Mixing

Technology for biobased products

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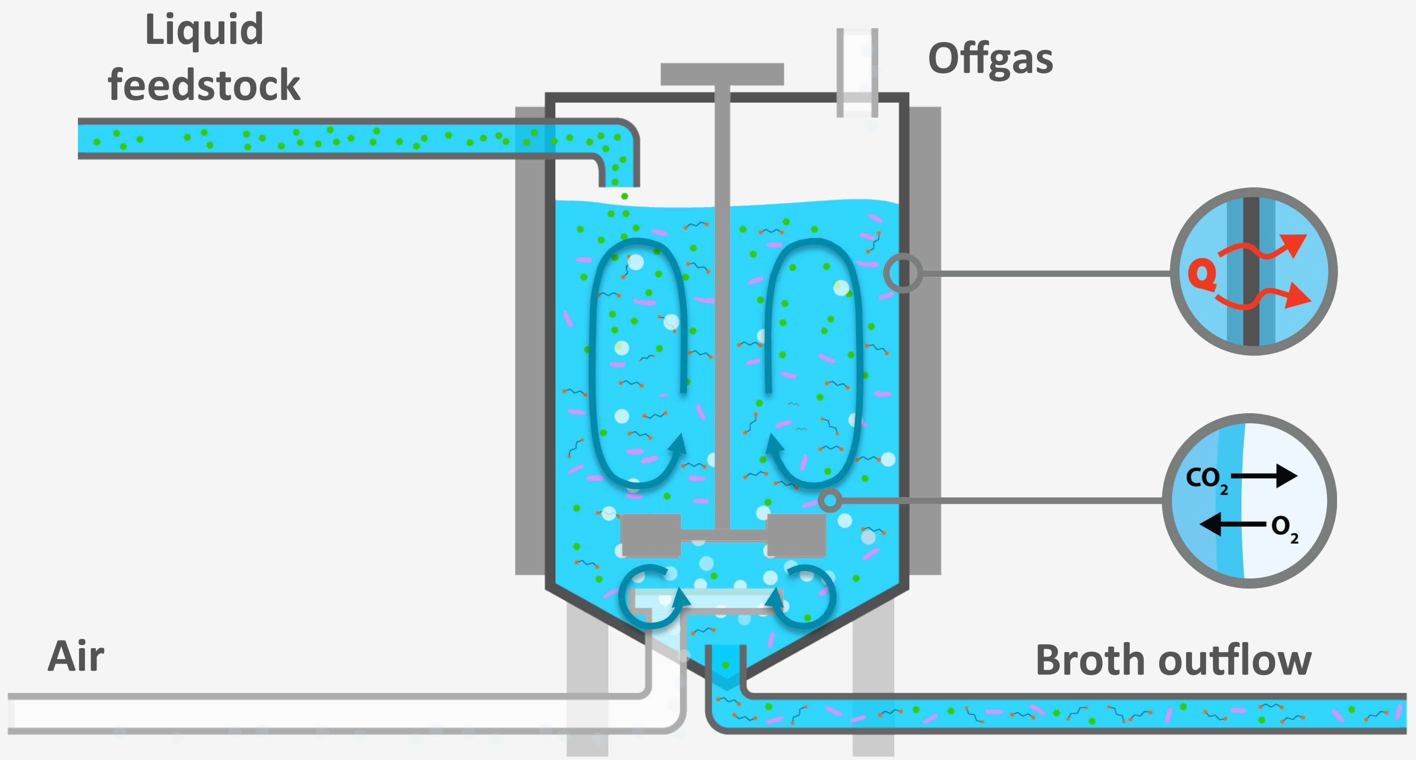
Challenge the future

