Separation of Molecules, Macromolecules and Particles

Providing chemical engineering undergraduate and graduate students with a basic understanding of how the separation of a mixture of molecules, macromolecules or particles is achieved, this textbook is a comprehensive introduction to the engineering science of separation.

- Students learn how to apply their knowledge to determine the separation achieved in a given device or process.
- Real-world examples are taken from biotechnology, chemical, food, petrochemical, pharmaceutical and pollution
- control industries.Worked examples, elementary separator designs and chapter-end problems give students a practical understanding of separation.

The textbook systematically develops different separation processes by considering the forces causing the separation, and how this separation is influenced by the patterns of bulk flow in the separation device. Readers will be able to take this knowledge and apply it to their own future studies and research in separation and purification.

Kamalesh K. Sirkar is a Distinguished Professor of Chemical Engineering and the Foundation Professor of Membrane Separations at New Jersey Institute of Technology (NJIT). His research areas are membranes and novel membrane based processes.

"The first comprehensive book that takes the fundamentals of separation on a molecular level as the starting point! The benefit of this approach is that it gives you a thorough insight in the mechanisms of separation, regardless of which separation is considered. This makes it remarkably easy to understand any separation process, and not only the classical ones. This textbook finally brings the walls down that divide separation processes in classical and non-classical."

Bart Van der Bruggen, University of Leuven, Belgium

"This strong text organizes separation processes as batch vs continuous and as staged vs differential. It sensibly includes coupled separation and chemical reaction. Supported by strong examples and problems, this non-conventional organization reinforces the more conventional picture of unit operations."

Ed Cussler, University of Minnesota

"This book fills the need by providing a very comprehensive approach to separation phenomena for both traditional and emerging fields. It is effectively organized and presents separations in a unique manner. This book presents the principles of a wide spectrum of separations from classical distillation to modern field-induced methods in a unifying way. This is an excellent book for academic use and as a professional resource."

C. Stewart Slater, Rowan University

"This book is an excellent resource for the topic of chemical separations. The text starts by using examples to clarify concepts. Then throughout the text, examples from many different technology areas and separation approaches are given. The book is framed around various fundamental approaches to chemical separations. This allows one to use this knowledge for both current and future needs."

Richard D. Noble, University of Colorado

"This book provides a unique and in depth coverage of separation processes. It is an essential reference for the practicing engineer. Unlike more conventional textbooks that focus on rate and equilibrium based separations, Prof Sirkar focuses on how a given separation takes place and how this is used in practical separation devices. Thus the book is not limited by application e.g. chemical or petrochemical separations.

"As chemical engineering becomes increasingly multidisciplinary, where the basic principles of separations are applied to new frontier areas, the book will become an essential guide for practitioners as well as students.

"The unique layout of the text book allows the instructor to tailor the content covered to a particular course. Undergraduate courses will benefit from the comprehensive and systematic coverage of the basics of separation processes. Whether the focus of a graduate course is traditional chemical separations, bioseparations, or separation processes for production of renewable resources the book is an essential text."

Ranil Wickramasinghe, University of Arkansas

"This advanced textbook provides students and professionals with a unique and thought-provoking approach to learning separation principles and processes. Prof. Sirkar has leveraged his years of experience as a separation scientist and membrane separation specialist, to provide the reader with a clearly written textbook full of multiple examples pulled from all applications of separations, including contemporary bioseparations. Compared to other separations textbooks, Prof. Sirkar's textbook is holistically different in its approach to teaching separations, yet provides the reader with a rich learning experience. Chemical engineering students and practicing professionals will find much to learn by reading this textbook."

Daniel Lepek, The Cooper Union

Separation of Molecules, Macromolecules and Particles

Principles, Phenomena and Processes

Kamalesh K. Sirkar New Jersey Institute of Technology



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Preface

This is an introductory textbook for studying separation. Primarily, this book covers the separation of mixtures of molecules; in addition, it provides a significant treatment of particle separation methods. Separation of macromolecules has also received some attention. The treatment and coverage of topics are suitable for chemical engineering students at undergraduate and graduate levels. There is enough material here to cover a variety of introductory courses on separation processes at different levels.

This book is focused on developing a basic understanding of how separation takes place, and of how the resulting separation phenomenon is utilized in a separation device. The role of various forces driving molecules or particles from a feed mixture into separate phases/ fractions/regions is basic to such an approach to studying separation. The separation achieved is then amplified in an open separator via different patterns of bulk-phase velocities vis-à-vis the direction(s) of the force(s). The forces are generated by chemical potential gradient, electrical field, rotational motion, gravity, magnetic field, etc. The resulting separation is studied under three broad categories of separation processes.

