BIOTECHNOLOGY

A handbook of practical formulae

DIETER A. SUKATSCH

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Contents

Preface	5
Microbiology	7
Biochemistry	48
Physical Chemistry	65
Biochemical Engineering	102
Appendix	143
Index	156

Preface

This formulary is a summary of current nomenclature, definitions and associated equations currently in use in the field of biotechnology. It has not been attempted to extensively cover all aspects of microbiology, biochemical engineering, biophysics, molecular biology, physical chemistry and kinetics pertaining to the multidisciplinary field of biotechnology. It was, however, our aim to present a concise source of practical information. Therefore, terminology and those equations in more general use were given preference. Complex, specialized terminology has, as a consequence, not been included. We are aware that this is a compromise subject to criticism and any suggestions as well as any comments would be most welcome.

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MICROBIOLOGY

Growth kinetics – Number of cells
Discontinuous culture (batch)

$$N_t = N_0 \cdot 2^n$$

$$n = \frac{\log N_t - \log N_0}{\log 2}$$

$$\nu = \frac{n}{t} = \frac{1}{g} = \frac{\log N_t - \log N_0}{\log 2(t_t - t_0)}$$

N_t = number of cells at time t_t

N_0 = number of cells at time t_0

n = number of cell divisions

ν = rate of cell division $[h^{-1}]$

g = generation time [h]

t = time [h]

Extent of validity: during the phase of exponential growth.

Growth kinetics – Biomass
Discontinuous culture (batch)

$$\frac{dX}{dt} = \mu \cdot X \qquad X_t = X_0 \cdot e^{\mu t}$$

$$t_d = \frac{\ln 2}{\mu} \qquad \mu = \frac{\ln X_t - \ln X_0}{t_t - t_0}$$

X_t = biomass at time t_t [$g \cdot l^{-1}$]

X_0 = biomass at time t_0 [$g \cdot l^{-1}$]

t_d = doubling time of biomass [h]

μ = specific rate of growth [h^{-1}]

Extent of validity: during the phase of exponential growth, biomass is defined as dry material, often expressed as: [$g_{dm} \cdot l^{-1}$].

Growth kinetics – "Standard cells"

$\mu = \nu \cdot \ln 2$

$t_d = g$

μ = specific rate of growth [h^{-1}]

ν = rate of cell division [h^{-1}]

t_d = doubling time of biomass [h]

g = doubling time of cell number [h], equal to generation time

Extent of validity: for "standard cells", a doubling of the number of cells is equal to a doubling of biomass. This relationship holds true only during the phase of exponential growth.

Growth kinetics – Continuous culture Monod relationship

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

μ = specific rate of growth [h^{-1}]

μ_{max} = maximum specific rate of growth [h^{-1}]

S = substrate concentration [$g \cdot l^{-1}$]

K_s = saturation constant [$g \cdot l^{-1}$], substrate concentration at which $\mu = 0.5\,\mu_{max}$

The Monod relationship is only valid for special conditions analogous to those related to Michaelis–Menten-kinetics for enzyme activity (cf. enzyme kinetics). S is the concentration of the limiting substrate in the homogeneous continuous culture (chemostat).

Model equations for simple growth kinetics (no inhibition, no limitation)

$$\mu = \mu_{max} \frac{S}{K_S + S}$$

$$\mu = \mu_{max} \left[1 - e^{-S/K_S}\right]$$

$$\mu = \mu_{max} \frac{S^n}{K_S + S^n}$$

$$\mu = \mu_{max} \frac{S}{K_S \cdot X + S}$$

For explanation of symbols see previous pages.

Biomass determinations in technical media

$$\bar{X} = \frac{S_{ed} - \left(\frac{S_{ed}}{DW}\right)_0 \cdot DW}{\left(\frac{S_{ed}}{DW}\right)_1 - \left(\frac{S_{ed}}{DW}\right)_0}$$

$\bar{X}$ = average concentration of biomass

S_{ed} = sediment after filtration or centrifugation and drying [$g \cdot l^{-1}$]

DW = total dry mass of the media [$g \cdot l^{-1}$]

0 ≙ before inoculation

1 ≙ during course of bioprocess

This method is used for fermentation media containing insoluble substrates. The value of $(S_{ed} \cdot DW^{-1})_0$ must be determined only once before inoculation. Values for S_{ed} or DW can also be determined by quick methods such as infra-red or microwave drying.

Yield coefficients – Substrate

$$Y_{X/S} = \frac{\Delta X}{\Delta S} = \frac{X_t - X_0}{S_0 - S_t}$$

$$Y_{S/X} = \frac{\Delta S}{\Delta X} = (Y_{X/S})^{-1}$$

ΔX = biomass increase $[g_{dm} \cdot l^{-1}]$

ΔS = substrate consumption $[g_s \cdot l^{-1}]$ or $[mol_s \cdot l^{-1}]$

$Y_{X/S}$ = yield coefficient with respect to substrate $[g_{dm} \cdot g_s^{-1}]$ or $[-]$, or $[g_{dm} \cdot mol_s^{-1}]$

$Y_{X/S}$ is often expressed as Y_s. To avoid incorrect interpretations both subscripts should be used. Reciprocal values can be expressed as either $(Y_{X/S})^{-1}$ or $1/Y_{X/S}$. When being used in a dimensionless form in other mathematical derivations it should be taken into consideration that different masses are involved, i.e. grams of dry mass and grams of substrate.

These rules also apply for all subsequent coefficients.

Yield coefficients – Oxygen

$$Y_{X/O_2} = \frac{\Delta X}{\Delta c_{O_2}} \qquad Y_{O_2/X} = (Y_{X/O_2})^{-1}$$

Δc_{O_2} = oxygen consumption $[g_{O_2} \cdot l^{-1}]$ or $[mol_{O_2} \cdot l^{-1}]$

Y_{X/O_2} = yield coefficient for biomass with respect to oxygen $[g_{dm} \cdot mol_{O_2}^{-1}]$

The symbols $Y_{X/O}$ and Y_O are also used. It should be noticed that the symbol "O" refers to a gram atom of oxygen and that a different value must be taken into account.

Yield coefficients – Product formation

$$Y_{X/P} = \frac{\Delta X}{\Delta P} \qquad Y_{P/X} = (Y_{X/P})^{-1}$$

ΔP = product formation
$[g_P \cdot l^{-1}]$ or $[mol_P \cdot l^{-1}]$

$Y_{X/P}$ = yield coefficient for biomass with respect to product formation
$[g_{dm} \cdot mol_P^{-1}]$

See page 14 for further explanations.