One of four limiting transport steps: Mixing



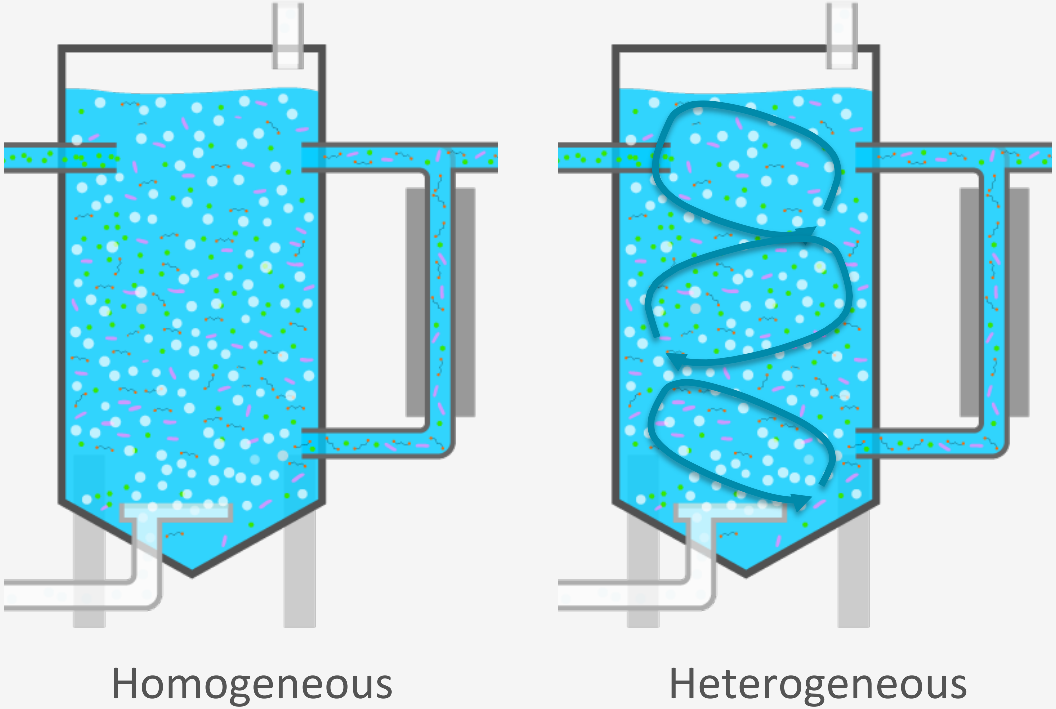
Bubble column: liquid circulation patterns

Homogeneous → heterogeneous around superficial gas velocity of 0.04-0.08 m/s

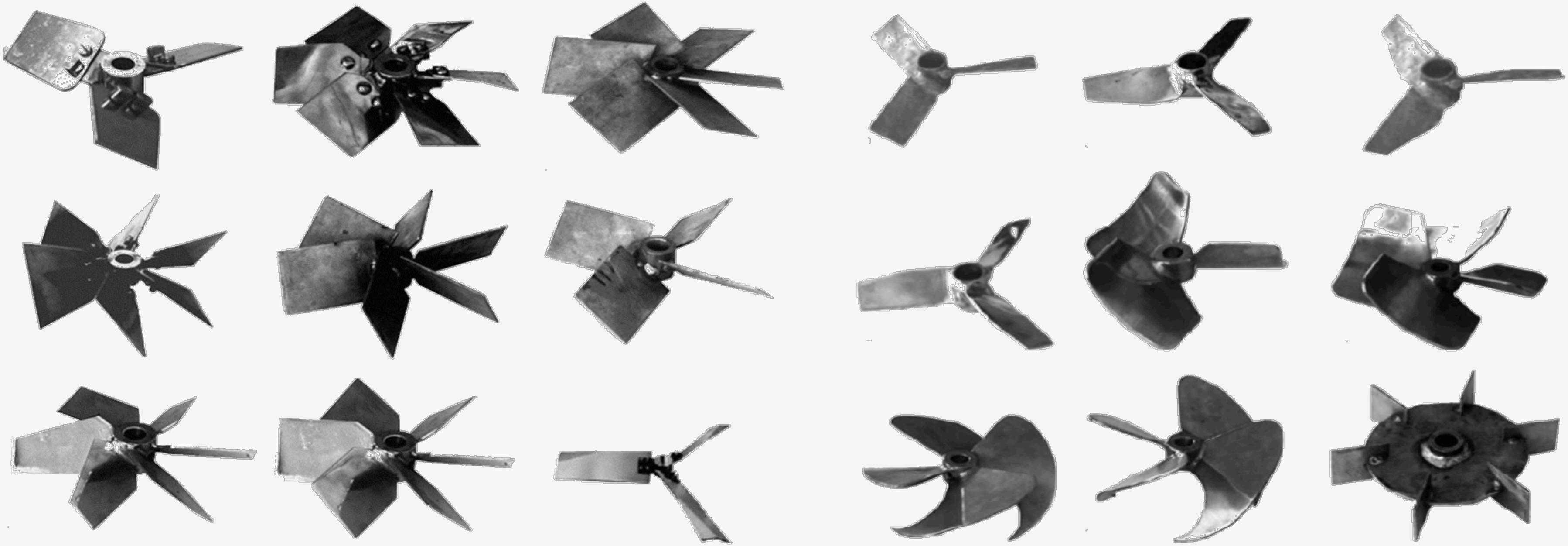
Remember the superficial gas velocity? (m/s)

