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Biochemical Engineering
Exercise Session 7 Correction

1) Chemostat Theory

Draw a x-D diagram <u>with consideration of maintenance energy</u> and insert, biomass, volumetric productivity, specific productivity, residual glucose concentration s, D_{opt} and D_{crit}.

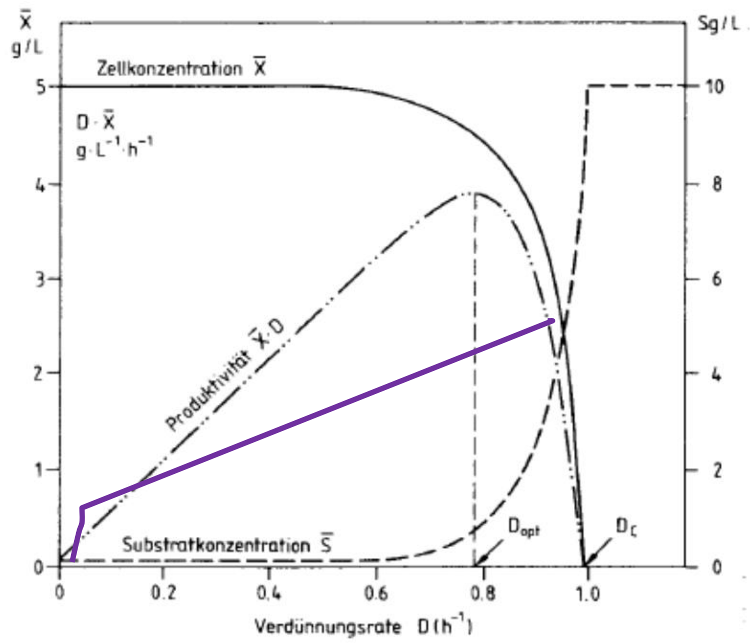

Figure 1: The purple function corresponds to the specific productivity $q_P = \mu / Y_{X/S}$

What do you understand under a turbidostat and a pH auxostat?

In other techniques, a fermenter variable, e.g., turbidity or pH, will be monitored using an appropriate detector and the liquid flow rate will be automatically adjusted so as to maintain the variable at a constant level (**closed loop control**)

What are their differences to a chemostat?
The dilution rate is not constant, the specific growth rate of the cells is close to μ_{max}. Tricky to run in a stable way (fast analytics needed and good algorithms).

2) Substrate conversion and biomass productivity

A 5 m^3 fermenter is operated continuously with a feed substrate concentration of 20 kg m^{-3}. The genetically engineered *E. coli* cultivated in the reactor has the following characteristics:

μ_{max} = 0.45 h^{-1}; K_s = 800 g m^{-3}; $Y_{X/S}$ = 0.55 kg kg^{-1}

a) What feed flow rate is required to achieve 90% substrate conversion?

At steady state the substrate concentration is expressed as follows, with $S = 0{,}9 \cdot S_0$

$$S = K_S \frac{D}{\mu_{max} - D} \quad \Leftrightarrow D = \frac{S \cdot \mu_{max}}{K_S + S} = \frac{2\,{}^{kg}/_{m^3} \cdot 0.45\,{}^{1}/_{h}}{0.8\,{}^{kg}/_{m^3} + 2\,{}^{kg}/_{m^3}} = 0.321\,{}^{1}/_{h}$$

$$Q = 0{,}321 \frac{1}{h} \cdot 5m^3 \ = \mathbf{1.6 \frac{m^3}{h}}$$

b) How does the biomass productivity at 90% substrate conversion compare with the maximum possible?

$$D_m = D_{opt} = \mu_{max}\left(1 - \sqrt{\frac{K_S}{K_S + S_0}}\right) = 0.45\,{}^{1}/_{h}\left(1 - \sqrt{\frac{0.8\,{}^{kg}/_{m^3}}{0.8\,{}^{kg}/_{m^3} + 20\,{}^{kg}/_{m^3}}}\right) = \mathbf{0.362\,{}^{1}/_{h}}$$

c) What is the biomass concentration in case of an at the optimal dilution rate?

$$X = Y_{X/S}\left(S_0 - \frac{K_S \cdot D}{\mu_{max} - D}\right) = 0.55\left(20 - \frac{0.8 \cdot 0.321}{0.45 - 0.321}\right) = \mathbf{9.9\,{}^{kg}/_{m^3}}$$
$$X_{opt} = Y_{X/S}\left(S_0 - \frac{K_S \cdot D_{opt}}{\mu_{max} - D_{opt}}\right) = 0.55\left(20 - \frac{0.8 \cdot 0.362}{0.45 - 0.362}\right) = \mathbf{9.19\,{}^{kg}/_{m^3}}$$

3) Growth inhibition

The specific growth rate for inhibited growth in a chemostat is given by the following equation:

$\mu = \mu_{max}\, S /(K_s + S + I\, K_s / K_i)$

Where

s_0 = 10 g L^{-1}, K_s = 1 g L^{-1}; I = 0.05 g L^{-1}, Y_{xs} = 0.1 g g^{-1}
x_0 = 0 , K_i = 0.01 g L^{-1}, μ_{max} = 0.5 h^{-1}

a) Determine x and s as function of D when I = 0

The equation of the growth rate can be rearranged and solved for the substrate concentration,

$$S = K_S \frac{D}{\mu_{max} - D} \qquad if\ I = 0\ and\ \mu = D$$

The same result is also obtained if the general formula expressing the biomass concentration is used

$$X = Y_{\frac{X}{S}}(S_0 - S) = Y_{\frac{X}{S}}\left(S_0 - K_S\frac{D}{\mu_{max} - D}\right) \Leftrightarrow S = K_S\frac{D}{\mu_{max} - D}$$

b) With inhibitor added to a chemostat, determine the effluent substrate concentration and x as function of D

$$S = \frac{D(K_S + \frac{IK_S}{K_I})}{\mu_{max} - D}$$

$$X = Y_{\frac{X}{S}}(S_0 - \frac{\left(\left(K_S + \frac{IK_S}{K_I}\right) \cdot D\right)}{\mu_{max} - D})$$

c) Determine the volumetric cell productivity, DX, as a function of dilution rate

The productivity is expressed by $P_X = D \cdot X$ with the biomass concentration X calculated in part b.

4) Wash-out experiment

What is the biomass concentration in a chemostat when one knows the following parameters:

V = 2.200 L F = 200 mL/h
x_0 = 10 g L^{-1} (at t = 0 h) μ_{max} = 0.3 h^{-1}
Ks = 0.2 g glucose/L $Y_{X/S}$ = 0.5 g cells / g glucose

(consider not metabolized glucose s!)

What is the concentration of the biomass at different times when the dilution rate was changed to D = 1.0 h^{-1}? Fill in the table below.

What is the concentration of the biomass at different times?

$$lnX = (\mu_{max} - D) \cdot t + lnX_0$$

$$X = 1000 \cdot X_0 exp((\mu_{max} - D) \cdot t)$$ (in mg/L)

Time [h]	**Biomass concentration [mg L^{-1}] (3 digits after the comma !)**
1	2461.336
5	149.6764
15	0.136
25	0.000