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Resources

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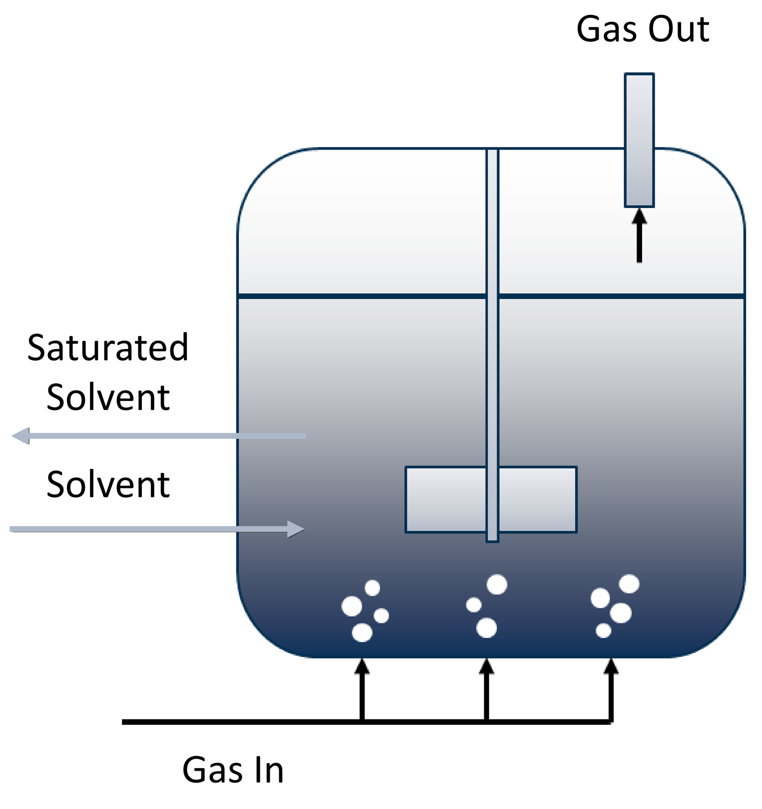
Intensification of mass transfer in gas-liquid processes

CONVENTIONAL: BULK LIQUID-TO-ATOMIZED GAS EXCHANGE



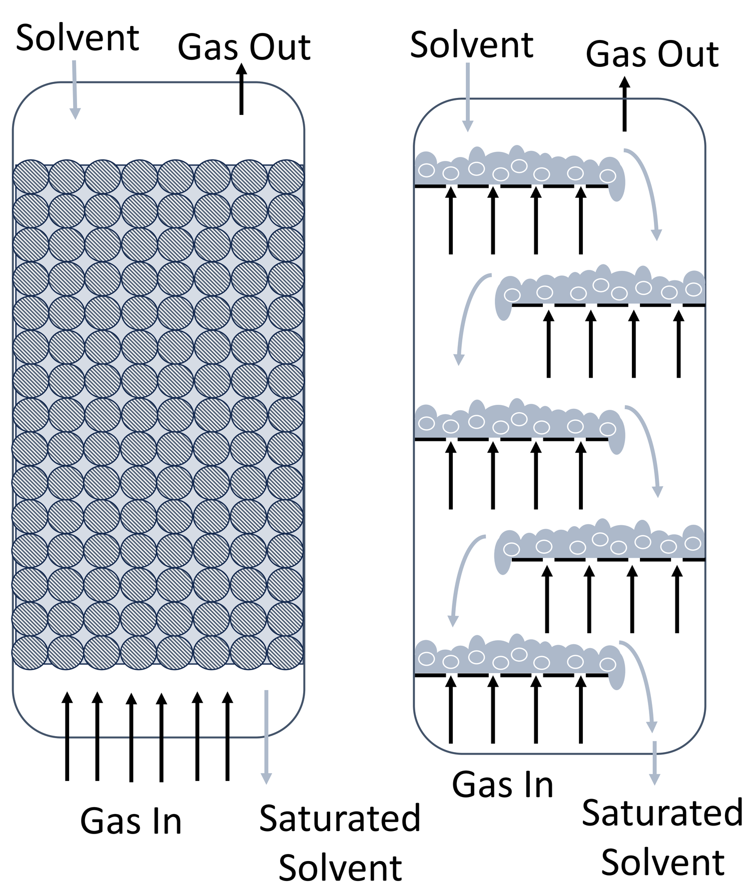
Bubble Contactors
Typical Mass Transfer Rates: 0.005-0.05 s^{-1}