$$v_{gs} = \frac{F_g}{A_\perp}$$

Scale-up
At lab scale: often homogeneous
At full scale: heterogeneous

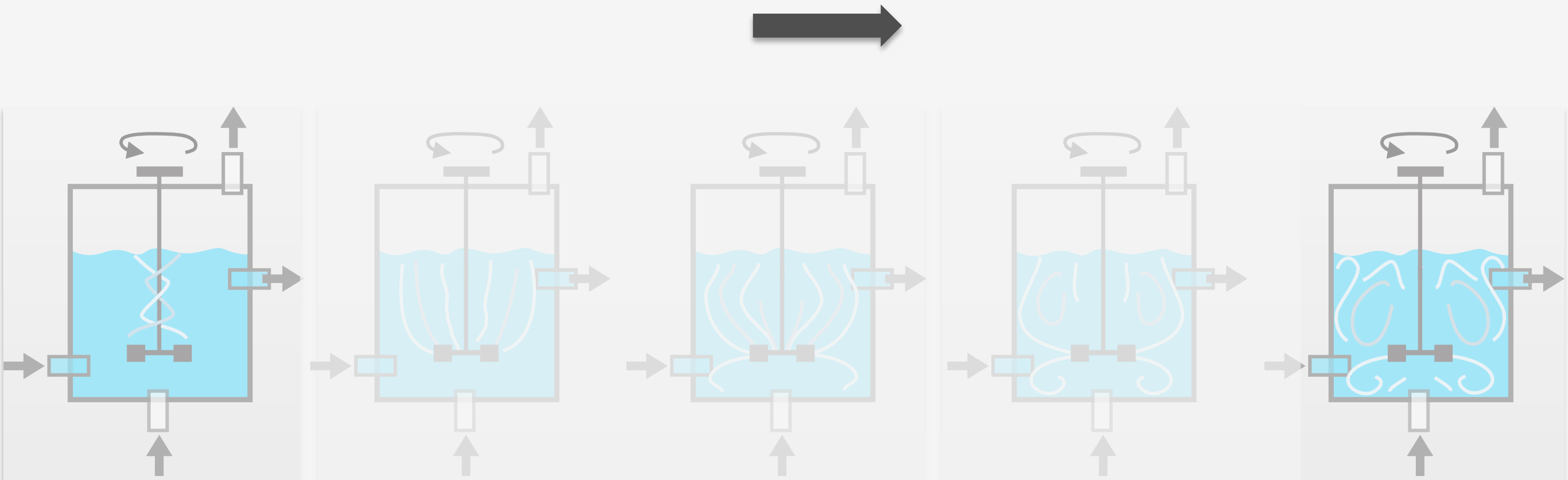


Stirred Tank Reactor (STR): Impeller designs



Gassed STR

Impeller power input
(same gas flow rate)

