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SELECTION OF TERMS, SYMBOLS AND UNITS RELATED TO MICROBIAL PROCESSES

(IUPAC Recommendations 1992)

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Selection of terms, symbols and units related to microbial processes (IUPAC Recommendations 1992)

The present List of the Selected Terms, Symbols and Units Related to Microbial Processes differs from the one recommended earlier (Pure and Appl. Chem., Vol.54, No.9, pp.1743-1749, 1982) by some clarifications and additions. These are due to the developed knowledge and, correspondingly, new quantities formulated which describe particular characteristics of growth and product formation, specifically, integral energy characteristics.

Substantial difference of the present List also lies in the fact that the nomenclature of characteristics and processes connected with microbial growth has been brought to maximal accordance with the newly established IUPAC recommendations mostly contained in "Quantities, Units and Symbols in Physical Chemistry" (I. Mills, T. Cvitas, K. Homann, N. Kallay and K. Kuchitsu) published on behalf of the IUPAC by Blackwell Scientific Publications, Oxford, 1988.

Ambiguity of a term leads to misinterpretation, it can complicate mutual understanding between scientists. Therefore, in describing particular terms, both existing and new, short explanations are given when deemed necessary.

DESCRIPTIONS AND/OR DEFINITIONS OF TERMS	RECOMMENDED SYMBOLS AND UNITS[1)]		
	SYMBOL	SI UNIT	CUSTOMARY UNIT
GENERAL QUANTITIES			
Molar activation energy	E	J mol^{-1}	J mol^{-1}
for specific growth rate	E_μ		kJ mol^{-1}
for cell biomass yield	E_Y		
for cell death	E_δ		
Area per volume	a	m^{-1}	cm^{-1}
Available electron amount per mole of $C_iH_jO_kN_l$: $4i + j - 2k - 3l$			
available electrons (AE) of a substance $C_iH_jO_kN_l$ are, by definition, the electrons accepted by oxygen when the substance is oxidized to CO_2, H_2O and NH_3; available electron number which can be accepted by O_2 mole: 4			
Linear dimensions			
impeller diameter	d_i	m	m, cm
tank diameter	d_t	m	m, cm
tank height	h_t	m	m, cm
liquid depth	h_l	m	m, cm
baffle width	w_b	m	m, cm
Pressure	p	Pa	atm, bar
denote partial pressure with appropriate subscript, e.g. p_o for partial pressure of oxygen			
Ratio, in general	R	1[2)]	1
for stoichiometric mass ratio, e.g. mass of substrate A consumed divided by mass of substrate B consumed	$R_{A/B}$	1	1

1) Space between units is preferable to a multiplication sign (dot).

2) Dimensionless ratio.

DESCRIPTIONS AND/OR DEFINITIONS OF TERMS	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	SI UNIT	CUSTOMARY UNIT
GENERAL QUANTITIES (cont.)			
for stoichiometric amount[3] ratio, e.g. amount of substrate A consumed divided by amount of substrate B consumed	$R^{mol}_{A/B}$	1	1
Temperature			
thermodynamic[4]	T	K	K
Celsius	t	°C	°C
Time	t	s	min, h, d[5]
identify specific time periods by appropriate subscripts, e.g. t_d for doubling time, t_l for lag time, and t_r for replacement or mean residence time			
Volume	V	m^3	1
identify by subscript, e.g. V_1 for volume of stage 1, etc.			
Yield[6], ratio expressing the efficiency of a conversion process:			
mass yield, general mass ratio expressing formation of a definite substance over consumption of a definite substrate	Y	1	1
fed yield, general mass ratio expressing ratio of biomass or another product formation to substrate input which is the sum of consumed and residual substrate	Y^f	1	1
carbon yield, ratio of carbon amounts expressing formation over consumption	y	1	1
energy yield, ratio of available electron amounts expressing formation over consumption	η	1	1
Y, y and η should be further defined by subscripts to denote the ratio, e.g.			
$Y_{X/S}$, $y_{X/S}$, $\eta_{X/S}$ for cell biomass yields from energetic substrate,			
$Y_{P/S}$, $y_{P/S}$, $\eta_{P/S}$ for product yields from energetic substrate,			
$Y_{X/O}$, $\eta_{X/O}$, $Y_{P/O}$, $\eta_{P/O}$ for yield from oxygen,			
$Y_{L/S}$, $\eta_{L/S}$ for yields of cellular lipids from energetic substrate, etc.			
yield of cell biomass per amount of ATP produced in cells	Y_{ATP}	kg mol^{-1}	g mol^{-1}

3) Amount of a substance is measured in moles.

4) Formerly called absolute temperature.

