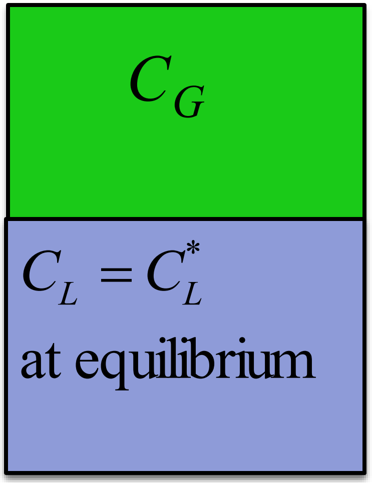
$$N_{O_2,G} = k_G a \cdot (C_G - C_{G,i})$$

Rate of O_2 mass transfer in liquid phase:

$$N_{O_2,L} = k_L a \cdot (C_{L,i} - C_L)$$

$N_{O_2,G} = N_{O_2,L}$ at steady state





$C_L = C_L^*$

at equilibrium

T, P

$$\frac{C_G}{C_L^*} = m$$

Phase equilibrium assumption

Rate of O_2 mass transfer in gas phase:

$$N_{O_2,G} = k_G a \square (C_G - C_{G,i})$$

Rate of O_2 mass transfer in liquid phase:

$$N_{O_2,L} = k_L a \square (C_{L,i} - C_L)$$

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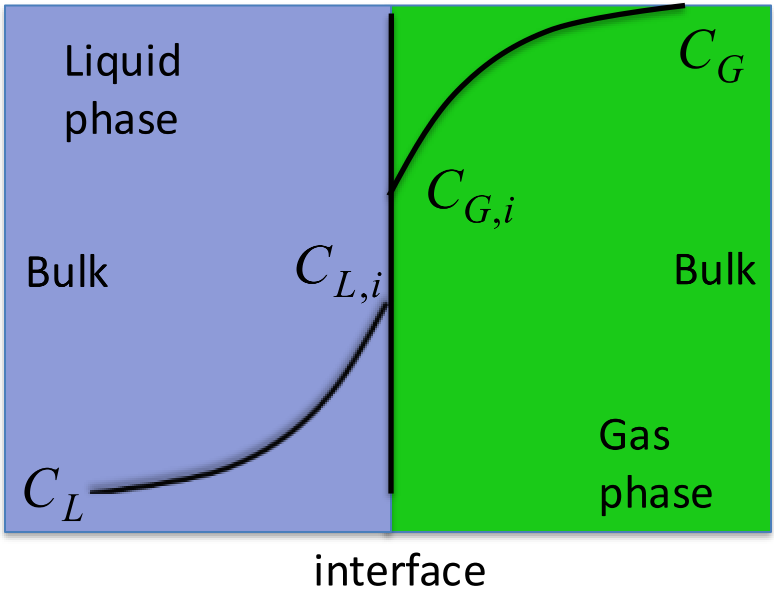


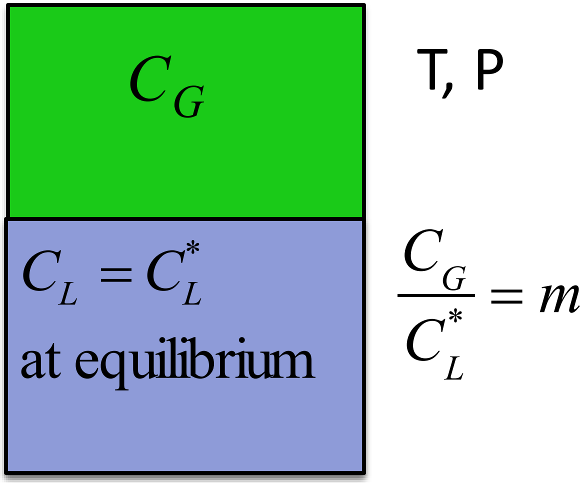
We assume equilibrium between liquid and gas phase at the interface:

$C_{G,i} = m \square C_{L,i}$ $\quad m =$ Henry's Law constant

Assume major resistance to oxygen transfer is in the liquid phase:

$$C_G \square C_{G,i}$$

$$\Rightarrow \quad N_{O_2,L} = k_L a \square \left(\frac{C_G}{m} - C_L\right)$$



$C_L = C_L^*$

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Phase equilibrium assumption

