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APPLIED CHEMISTRY DIVISION

COMMISSION ON BIOTECHNOLOGY*

LIST OF SYMBOLS WITH UNITS RECOMMENDED FOR USE IN BIOTECHNOLOGY

Prepared for publication by
R. C. RIGHELATO

Comments on these recommendations are welcome and should be sent within 8 months from September 1982 to the Secretary of the Commission:

Dr. R. C. Righelato,
Tate and Lyle Ltd.,
Group Research and Development,
Philip Lyle Memorial Research Laboratory,
University of Reading,
POB 68, Whiteknights Park,
Reading, Berkshire RG6 2BX,
UK.

Comments from the viewpoint of languages other than English are especially encouraged. These may have special significance regarding the publication in various countries of translations of the nomenclature eventually approved by IUPAC.

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LIST OF SYMBOLS WITH UNITS RECOMMENDED FOR USE IN BIOTECHNOLOGY

The list given hereunder is intended for use in conjunction with other IUPAC recommendations on symbols, in particular *Manual of Symbols and Terminology for Physicochemical Quantities and Units* (Pergamon Press, Oxford, 1979) and by the American Institute of Chemical Engineers, 'Letter Symbols for Chemical Engineering', *Chem. Engng. Prog.* (1978), pp. 73-80.

SYMBOLS FOR GENERAL CONCEPTS

	RECOMMENDED SYMBOLS AND UNITS		
DESCRIPTION AND/OR DEFINITION	SYMBOL	S.I.UNITS	CUSTOMARY UNITS
Activation energy	E	$J.mol^{-1}$	$cal.\ mol^{-1}$
for growth	Eg		
for death	Ed		
Area dimensions			
Area per unit volume	a	m^{-1}	cm^{-1}
Linear dimension			
Impeller Diameter	D_i	m	m
Tank Diameter	D_t	m	m
Liquid Depth	D_l	m	m
Width of baffle	D_b	m	m
Pressure			
Denote partial pressure with	p	Pa, bar	atm
appropriate subscript, e.g p_{O_2} for partial pressure of oxygen			
Ratio, in general	R	1	1
for stoichiometric mass ratio, e.g. mass of substrate A consumed per mass of substrate B consumed	$R_{A/B}$	1	1
for stoichiometric molar ratio, e.g. mol of substrate A consumed per mol of B consumed	$R_{MA/B}$	1	1
Temperature			
Absolute	T	K	K
General	t, T	°C	°C

SYMBOLS FOR GENERAL CONCEPTS (cont.)

	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	S.I. UNITS	CUSTOMER UNITS
Time			
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.	t	s	min, h
Volume dimensions			
Volume	V	m^3	L
Identify by subscript, e.g. V_1 for volume of stage 1, etc.			
Yield, general-mass ratio expressing output over input	Y	1	1
Without further definition, Y refers to the mass conversion ratio in terms of g biomass per g mass of substrate used. It should be further defined by subscripts to denote other ratios, e.g. $Y_{P/S}$, $Y_{P/X}$, for g mass of product per g mass of substrate and per g of biomass, respectively.			
Yield, growth-mass ratio corrected for maintenance, where $\frac{1}{Y} = \frac{1}{Y_G} + \frac{m}{\mu}$ or $q_s = \frac{\mu}{Y_G} + m$	Y_G	1	1
Yield, molar growth	Y_{GM}	$kg.mol^{-1}$	$g.mol^{-1}$
kg biomass formed per mole of mass used, or further defined as above to denote other molar yields			

SYMBOLS FOR CONCENTRATION AND AMOUNTS

	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	S.I. UNITS	CUSTOMER UNITS
Concentration			
Biomass, *			
total mass	X	kg	g
mass concentration	x	$kg.m^{-3}$	$g.L^{-1}$
volume fraction	$\emptyset$	1	1
total number	N	1	1
number concentration	n	m^{-3}	mL^{-1}
Substrate concentration			
mass or moles per unit volume	c_s	$kg.m^{-3}$,$kmol.m^{-3}$	$mg.L^{-1}$, $mmol.L^{-1}$
Product concentration	c_p	$kg.m^{-3}$,$kmol.m^{-3}$	$mg.L^{-1}$, $mmol.L^{-1}$
mass or moles per unit volume			
Gas hold-up			
volume of gas per volume of	H	1	1
liquid			
Inhibitor concentration			
mass or moles per unit volume	c_i	$kg.m^{-3}$,$kmol.m^{-3}$	$mg.L^{-1}$, $mmol.L^{-1}$
Inhibitor constant	K_i	$kg.m^{-3}$,	$g.L^{-1}$
dissociation constant of inhibitor-			
biomass complex			
Saturation constant	K_s	$kmol.m^{-3}$	$g.L^{-1}$ $mmol.l^{-1}$
as in the growth rate expression			
$\mu_m C_s/(K_s + C_s)$			
Total amount, e.g. mass or moles	C	kg, kmol	g, mol

* Note : because of the difficulty in expressing biomass (cells) in molar terms a separate symbol (other than C) is recommended

SYMBOLS FOR INTENSIVE PROPERTIES

Density, mass	ρ	$kg.m^{-3}$	$g.L^{-1}$
Diffusivity, molecular, volumetric	D_v	$m^2.s^{-1}$	$cm^2.s^{-1}$
Enthalpy, mass, of growth	H_x	$J.kg^{-1}$	$J.g^{-1}$
heat produced per unit of biomass			
formed +			

\+ Note: for enthalpy of growth, mass terms must be used because a molar concentration of biomass (cells) is usually unknown

SYMBOLS FOR INTENSIVE PROPERTIES (cont.)

