Bioreactor Design and Analysis

Overview of bioreactors

Modified batch and continuous reactors

Immobilized cell systems

Requirements for Cultivation Methods

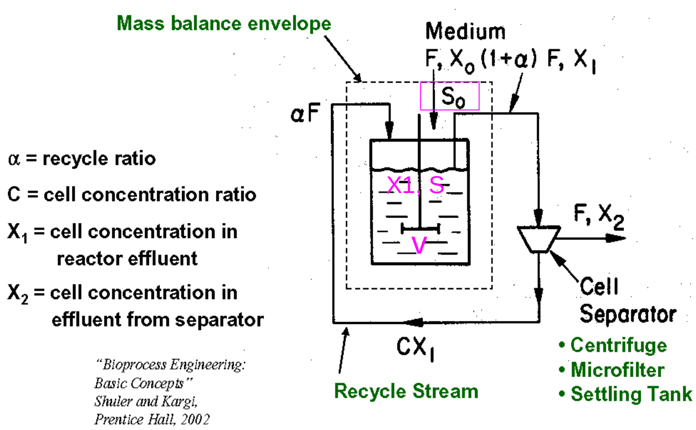
- Biomass concentration which must remain high
- Sterile conditions being maintained
- Effective agitation so that the distribution of substances in the reaction is uniform
- Heat removal
- Creation of the correct shear conditions - high may damage cells, low may lead to flocculation or growth on wall and stirrer

Chemostat with Cell Recycle

- Microbial conversions are autocatalytic, and the rate of conversion increases with cell concentration.
- To keep the cell concentration higher than the normal steady-state level in a chemostat, cells in the effluent can be **recycled back to the reactor**.
  - To increase the cell and growth-associated product yield.
  - For low-product-value processes: e.g. waste-water treatment

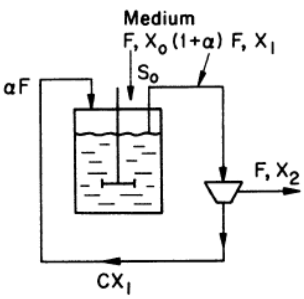
Chemostat with Cell Recycle

- Cells in the effluent stream are either centrifuged, filtered, or settled in a conical tank for recycling.



Chemostat with Cell Recycle

- Cell mass balance (q_p=0, $k_d \approx$0, X_o=0, Monod equation is applied):



$$FX_o + \alpha FCX_1 - (1+\alpha)FX_1 + V_R \mu X_1 = V_R \frac{dX_1}{dt}$$

$$\text{at steady-state } (\frac{dX_1}{dt} = 0) \text{ and sterile feed } (X_o = 0)$$

$$\alpha FCX_1 - (1+\alpha)FX_1 + V_R \mu X_1 = 0$$

and solving for μ

$$\mu = [1+\alpha(1-C)]D$$

where $\mu = \mu_{net} = \mu_g - k_d$

Since $C > 1$ and $\alpha(1-C) < 0$, then $\mu < D$

A chemostat can be operated at dilution rates higher than the specific growth rate when cell recycle is used.

Chemostat with Cell Recycle

$$\mu = [1+\alpha(1-C)]D$$

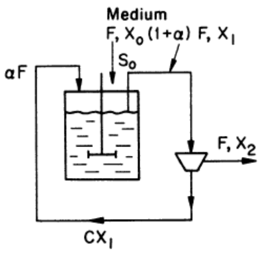
$$\text{Monod Equation, } \mu = \frac{\mu_{max} S}{K_S + S} \quad \text{when } k_d = 0$$

Substitute Monod Eqn. into above, solve for S

$$S = \frac{K_S D(1+\alpha(1-C))}{\mu_{max} - D(1+\alpha(1-C))}$$

Chemostat with Cell Recycle

- Mass balance on growth-limiting substrate (q_p=0, k_d≈0, X_o=0, Monod equation is applied):



$$FS_0 + \alpha FS - V\frac{\mu_g X_1}{Y^M_{X/S}} - (1+\alpha)FS = V\frac{dS}{dt}$$