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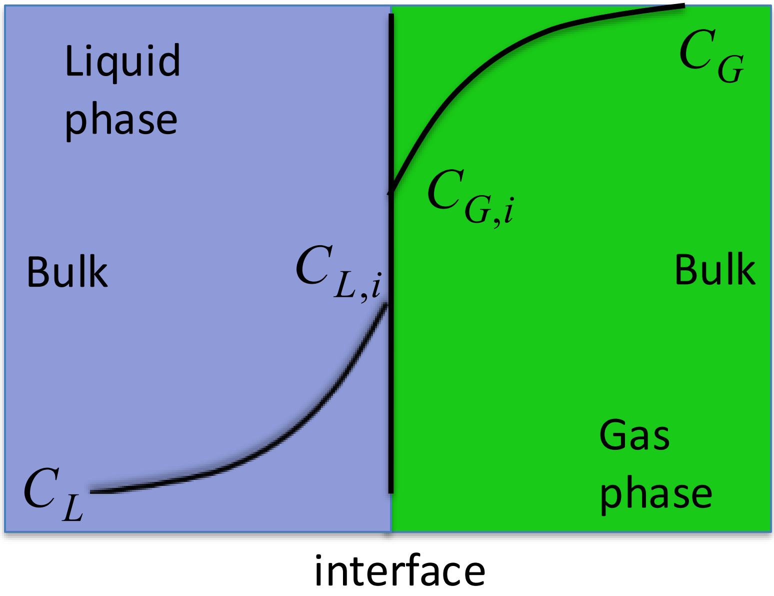


We assume equilibrium between liquid and gas phase at the interface:

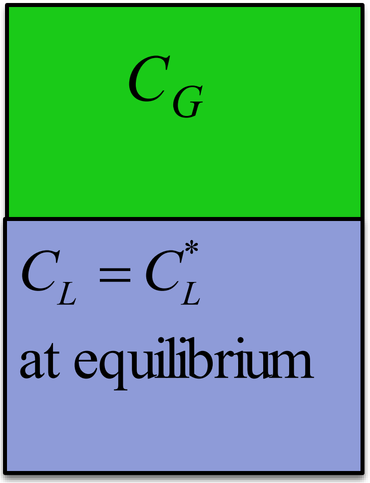
$C_{G,i} = m \cdot C_{L,i}$ $m =$ Henry's Law constant

Assume major resistance to oxygen transfer is in the liquid phase:

$$C_G \approx C_{G,i}$$

$$\Rightarrow \quad N_{O_2,L} = k_L a \cdot \left(\frac{C_G}{m} - C_L\right)$$

Divide the equation by V, volume of the bioreactor, and realizing that $C_G = m \cdot C_L^*$, we obtain $\frac{dC_L}{dt} = k_L a \cdot (C_L^* - C_L)$



T, P

$$\frac{C_G}{C_L^*} = m$$

About k_La

- Usually, we find an empirical correlation for estimating k_La

- It typically depends on power requirement in the aerated bioreactor, volume of the bioreactor, superficial gas speed or aeration rate, and rotational speed of the agitator (stirring rate)

- The measurement experiments can be done in the bioreactor when cells are absent, or when cell concentration is low (right after inoculation), so that oxygen consumption by the cells can be neglected

Kinetics that incorporate oxygen

- Reaction kinetics that incorporate aeration can be modeled based on substrate consumption, using a double Monod type relation:

$$r_S = v_m \frac{[S]}{K_S + [S]} \frac{C_L}{K_{C_L} + C_L}$$

- The rest of the mass balances become:

$$\frac{dS}{dt} = -r_s$$

$$\frac{dP}{dt} = Y_{P/S} \cdot r_s$$

$$\frac{dC_L}{dt} = k_L a(C_L^* - C_L) - Y_{\frac{O}{s}} \cdot r_s$$

- When $C_L << K_{CL}$ (low aeration rate), reaction is oxygen-limited; when $C_L >> K_{CL}$, reaction is non-oxygen limiting