	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	S.I. UNITS	CUSTOMER UNITS
Enthalpy, molar, of substrate consumption or of product formation	H_s, H_p	$J.mol^{-1}$	$J.mol^{-1}$
Vapour Pressure denote with appropriate subscript, e.g. p_a * = vapour pressure of material a	p*	Pa, bar	atm
Viscosity, absolute	μ	Pa.s	poise
Viscosity, kinematic	ν	$m^2.s^{-1}$	$cm^2.s^{-1}$
SYMBOLS FOR RATE CONCEPTS			
Death rate, specific ‡ $\delta = -(dn/dt)n$	δ	s^{-1}	s^{-1}, h^{-1}
Dilution rate 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
Flow rate, volumetric Identify stream by appropriate subscript, e.g. a for air, g for gas, l for liquid, etc.	F	$m^3.s^{-1}$	$L\text{-}h^{-1}$
Growth rate, colony radial rate of extension of biomass colony on a surface	K_r	$m.s^{-1}$	$\mu m.h^{-1}$
Growth rate, maximum specific	μ_m	s^{-1}	h^{-1}, d^{-1}
Growth rate, specific ‡ $\mu = (dx/dt)/x$			

‡ Note : If μ_d is used for death rate, then it is suggested that μ_g be used for growth rate

SYMBOLS FOR RATE CONCEPTS (cont.)

	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	S.I. UNITS	CUSTOMER UNITS
Heat transfer coefficient			
individual	h	$W.m^{-2}K^{-1}$	$cal.h^{-1}.cm^{-2}.{}^{o}C^{-1}$
overall	U	$W.m^{-2}K^{-1}$	$cal.h^{-1}.cm^{-2}.{}^{o}C^{-1}$
Maintenance coefficient, substrate or non-growth term associated with substrate consumption as defined in yield relationship (see yield term)	m	s^{-1}	h^{-1}
Mass Transfer coefficient (molar basis)			
Individual, area basis	k	$kmol.m^{-2}.s^{-1}$	$gmol.h^{-1}cm^{-2}$ (driving force)$^{-1}$ *
Gas film	k_G	"	"
Liquid film	k_L	"	"
Overall, area basis	K	"	"
Gas film basis	K_G	"	"
Liquid film basis	K_L	"	"
Individual, volumetric basis	ka	$kmol.m^{-3}.s^{-1}$	h^{-1}
Gas film	$k_G a$	"	h^{-1}
Liquid film	$k_L a$	"	h^{-1}
Metabolic rate, maximum specific	q_m	s^{-1}	h^{-1}
Metabolic rate, specific $q = (dc/dt)/x$ where c may be a substrate or product mass concentration. Subscripts may further define the rates, e.g. q_s, q_P, q_{O_2} which are substrate utilisation product formation, and oxygen uptake rates, respectively	q	s^{-1}	h^{-1}
Mutation rate	w	s^{-1}	h^{-1}

* Note : the driving force may be expressed as Δc for $kmol/m^3$, ΔP for bar, and ΔX for mole fraction.

SYMBOLS FOR RATE CONCEPTS (cont.)

	RECOMMENDED SYMBOLS AND UNITS		
	SYMBOL	S.I. UNITS	CUSTOMER UNITS
Power	P	W	W
Productivity, mass concentration rate	r	$kgm^{-3}s^{-1}$	$kgm^{-3}h^{-1}$
basis, use appropriate subscripts			
e.g. r_X for biomass productivity and			
r_P for product productivity			
Revolution per unit time or stirring	n	s^{-1}	s^{-1}
speed			
Velocity			
V_S for superficial gas	V	$m.s^{-1}$	$cm.s^{-1}$
velocity = $Fg/\pi D_t^2$			
V_i for impeller tip velocity			
= $\pi n D_i$			

This list is meant to be used in conjunction with the various lists of symbols and units by the International Union of Pure and Applied Chemistry such as the "Manual of Symbols and Terminology for Physiochemical Quantitites and Units" available from Pergamon Press, Ltd., 88 Kingsway, London, WC2B 6AB, and by the American Institute of Chemical Engineers, "Letter Symbols for Chemical Engineering", published in Chemical Engineering Progress, 1978, pp. 73-80. Any suggestions or recommendations for changes in this list should be communicated to the Secretary of the Commission on Biotechnology, VI.2, Division of Applied Chemistry, IUPAC, Bank Court Chambers, 2-3 Pound Way, Cowley Centre, Oxford OX4 3YF, United Kingdom.