Separation processes driven by a negative chemical potential gradient are generally multiphase systems and are treated under the broad category of phase equilibrium driven processes. External force driven processes populate the second category, and include those operating under an electrical field, rotational motion, magnetic field or gravity; thermal diffusion processes are also briefly included here. The third category of membrane based processes studied is driven generally by a negative chemical potential gradient; however, electrical force is also relevant for some processes. The treatment of any external force driven processes will cover both separation of molecules and particle separations.

These physical separation methods are often reinforced by chemical reactions, which are usually reversible. An elementary treatment of the role of chemical reactions in enhancing separation across a broad spectrum of phase equilibrium driven processes and membrane based processes has been included. The level of treatment in this book assumes familiarity with elementary principles of chemical engineering thermodynamics and traditional undergraduate levels of knowledge of ordinary differential equations and elementary partial differential equations.

Specific aspects of a given separation process are studied in the chapter devoted to those aspects for all separation processes. To study a particular separation process in great detail, one therefore has to go to different chapters. The footprints of a given separation process are provided at the beginning of the book (Tables 1–7); there are quite a few tables to cover a variety of separation processes. The list of processes is large; however, it is far from being all inclusive. The introductory chapter, which provides additional details about various chapters, as well as about the book, is preceded by a notation section. All references appear at the end of the book.

The description of the extent of separation achieved in a closed vessel for a mixture of molecules is treated in Chapter 1. Chapter 2 illustrates how to describe the separation of molecules in open separators under steady and unsteady state operation; a description of separation for a size-distributed system of particles is also included. Chapter 3 introduces various forces developing species-specific velocities, fluxes and mass-transfer coefficients, and illustrates how the spatial variation of the potential of the force field can develop multicomponent separation ability. The criteria for chemical equilibrium are then specified for different types of multiphase separation systems, followed by an illustration of integrated flux expressions for twophase and membrane based systems.

Chapter 4 develops the extent of separation achieved in a closed vessel to a variety of individual processes under each of the three broad categories of separation processes. Chapter 5 demonstrates how separation can be considerably enhanced by chemical reactions in phase equilibrium based and membrane based processes under both equilibrium- and rate-controlled conditions. For open separators having bulk flow in and out, including continuous stirred tank separators (CSTSs), Chapter 6 provides first the equations of change for molecular species concentration in single-phase and two-phase systems, the trajectory equation for a particle in a fluid and the general equation of change for a particle population. Chapter 6 then treats individual separation processes under each of the three broad categories of separation processes when the bulk flow is parallel to the direction of the force and in CSTS mode.

Chapter 7 follows this latter approach of treating individual separation processes under each of the three broad categories of separation processes when the bulk flow of feed-containing phase is perpendicular to the direction of the force. Chapter 8 follows the same approach when the bulk flows of two phases/regions in the separator are perpendicular to the direction(s) of the force(s). Chapter 9 briefly elaborates on cascades, which were already introduced in the countercurrent multistaged flow systems of Chapter 8. Chapter 10 introduces the energy required for a number of separation processes. Chapter 11 illustrates a few common separation sequences in a number of common industries involved in bioseparations, water treatment, chemical and petrochemical separations and hydrometallurgy. Conversion factors between various systems of units are provided in an Appendix.

Virtually all separation processes taught to chemical engineering students in a variety of courses have been covered via the approach illustrated in Chapters 3, 4, 6, 7 and 8; in addition, many particle separation methods have been treated. The structural similarity in the separation method between apparently unrelated separation processes becomes quite clear. A few basic principles equip the students with the capability to understand a wide variety of separation processes and techniques, including emerging ones. To aid the student, there are 118 worked examples, 300 problems, 340 figures, 100 tables and 1011 references. A website will provide guidance for computer simulations for a few selected problems.

The introductory chapter provides references to articles and books which influenced the development of various aspects of this book. I have benefitted considerably from the comments on selected chapters of the book by reviewers, anonymous or otherwise. Comments by Professors C. Stewart Slater, of Rowan University, Steven Cramer, of Rensselaer Polytechnic Institute, and Ranil Wickramasinghe, of Colorado State University (now at University of Arkansas), were particularly useful.

Many doctoral students and postdoctoral fellows were of invaluable help during the long gestation period of this book, either in formulating solutions of the problems or in developing illustrative drawings. I want to mention in particular Amit Sengupta, Theoharris Papadopoulos, Xiao-Ping Dai, Meredith Feins, Dimitrios Zarkadas, Quixi Fan, Praveen Kosaraju, Fei He, Atsawin Thongsukmak, Sagar Roy, Dhananjay Singh, John Tang and John Chau. The first two students helped me when we were at Stevens Institute of Technology. Sarah Matthews of Cambridge University Press patiently provided manuscript preparation guidelines and encouraging comments during an ever-shifting timetable. Irene Pizzie did an extraordinary job as the copy editor. Brenda Arthur of New Jersey Institute of Technology tirelessly typed the draft of the whole manuscript over a considerable length of time, while carrying out many other duties.

I must also mention at the end my wife, Keka, without whose patience, help and understanding this book would never have been finished.