- Small bubbles dispersed in large volumes of liquid gradually dissolve up to the saturation point, according to Henry's Law:

$$C_i^* = \frac{P_i\,[atm]}{H(T)\left[\frac{atm*L}{mol}\right]} \qquad H(T) = H_{ref}\exp\left[\frac{-\Delta H_{sol}}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$$

- The mass transfer rate constant, $k_L a$, is controlled by the gas flowrate, bubble size, and agitation rate
- The small surface area of contact between the gas bubbles and liquid solvent compared to the large volume of liquid severely limits mass transfer
- High energy inputs are required to induce good convective mass transfer through agitation

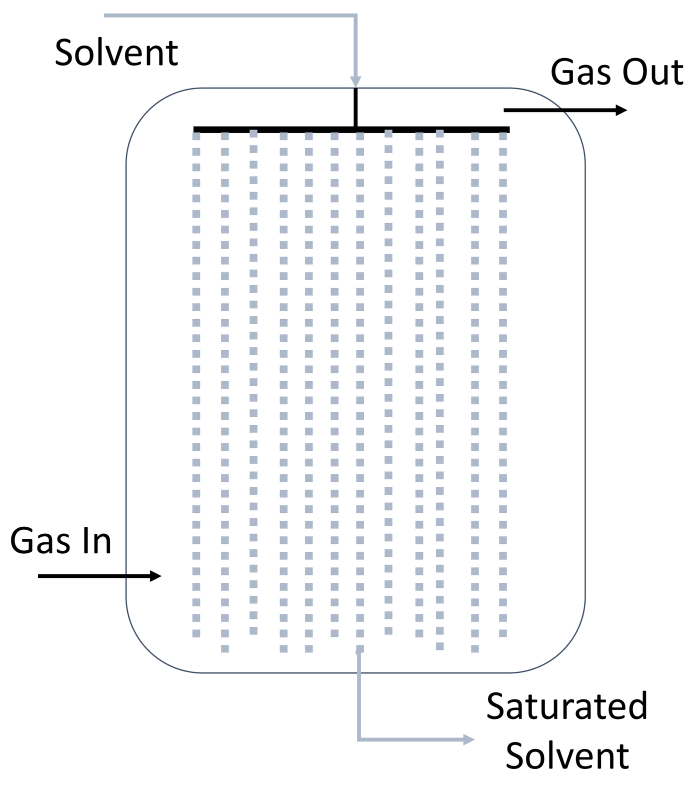
CONVENTIONAL: BULK GAS-TO-DISPERSED LIQUID EXCHANGE



Packed Bed and Trayed Contactors
Typical Mass Transfer Rates: 0.007-0.02 s^{-1}

- Gas flows over and through liquid films that form on bed packing or trays
- $k_L a$ is controlled by the packing material or tray design, the relative gas and liquid velocities, and the tower design
- Liquid film surface presents a relatively small surface area-to-volume ratio for mass transfer further limited by lack of convective mass transfer enhancement
- Large pressure drop required across column required to promote liquid flow through packing and prevent flooding
- Mass transfer may be greatly influenced by packing efficiency or weeping from tray
- Both configurations have high capital costs and require substantial maintenance