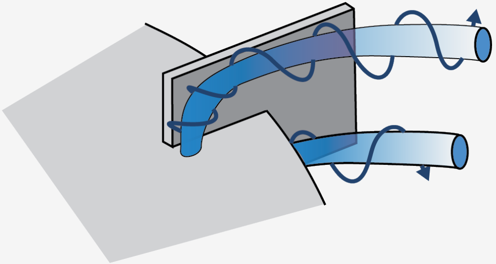


Impeller flooding

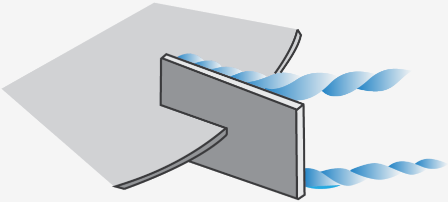
Impeller loading, but incomplete gas circulation

Complete gas recirculation

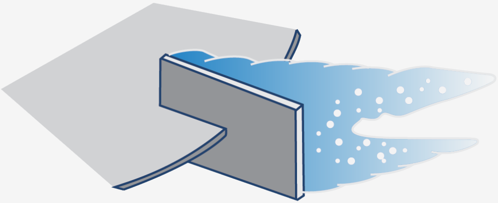
Gas dispersion



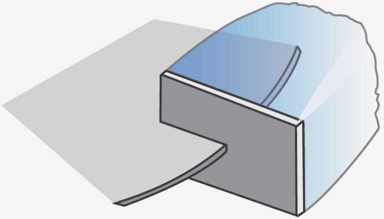
Unaerated



Vortex cavity



Clinging cavity

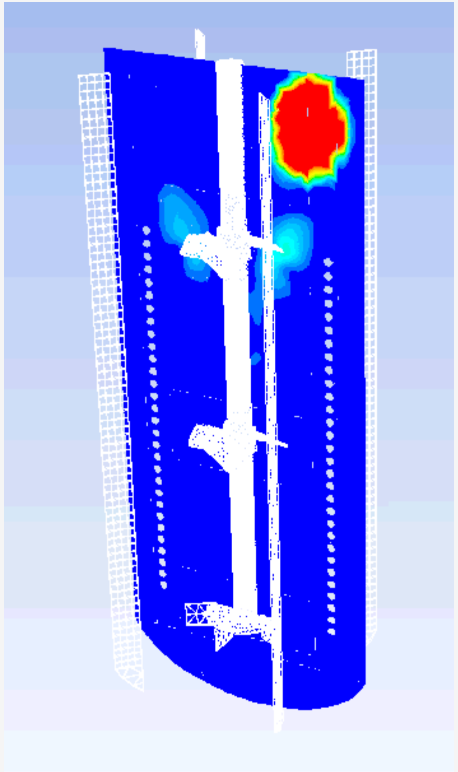


Large cavity

Mixing experiment

Mixing experiment

Computer simulation

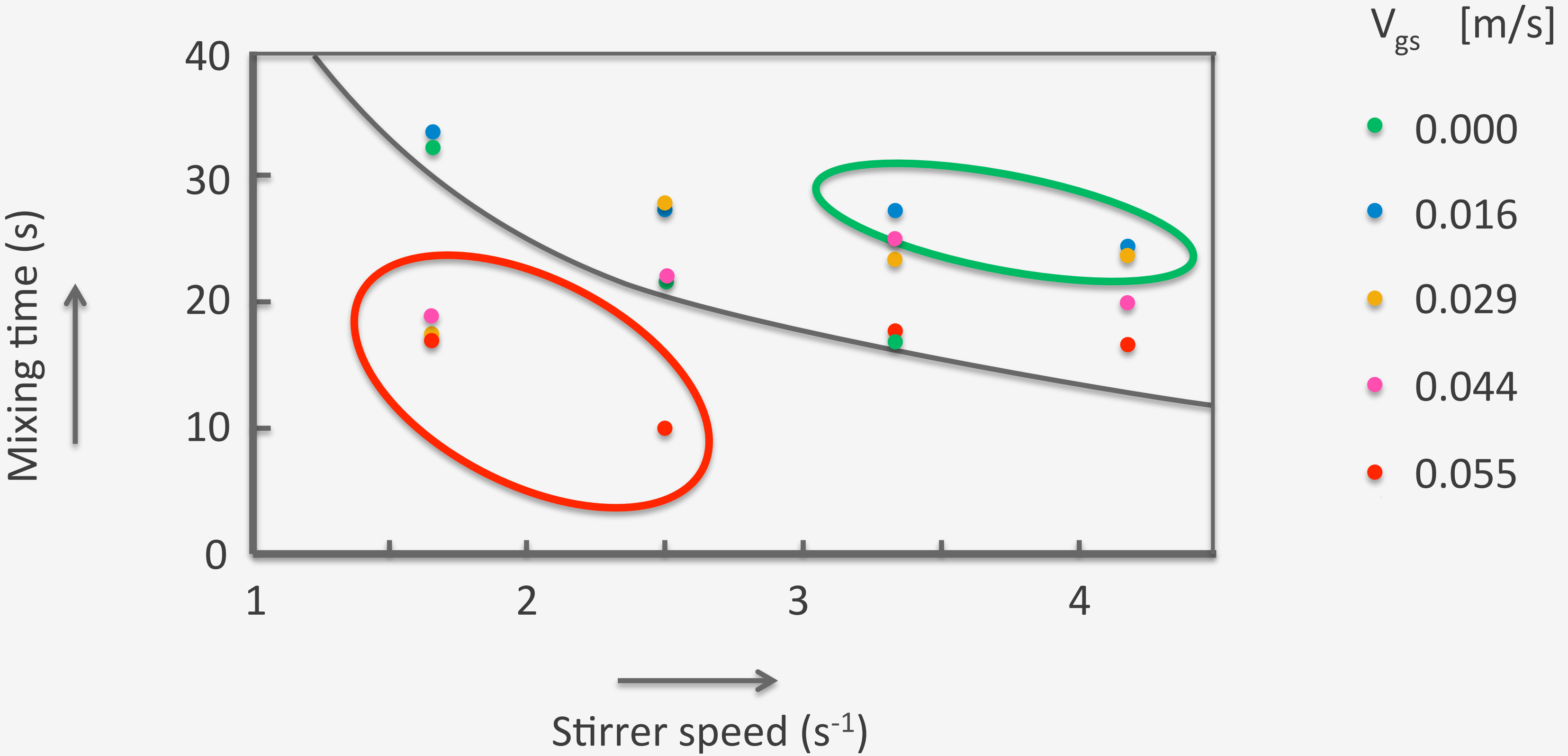


Mixing of tracer after injection

150 m^3 bioreactor: 1 radial and 2 axial impellers

95% mixing time 1 minute or more

The effect of aeration (30 m³ reactor)



Dimensionless mixing equation

Total power input (W/kg)

95% mixing time (s)

Reactor diameter (m)

Constant for the same geometry and liquid flow regime

Aspect Ratio
Height/diameter

$$Mixing\ number\ N_{mix} = \frac{t_m e^{\frac{1}{3}}}{D^{\frac{2}{3}}} = constant \cdot \left(\frac{H}{D}\right)^2$$

! Constant for **specified geometries**
! Strongly dependent on **aspect ratio**

Van 't Riet, K, Van der Lans, RGJM, 2011. Mixing in bioreactor vessels. In: Comprehensive Biotechnology, Volume 2: 63-80 (2nd edition), Moo-Young (Ed.), Elsevier, Amsterdam