5) d = day.

6) Utilization of such terms as harvest, economic coefficient, production level etc. to characterize yield as a physiological quantity is not recommended.

DESCRIPTIONS AND/OR DEFINITIONS OF TERMS	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	SI UNIT	CUSTOMARY UNIT
GENERAL QUANTITIES (cont.)			
maintenance-corrected mass yield	Y^G	1	1
Y^G is connected with yield, Y, specific growth rate, μ, and maintenance coefficient, m, as follows:			
$\frac{1}{Y_{X/S}} = \frac{1}{Y^G_{X/S}} + \frac{m_S}{\mu}$			
$\frac{1}{Y_{X/O}} = \frac{1}{Y^G_{X/O}} + \frac{m_O}{\mu}$			
$q_S = \frac{\mu}{Y^G_{X/S}} + m_S$			
$q_O = \frac{\mu}{Y^G_{X/O}} + m_O$			
maintenance-corrected energy yield	η^G	1	1
$\frac{1}{\eta_{X/S}} = \frac{1}{\eta^G_{X/S}} + \frac{m_e}{\mu}$			
maintenance-corrected yield per ATP	Y^G_{ATP}	kg mol^{-1}	g mol^{-1}
$\frac{1}{Y_{ATP}} = \frac{1}{Y^G_{ATP}} + \frac{m_{ATP}}{\mu}$			
CONCENTRATIONS AND AMOUNTS			
Concentration[7]			
biomass			
total mass	m, X[8]	kg	g
mass concentration	ρ, x[8]	kg m^{-3}	g l^{-1}
volume fraction	ϕ	1	1
number of cells	N	1	1
cell number concentration	n	m^{-3}	ml^{-1}, l^{-1}
substances other than biomass			
total mass	m, S[8]	kg	g, mg
total amount	n, C	mol	mol, mmol
mass concentration	ρ, s[8]	kg m^{-3}	g l^{-1} mg l^{-1}
amount concentration	c	mol m^{-3}	mol l^{-1} mmol l^{-1}
identify by subscript, e.g. c_0 for dissolved oxygen, c_0^* for saturation concentration of dissolved oxygen, c_p for a product, c_i for an inhibitor, etc.			
Gas hold-up	ε	1	1
volume of gas divided by volume of liquid			

7) Input quantities should be indicated by number subscript 0. In multi-stage systems the output quantities of each stage should be indicated by the number of the corresponding stage.

8) The symbol which conforms to the tradition.

DESCRIPTIONS AND/OR DEFINITIONS OF TERMS	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	SI UNIT	CUSTOMARY UNIT
CONCENTRATIONS AND AMOUNTS (cont.)			
Inhibitor constant dissociation constant of inhibitor-biomass complex	K_i	kg m^{-3}	g l^{-1}
Saturation constant as in the growth rate expression $\mu_m c_s / (K_s + c_s)$	K_s	kg m^{-3} mol m^{-3}	g l^{-1} mg l^{-1} mol l^{-1} mmol l^{-1}
INTENSIVE QUANTITIES			
Density, mass	ρ	kg m^{-3}	g l^{-1}
Diffusion coefficient, molecular, volumetric	D_V	$m^2 s^{-1}$	$cm^2 s^{-1}$
Specific enthalpy of growth heat produced by cells, divided by mass of cell biomass formed	H_X	J kg^{-1}	J g^{-1} kJ g^{-1}
Vapour pressure denote with appropriate subscript, e.g. p^*_A = vapour pressure of material A	p^*	Pa	atm, bar
Viscosity, dynamic	μ	Pa s	poise
Viscosity, kinematic	ν	$m^2 s^{-1}$	$cm^2 s^{-1}$
RATE QUANTITIES			
Death rate, specific $\delta = -(\Delta n/\Delta t)/n$[9]	δ	s^{-1}	s^{-1}, h^{-1}
Dilution rate[10] volume flow rate/culture volume	D	s^{-1}	h^{-1}, d^{-1}
Dilution rate, critical value at which biomass washout occurs in continuous flow culture	D_c	s^{-1}	h^{-1}, d^{-1}
Doubling time, biomass $t_d = (\log_e 2)/\mu$	t_d	s	min, h, d
Volume flow rate[10] identify stream by appropriate subscript, e.g. a for air, g for gas, l for liquid, etc.	F, q	$m^3 s^{-1}$	l h^{-1}
Growth rate, colony radial rate of extension of biomass colony on a surface	K_r	m s^{-1}	m h^{-1}
Maximum specific growth rate (mass basis)	μ_m	s^{-1}	h^{-1}, d^{-1}
Maximum specific growth rate (cell number basis)	ν_m	s^{-1}	h^{-1}

9) Symbol Δ means a small difference caused just by the growth or death process.
10) In multi-stage systems, the flow rate and the dilution rate related to each stage should be indicated by the number of the stage.

