7. Stoichiometry of Microbial Growth and Product Formation

- 7.1. Introduction

- 7.2. Some Definitions of Yield Coefficients
  - Growth yield and etc.
  - RQ : respiratory quotient
    - Defined as the moles of CO_2 produced per mole of oxygen consumed

7.3. Stoichiometric Calculations

- 7.3.1. Elemental Balances

  One mole of biological materials is defined as the amount containing 1 gram atom of carbon, such as $CH_{\alpha}O_{\beta}N_{\delta}$.

  Assumption: No extracellular products other than H_2O and CO_2 are produced.

Elemental Balances

$$CH_mO_n + a\,O_2 + b\,NH_3 \rightarrow c\,CH_\alpha O_\beta N_\delta + d\,H_2O + e\,CO_2 \quad \text{Eq(1)}$$

where CH_mO_n : 1mole of carbohydrate

$CH_\alpha O_\beta N_\delta$: 1 mole of cellular material

Elemental Balances

C:	$1 = c + e$	
H:	$m + 3b = c\alpha + 2d$	Eq(2)
O:	$n + 2a = c\beta + d + 2e$	
N:	$b = c\delta$	
RQ = e/a		Eq(3)

We have five equations and five unknowns (a, b, c, d, e). With a measured value of RQ, these equations can be solved to determine the stoichiometric coefficients.

7.3.2. Degree of Reduction

- Elemental balances provide no insight into the energetics of a reaction.
  - The concept of degree of reduction has been developed and used for proton-electron balances in bioreactions.

- Degree of reduction (γ) for organic compounds
  - Defined as the number of equivalents of available electrons per gram atom C.

Degree of Reduction

- Degree of reduction for some key elements

  C=4, H=1, N =-3, O =-2, P=5, S=6

- Calculation of γ
  - Methane (CH_4): 1x4 + 4x1 = 8

    γ = 8/1 = 8
  - Glucose ($C_6H_{12}O_6$): 6x4 + 12x1 + 6x(-2)=24

    γ = 24/6 = 4
  - Ethanol (C_2H_5OH): 2x4 + 6x1 + 1x(-2) = 12

    γ = 12/2 =6

Aerobic production of a single extracellular product

$CH_mO_n + a\ O_2 + b\ NH_3 \rightarrow$

substrate (s)

$$c\ CH_\alpha O_\beta N_\delta + d\ CH_xO_yN_z + e\ H_2O + f\ CO_2 \quad \text{Eq(4)}$$

biomass (b) product (p)

$$\gamma_s = 4 + m - 2n$$
$$\gamma_b = 4 + \alpha - 2\beta - 3\delta \quad \text{Eq(5)}$$
$$\gamma_p = 4 + x - 2y - 3z$$

For CO_2, H_2O, and NH_3, the degree of reduction is zero.

Aerobic production of a single extracellular product

- Eq(4) can lead to
  - elemental balance on C, H, O, and N
  - available electron balance
  - energy balance
  - total mass balance

- Of the equations, only six will be independent.
  - We would typically choose a carbon, a nitrogen, and an available-electron balances.

Balance Equations

C:	$c + d + f = 1$	Eq(6)
N:	$c\,\delta + d\,z = b$	Eq(7)
elec:	$c\,\gamma_b + d\,\gamma_p = \gamma_s - 4\,a$	Eq(8)
	$RQ = f / a$	Eq(9)
	$Yx/s = c$	Eq(10)
	$Yp/s = d$	Eq(11)