Comparison ALR, STR and BC

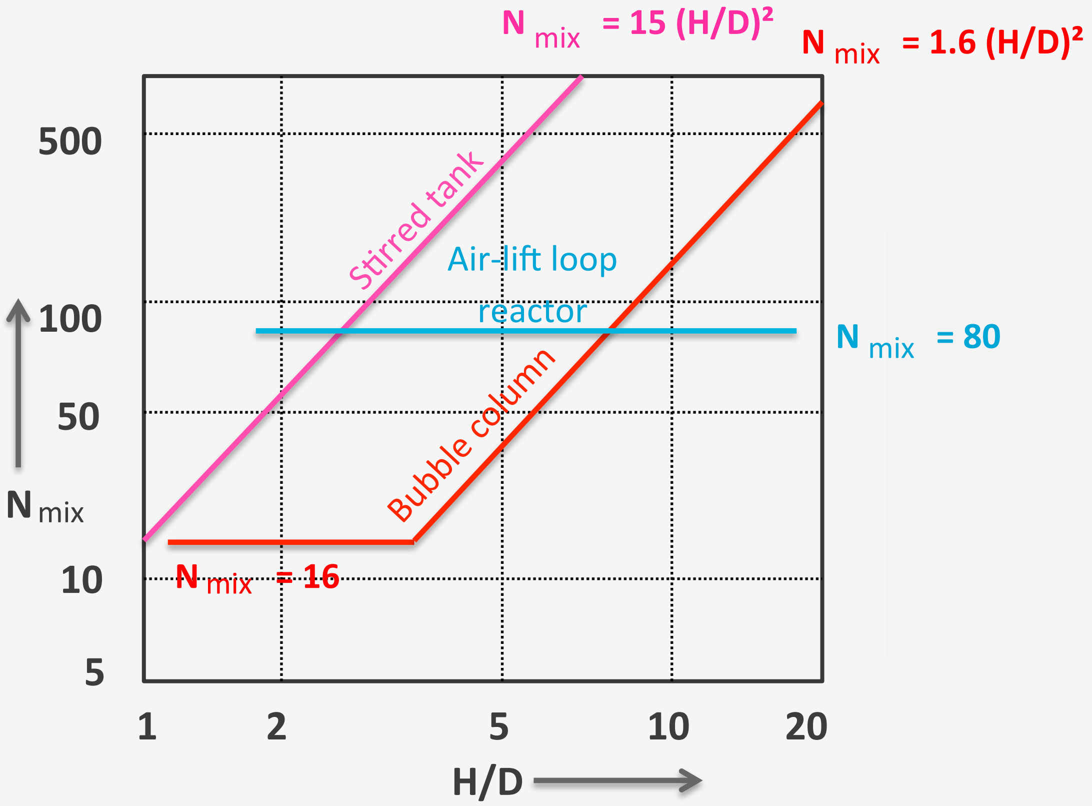
compared for 2 W/kg power input

Lower N_{mix} means better mixing!

