EXAMPLE: DESIGN OF CSTR WITH BIOMASS RECYCLE

Oxygen supply is an important constraint for process design.

- Oxygen transfer through conventional aeration devices is limited, with 1,000 g-O_2/m^3-d to be assumed to be a maximum rate of oxygen supply
- Aeration via compressed air supplied by mechanical blowers (bubble) or turbines is costly – especially in terms of energy consumption

Purpose of this example: develop a CSTR-biomass recycle process to minimize plant size while maintaining oxygen requirement < 1,000 g-O_2/m^3-d.

Given

S_{SO} = 250 g/m^3 COD
$S_S \leq$ 10 g/m^3 COD (discharge permit)
S_{NHO} = 40 g/m^3 NH_4-N
$S_{NH} \leq$ 0.5 g/m^3 NH_4-N

Kinetic and stoichiometric data,

$$\hat{\mu}_H = 4d^{-1}$$

$$\hat{\mu}_A = 1d^{-1}$$

K_S = 25 g/m^3 COD
K_{NH} = 3 g/m^3 NH_4-N
b = 0.05 d^{-1} for both heterotrophs and nitrifiers
Y_H = 0.64 g-heterotrophic cell COD/g-substrate COD
Y_A = 0.12 g- autotrophic cell COD/g- NH_4-N

f_D = 0.2 g-debris COD/g-biomass COD decayed
i_{NXB} = i_{NXD} = 0.09 g- NH_4-N/g-cell COD

$$\mu_H = \hat{\mu}_H \frac{S_S}{(K_S + S_S)}$$

$$\mu_A = \hat{\mu}_A \frac{S_{NH}}{(K_{NH} + S_{NH})}$$

assume $X_{BA} << X_{BH}$ and nitrogen synthesis requirement to autotrophs can be neglected

1. Relation between Θ and S_S and S_{NH}

For $\Theta > 0.5$ d, discharge permit for COD is satisfied.

For $\Theta > 11$ d, discharge permit for ammonia-nitrogen is satisfied.

2. Relation between Θ and X_{BH}

Recall that the product $X_{BH}\tau$ = function of (Θ) and decreases as Θ increases. Also products $X_D\tau$ and $X_T\tau$ both increase as Θ increases.

3. OXYGEN CONSTRAINT for design of CSTR

$$r_{O,max} = RO/V = 1{,}000 \text{ g-}O_2/m^3\text{-d}$$

Note that minimum volume of CSTR is achieved at minimum $\tau = \tau_{min}$.

for COD oxidation only,

$$\tau_{min} = \frac{1}{r_{O,max}} \left[(S_{SO} - S_S)(1 - Y_{HOBS}) \right]$$

and $X_{max} = (X\tau)/\tau_{min}$ where $X\tau = X\tau(\Theta)$

4. Other constraints:

$$3 \text{ days} < \Theta$$

$$X_T > 1{,}500 \text{ g/m}^3 \text{ COD}$$

5. Adding nitrification

$$\tau_{min} = \left(\frac{1}{r_{O,max}}\right) \left\{ \left[(S_{SO} - S_S)(1 - Y_{HOBS}) \right] + 4.57 \left[(S_{NHO} - S_{NH}) - i_{NXB} Y_{Hobs} (S_{SO} - S_S) \right] \right\}$$

6. Note that wasting rate, observed yield and nitrogen synthesis requirements all decrease as Θ increases