DESCRIPTIONS AND/OR DEFINITIONS OF TERMS	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	SI UNIT	CUSTOMARY UNIT
RATE QUANTITIES (cont.)			
Specific growth rate (mass basis) $\mu = (\Delta x/\Delta t)/x$[9]	μ	s^{-1}	h^{-1}, d^{-1}
Specific growth rate (cell number basis) $\nu = (\Delta n/\Delta t)/n$[9]	ν	s^{-1}	h^{-1}
Heat transfer coefficient	h	$W\ m^{-2}\ K^{-1}$	$W\ cm^{-2}\ {}^{\circ}C^{-1}$
Maintenance coefficient	m		
non-growth term associated with consumption of different substances as defined in yield relationship (see yield term):			
in mass form	m_s, m_o	s^{-1}	h^{-1}
(mass of substrate or oxygen divided by dry mass of cells and by time)			
in mass-molar form	m_{ATP}	$mol\ kg^{-1}\ s^{-1}$	$mol\ g^{-1}\ h^{-1}$
in mass-energy form	m_e	s^{-1}	h^{-1}
(amount of available electrons of substrate divided by amount of available electrons of cell biomass and by time)			
Mass transfer coefficient, based on the equation: $\frac{dc}{dt} = \pm ka\beta + \text{other terms}$ where concentration c is measured as $mol\ m^{-3}$ or $mol\ l^{-1}$; a is bubble area per unit volume; β is the driving force, e.g. Δc, Δp, Δx (x is mole fraction); unit of β is denoted as $[\beta]$			
area basis[11]	k	$mol\ m^{-2} \cdot \cdot s^{-1}\ [\beta]^{-1}$	$mol\ cm\ l^{-1} \cdot \cdot h^{-1}\ [\beta]^{-1}$
gas film	k_G	"	"
liquid film	k_L	"	"
volumetric basis[11]	ka	$mol\ m^{-3} \cdot \cdot s^{-1}\ [\beta]^{-1}$	$mol\ l^{-1} \cdot \cdot h^{-1}\ [\beta]^{-1}$
gas film	$k_G a$	"	"
liquid film	$k_L a$	"	"
Maximum specific amount metabolic rate	q_m^{mol}	$mol\ kg^{-1}\ s^{-1}$	$mol\ g^{-1}\ h^{-1}$
Specific amount metabolic rate $q^{mol} = (\Delta c/\Delta t)/x$[9] where c may be the amount concentration of a substrate, product, or intracellular component. Subscripts may further define the rates, e.g. q_s, q_p, q_o, which are substrate utilization, product formation, and oxygen uptake rates, respectively. Numerical subscripts, e.g. for intracellular components, are also possible.	q^{mol}	$mol\ kg^{-1}\ s^{-1}$	$mol\ g^{-1}\ h^{-1}$

11) When the driving force is $\beta = \Delta c$, the units for k are $m\ s^{-1}$ and $cm\ h^{-1}$, the units for ka are s^{-1} and h^{-1}.

DESCRIPTIONS AND/OR DEFINITIONS OF TERMS	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	SI UNIT	CUSTOMARY UNIT
RATE QUANTITIES (cont.)			
Maximum specific mass metabolic rate	q_m	s^{-1}	h^{-1}
Specific mass metabolic rate $q = (\Delta s/\Delta t)/x$ [9] where s may be the mass concentration of a substrate, product, etc. Identify by a letter or numerical subscript similarly to specific amount metabolic rate.	q	s^{-1}	h^{-1}
Amount metabolic rate per volume $Q^{mol} = \Delta c/\Delta t$ [9] see the description of q^{mol} (above)	Q^{mol}	mol m^{-3} s^{-1}	mol l^{-1} h^{-1}
Mass metabolic rate per volume $Q = \Delta s/\Delta t$ [9] see the description of q (above)	Q	kg m^{-3} s^{-1}	g l^{-1} h^{-1}
Productivity, the same as amount or mass metabolic rate per volume (above)			
Mutation rate	w	s^{-1}	h^{-1}
Power	P	W	W
Rate of metabolic heat production, volumetric	Q_H	J m^{-3} s^{-1}	J l^{-1} h^{-1} kJ l^{-1} h^{-1}
Stirring speed or revolution per time	n	s^{-1}	min^{-1}
Velocity	v	m s^{-1}	cm s^{-1}
superficial gas velocity	v_s		
impeller tip velocity	v_i		