INNOVATION: BULK GAS-TO-ATOMIZED LIQUID (BGAL) EXCHANGE



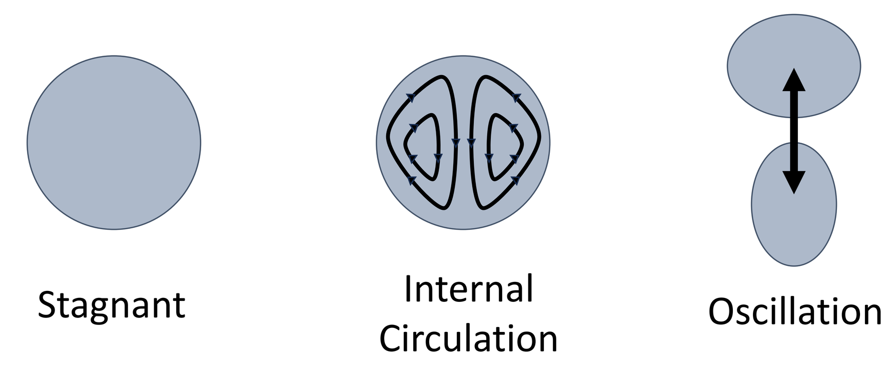
Vertical Droplet Array Towers
Estimated Mass Transfer Rates: 0.01-3.0 s^{-1}

Hypothesis: Utilizing a vertical droplet tower will enhance mass transfer compared to other gas-liquid contacting methods and facilitate prediction of tower mass transfer performance

- Gas contacts small droplets falling through the column
- $k_L a$ is controlled by droplet size and hydrodynamic characteristics
- Droplets posses large surface area-to-volume ratio, reducing mass transfer limitations
- Droplet manifold designed and operated to reduce jet formation and control droplet size
- Vertical droplet fall pattern reduces inter-droplet and wall interactions

PREDICTIVE MODELING OF DROPLET COLUMN PERFORMANCE

Droplets may exist in three hydrodynamic regimes:



Internal Circulation Model
Amokrane et al. (1994)

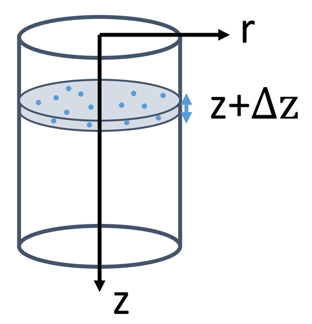
$$k_L a = \frac{6}{d}\left[0.8\sqrt{\frac{D_{AB}u^*}{d}}\right]$$

Oscillating Model
Angelo et al. (1966)

$$k_L a = \frac{6}{d}\left[2\sqrt{\frac{D_{AB}}{\pi\tau_{osc}}}\right]$$

Previous work suggests that mass transfer in singular falling droplets most closely agrees with predictions of the internal circulation and oscillation models.

The droplet column is modeled under plug flow assumptions using the droplet diameter distribution and residence time of each droplet within each slice.



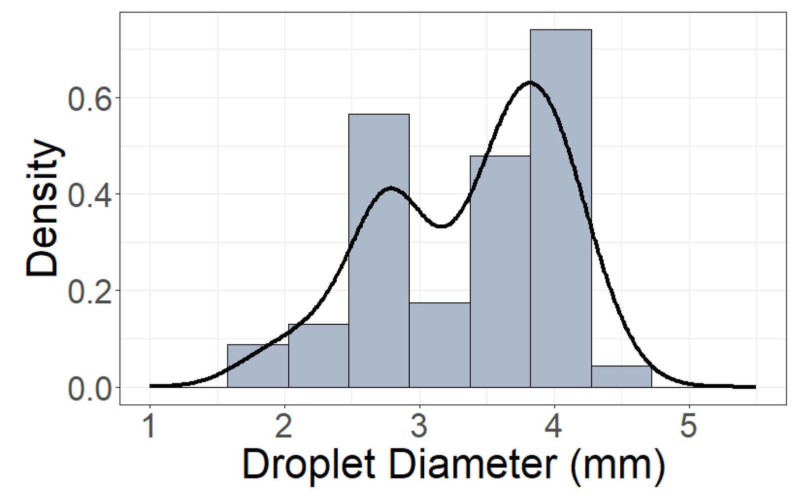
Mean concentration within each slice:

$$C(z) = C^* - \left(C^* - C(z-\Delta z)\right)e^{-k_L a \tau_{res}(z)}$$

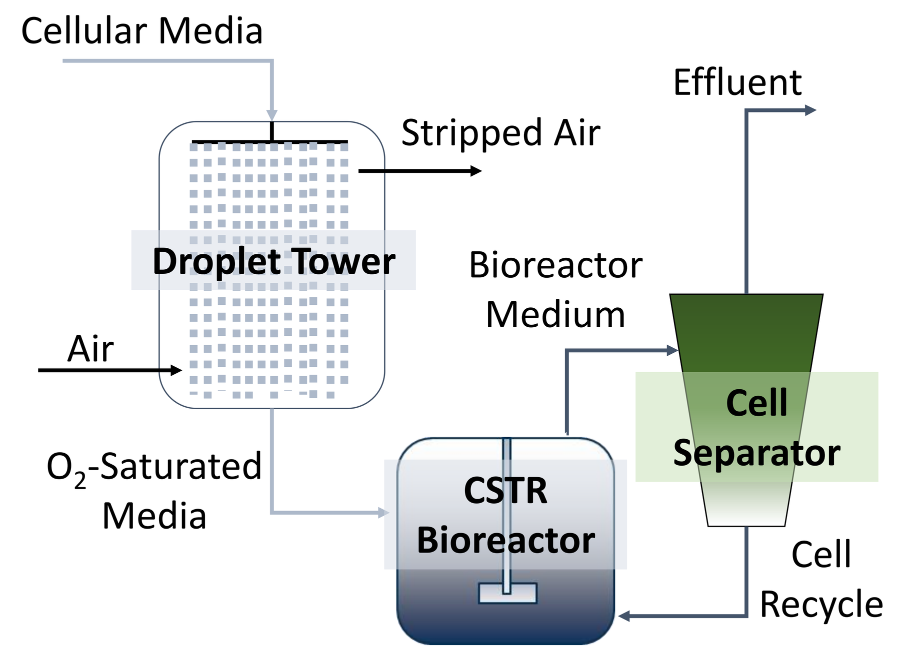
where C^* is saturation concentration.
Mean volumetric transfer rate within each slice:

$$\langle \dot{m}(d,z)\rangle = k_L(d,z)a(d)\left(C^* - C(z)\right)$$

The droplet diameter probability distribution is determined by high-speed imaging:



GAS FERMENTATION FOR PRODUCTION OF SINGLE CELL PROTEIN



To determine the theoretical maximum cell concentration maintained in the bioreactor under continuous operation, the oxygen transfer rate (OTR) and oxygen uptake rate (OUR) can be utilized:

