BIOREACTOR ENGINEERING
Chapter 3
Culture Kinetic Study of Continuous Fermentation

by

Chew Few Ne
Faculty of Chemical & Natural Resources Engineering
cfne@ump.edu.my

Chapter Description

- Topic Outcome
  - Perform calculation regarding culture kinetics of continuous fermentation

- References
  - Doran, P.M. (2013) Bioprocess Engineering Principles. Elsevier.
  - Liu, S. (2013) Bioprocess Engineering: Kinetics, Biosystem, Sustainability and Reactor Design. Elsevier.
  - Rao, D.G. (2010) Introduction to Biochemical Engineering. McGraw Hill.

Topic Outline

- Kinetics of Cell Growth
- Kinetics of Substrate Consumption
- Kinetics of Product Formation

Kinetics of Cell Growth

- Material balance around the chemostat on the cell:

Cell accumulation = cell in – cell out + cell growth – cell death

Please write the formula = ?

F = volumetric flow rate of medium (feed & effluent) (L/h)
S_0 = substrate concentration in the feed (g/L)
X_0 = cell centration in the feed (g/L)
P_0 = product concentration in the feed (g/L)
S = substrate concentration in the fermenter (g/L)
X = cell concentration in the fermenter (g/L)
P =product concentration in the fermenter (g/L)
V = liquid volume of fermenter (L)
μ = specific growth rate (h^{-1})
k_d = specific death rate (h^{-1})

Kinetics of Cell Growth

- For single-stage chemostat, medium supply is usually sterile
- During exponential phase: $k_d << \mu \rightarrow k_d \approx 0$
- So, $\frac{dX}{dt} = -\frac{F}{V}X + \mu X$
- Let dilution rate, D: $D = \frac{\text{medium flowrate}}{\text{culture volume}} = \frac{F}{V}$
- So, Please write the formula = ?
- During steady state, $\frac{dX}{dt} = 0$ $\therefore \mu = D$
- The equation shows that by varying the medium supply rate, the growth rate can be varied

Kinetics of Cell Growth

- From Monod equation: $\mu = \mu_{max} \frac{S}{K_s + S}$
- Thus, D= $\mu_{max} \frac{S}{K_s + S}$ OR S= $\frac{K_S D}{\mu_{max} - D}$

Kinetics of Cell Growth

- Exercise 1

Kinetics of Substrate Consumption

- Material balance around the chemostat on the limiting substrate:

substrate accumulation = substrate in – substrate out – substrate for growth– substrate for product formation – substrate for maintenance

Please write the formula = ?

F = volumetric flow rate of medium (feed & effluent) (L/h)
V = liquid volume of fermenter (L)
S_0 = limiting substrate concentration in the feed (g/L)
S = limiting substrate concentration in the fermenter (g/L)
$Y_{X/S}$ = the theoretical yield of cell from substrate (g cell dry weight formed per g substrate consumed)
$Y_{P/S}$ = the theoretical yield of product from substrate (g product formed per g substrate consumed)
μ = specific growth rate (h^{-1})
q_p = specific product formation rate (h^{-1}).
m = the maintenance coefficient (g substrate consumed per g cell dry weight per hour)

Kinetics of Substrate Consumption

- In general, $mX \ll \frac{\mu X}{Y_{X/S}}$ and can be neglected
- If no product is formed, so: Please write the formula = ?
- During steady state, $\frac{dS}{dt} = 0$ and $\frac{F}{V} = D$
- So: X$= Y_{X/S}(S_0 - S)$
- With S$= \frac{K_S D}{\mu_{max} - D}$ → X$= Y_{X/S}\left(S_0 - \frac{K_S D}{\mu_{max} - D}\right)$

Kinetics of Substrate Consumption

- From the graph of cell and substrate concentration as a function of dilution rate,
  - At low D, all the substrate is consumed at steady state, S ≈ 0 and X is high: $X = Y_{X/S} S_0$
  - As D increases, S increases and X decreases.
- For X falls to zero rapidly,
  - This is called a washout condition.
  - The rate at which cells are removed in the outlet stream is greater than the rate of generation by growth.
  - Although μ can be manipulated by changing D, the cell growth rate is ultimately limited to μ_{max}
  - During washout, D = D_c (critical dilution rate)

Kinetics of Substrate Consumption

- To calculate the value of D_c, from previous:

$$D = \mu_{max}\frac{S}{K_s + S}$$

- If $D = D_c$, $S = S_0$ when $X = 0$, and $K_s << S_0$
- So,

$$D_c = \mu_{max}$$

- We must avoid washout in practical operation where $D < D_c$
- When the $D \approx D_c$, small changes in D cause large changes in X and S (due to fluctuation in the flow rate).

Kinetics of Product Formation

- The cell productivity of a chemostat: $P_X = DX$

  P_X = volumetric rate of cell production (g/L.h)
  D = dilution rate (h^{-1})
  X = cell concentration (g/L)

- From previous: $X = Y_{X/S}\left(S_0 - \frac{K_s D}{\mu_{max} - D}\right)$

- So, $P_X = DY_{X/S}\left(S_0 - \frac{K_s D}{\mu_{max} - D}\right)$

Kinetics of Product Formation

- From the graph of cell productivity as a function of dilution rate, the dilution rate giving rise to maximum productivity, D_{opt} can be calculated by solving:

$$\frac{dP_X}{dD} = 0$$

- So,

$$D_{opt} = \mu_{max}\left(1 - \sqrt{\frac{K_S}{K_S + S_0}}\right)$$

- If K_s <<S_0, $D_{opt} \approx \mu_{max} \approx D_c$ (Washout may occur)

Kinetics of Product Formation

- Exercise 2

CREDITS

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