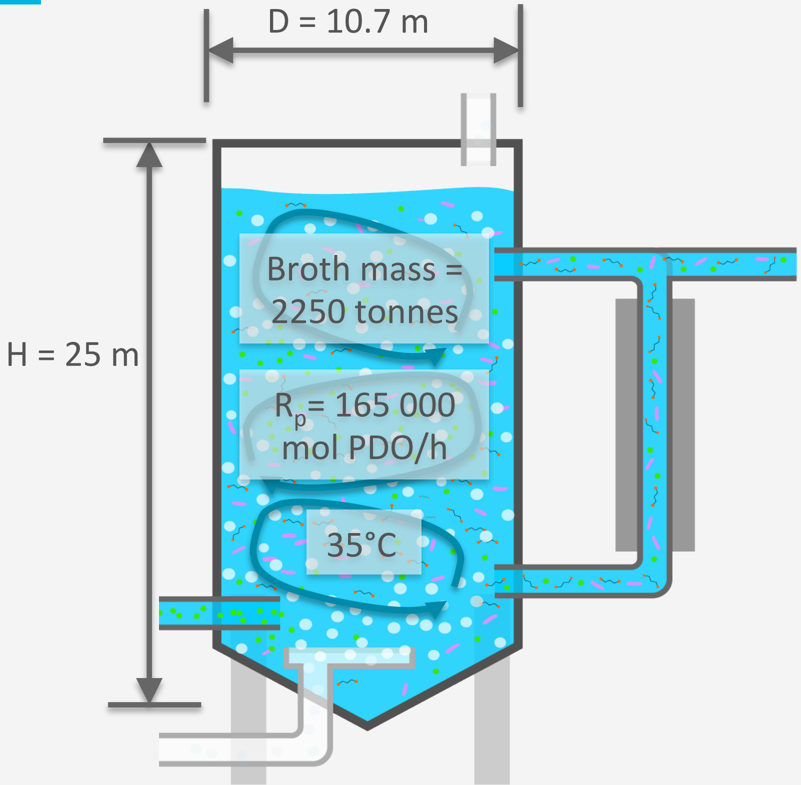
Low aspect ratio is favourable

At the same aspect ratio (H/D),
BC mixing is better than STR mixing

Mixing in an ALR is largely unaffected by the aspect ratio



The PDO process scheme



Power input:

$$\mathbf{e} = \frac{F_n RT\ln\left(\frac{p_{bottom}}{p_{top}}\right)}{\text{broth mass}}$$

$$= \frac{3561146 * 8.314 * 308 * \ln\left(\frac{3.5}{1}\right)}{2250000/(3600\ \text{s/h})} = \mathbf{1.41\ W/kg}$$

Bubble column with H/D = 2.34 → $\mathbf{N_{mix} = 16}$

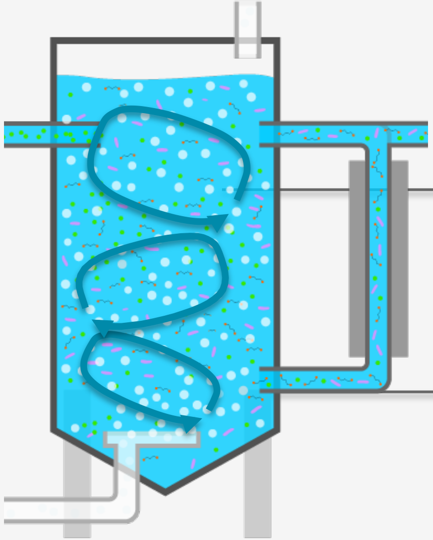
95% mixing time t_{mix} = 16 × 10.7$^{2/3}$ / 1.41$^{1/3}$ = 69 s

Mean broth circulation time $t_{mix}/4$ = 17 s
Mean broth circulation velocity v_L = H / 17 = 1.5 m/s
Broth circulation rate 2250 / 17 = 132 m^3/s

Substrate concentration gradients

Concentration close to glucose feed inlet:

$$C_{s,feed} = \frac{F_{N,glucose}\ (mol/s)}{F_{circulation}\ (m^3/s)} = \frac{3 \times 71225 / 3600}{132} = 0.45 \text{ mol glucose} / m^3$$



Factor 5 difference

Concentration in the outlet:

$$C_{s,out} = 0.085 \text{ mol glucose} / m^3$$

Mixing design

- BC: heterogeneous flow at full scale
- STR: several different flow regimes
- Low aspect ratios favourable for mixing
- Fewer (radial) stirrers better for mixing
- Aeration has minor influence at usual regime
- BC often better than STR
- ALR independent of aspect ratio

See you in the next unit!