$$OTR = k_L a(C^* - C_{O_2}) \qquad OUR = Q_{O_2}X$$

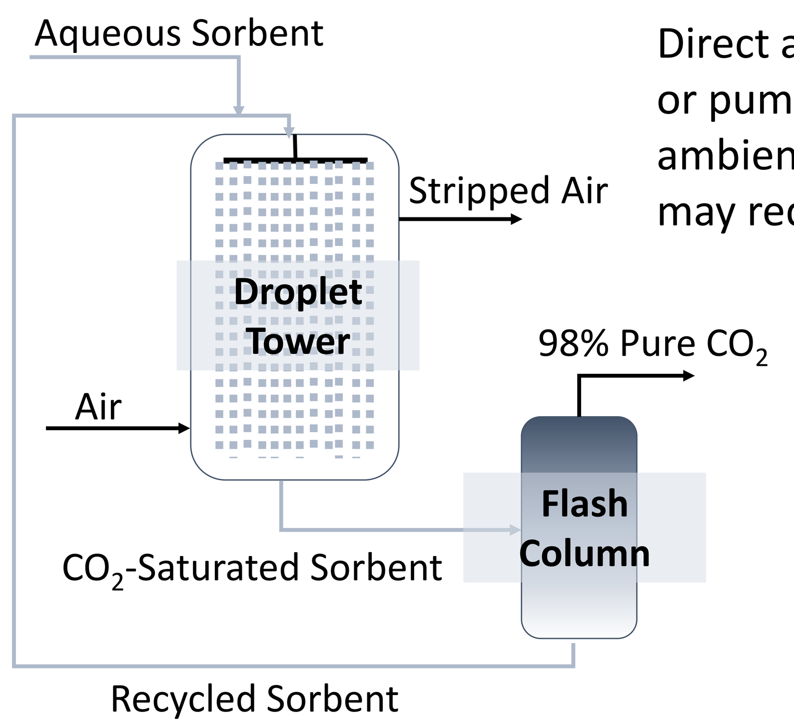
At steady state conditions: $OTR = OUR$

Ienczak, J.L. *et al.* (2011) found a maximum specific oxygen uptake rate, Q_{O_2}, for *Cupriavidus necator* of $30\,\frac{mg\ O_2}{g\ cell - h}$.

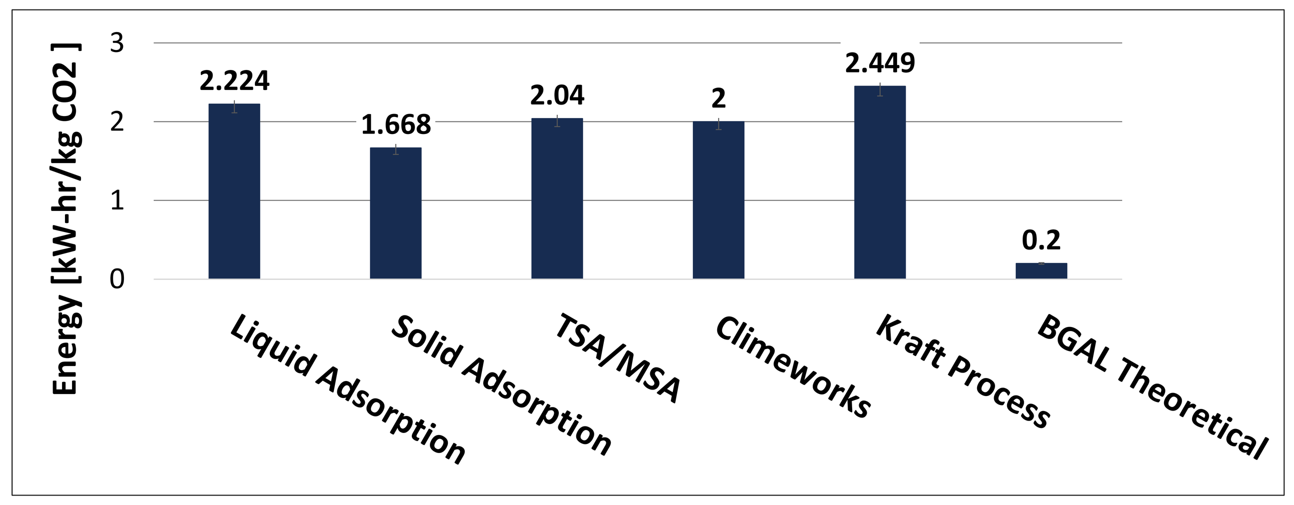
Using an oscillation model, the theoretical cell concentration, X, at steady state increases by 7-fold by utilizing the droplet tower to enhance mass transfer compared to a bubbled gas fermenter:

Fermentation Scheme	$k_L a$ (h^{-1})	C^* (mg/L)	C_{O_2} (mg/L)	OTR (mg O_2/L-h)	Theoretical X (g cell/L)
Bubbled CSTR (Ienczak, J.L. *et al.* (2011))	250	8.3	2.5	1450	48.3
CSTR with Droplet Tower	1620	8.6	2.5	9900	330

DIRECT AIR CAPTURE OF GREENHOUSE GASES



Direct air capture methods may be very energy intensive due to high heat or pumping requirements. Using a droplet tower to adsorb CO_2 from ambient air and a vacuum flash column to regenerate the aqueous sorbent may reduce the energy requirements of direct air capture by up to 90%.



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