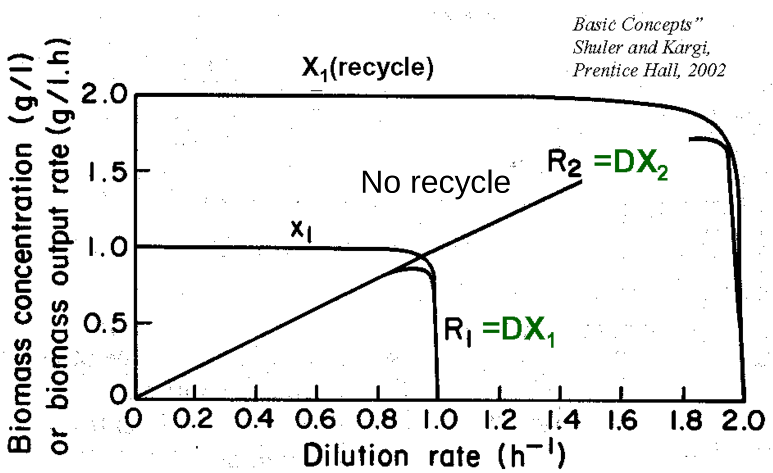
At steady state, dS/dt = 0,

$$X_1 = \frac{D}{\mu_g} Y^M_{X/S}(S_0 - S) \qquad S = \frac{K_S D(1+\alpha-\alpha C)}{\mu_m - D(1+\alpha-\alpha C)}$$

Since $\mu_g = [1+\alpha(1-C)]D$,

$$X_1 = \frac{Y^M_{X/S}(S_0 - S)}{1+\alpha-\alpha C}, \quad X_1 = \frac{Y^M_{X/S}}{[1+\alpha(1-C)]}\left[S_0 - \frac{K_s D(1+\alpha-\alpha C)}{\mu_m - D(1+\alpha-\alpha C)}\right]$$

Chemostat with Cell Recycle



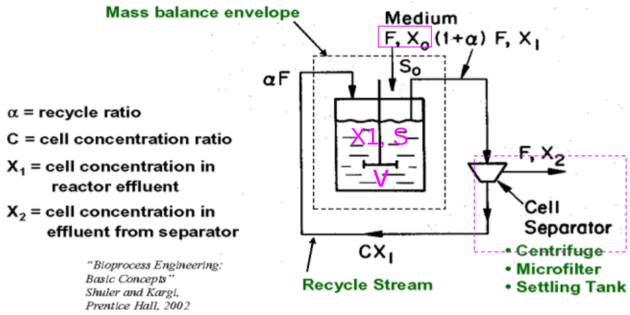
X = biomass concentration in chemostat

R = biomass output rate per unit volume

μ_m=1.00 h^{-1}, S_0=2.0 g/l, Ks=0.01 g/l, $Y_{X/S}$ = 0.5 g/g, concentration factor C=2.0 and recycle ratio α=0.5

Chemostat with Cell Recycle

Cell mass balance around the cell separator.



$$(1+\alpha)FX_1 = FX_2 + \alpha FCX_1 \Rightarrow X_2 = (1+\alpha)X_1 - \alpha CX_1$$

The average residence time in cell separator θ

$$\theta = \frac{V_{\text{cell separator}}}{(1+\alpha)F}$$

Example-Chemostat with Cell Recycle

- Organisms are cultured in a chemostat with cell recycle. The system is operated under glucose limitation.

$$\mathrm{F = 100\ ml/h,\ V = 1000\ ml,\ \ S_0 = 10\ g\ glucose/L}$$

$$\mathrm{Y_{X/S}^{M} = 0.5g\ cells/g\ substrate;\ \mu_m = 0.2\ h^{-1},}$$

$$\mathrm{K_S = 1\ g/L,\ C = 1.5,\ \ \alpha = 0.7,\ X_0 = 0,\ k_d \approx 0}$$

a. Determine specific growth rate μ_{net}, S in the reactor effluent, cell concentration in the recycle stream (CX_1) and in the concentrator effluent (X_2)

b. If the concentrator has a volume of 300 ml, what is the residence time in it?