Notation

Equation numbers identify where the symbols have been introduced or defined.

e following s	tyles have been adopted.	a_{sp}	pore surface area per unit volume of
ld vector quantity		a a	the porous medium of porosity ε
		u_{v}, u_{vc}	particle volume, value of a_v in a cake
ines			(6.3.135j)
quantity averaged over time or a specific coordinate direction, multicomponent system, Laplace transformed dependent variable averaged quantity quantity in a mixture, per unit mass of bulk phase		a _± A; A ₁ , A ₂ , A ₃	mean electrolyte activity (3.3.119d) amplitude (7.3.18), pure-water permeability constant in reverse osmosis and diffusive ultrafiltration; constants in (7.1.90b), three surface areas in control volume of Figure 7.2.6(b)
rlines		<i>A</i> (r)	cross-sectional area of a cone in centrifugal elutriation
hypothetica	l binary system quantity (2.4.23), (2.4.24)	A_c	cross-sectional area of duct
vector quantity, tensor quantity		$A_{ ext{hex}}$; A_{ij} ; A_{m} ; A_m^t ; $A_i(T)$; $A_i^{ ext{o}}$	heat exchanger surface area; constant in equations for activity coefficients
ets			(4.1.34d); surface area of memorane; total membrane surface area; modified
$\langle v_{ij} \rangle$ average value of v_{ij} over surface area S_j			equilibrium constant (7.1.66); constant (7.1.72b)
	ellipsoid semiaxis dimension; see also	$A_{1\rho}$	constant in crystal growth rate equation (6.4.27)
	(3.1.10a); constant in relations (3.1.49), (4.3.7) and (4.3.43a); interfacial area per unit volume. defined by (7.2.191). (7.3.25)	A_p	projected area of a particle (3.1.64); transport coefficient in solution- diffusion-imperfection model (3.4.60a)
<i>a</i> ₃ ,	constant in (3.3.105), (4.1.42b), (4.3.29) and (5.2.147); constants in (7.2.73),	$A_p^+(\mathbf{x})$	cumulative crystal surface area distribution fraction (6.4.17)
	(7.3.50) and (7.3.139)	A_T	total particle surface area per unit
	constant in (7.2.198a) stoichiometric coefficient for species A		volume of total mixture (Example 2.4.2): total crystal surface area per
	Hamaker constant (3.1.16)		unit liquid volume (6.4.16)
T); a_{ij} , a_{il} ; $a_{ms\ell}$	activity of species <i>i</i> ; equilibrium constant (7.1.63); atom fraction of <i>i</i> th	Am ⁺ , Am ⁻ , Am [±]	three forms of amino acid
; a _{sw}	isotope of an element in region j (1.3.6), value of a_i in region j and liquid phase, respectively; amplitude (7.1.72b); constant in (4.3.43c); membrane surface per unit channel length (7.2.70) surface area of a particle activity of solvent s in regions 1 and 2, respectively; activity of salt in water	b	ellipsoid semiaxis dimension; proportionality constant in osmotic pressure relation (3.4.61b); half of channel gap; width of region of gas flow completely cleaned up by a fiber (6.3.42a); constant in crystal growth rate expression (6.4.35); parameter (7.2.18); liquid envelope radius (7.2.208)
	the following since vector quantity avector quantity avector quantity avector quantity averaged quantity in coordinate of Laplace transveraged quantity in coordinate of the provide the sector quantity in the sector quantity in the sector quantity is a vector quantity avector quantity in a_{3} , $(T); a_{ij}, a_{li}; a_{ms\ell}$	te following styles have been adopted. vector quantity ines quantity averaged over time or a specific coordinate direction, multicomponent system, Laplace transformed dependent variable averaged quantity quantity in a mixture, per unit mass of bulk phase rlines hypothetical binary system quantity (2.4.23), (2.4.24) vector quantity, tensor quantity terts average value of v_{ij} over surface area S_j ellipsoid semiaxis dimension; see also (3.1.10a); constant in relations (3.1.49), (4.3.7) and (4.3.43a); interfacial area per unit volume, defined by (7.2.191), (7.3.25) $a_3,$ constant in (3.3.105), (4.1.42b), (4.3.29) and (5.2.147); constants in (7.2.73), (7.3.50) and (7.3.139) constant in (7.2.198a) stoichiometric coefficient for species A Hamaker constant (3.1.16) $t); a_{ij}, a_{ij}$ activity of species $i;$ equilibrium $a_{ms\ell}$ constant (7.1.63); atom fraction of <i>i</i> th isotope of an element in region <i>j</i> (1.3.6), value of a_i in region <i>j</i> and liquid phase, respectively; amplitude (7.1.72b); constant in (4.3.43c); membrane surface per unit channel length (7.2.70) surface area of a particle per unit channel length (7.2.70)	e following styles have been adopted. a_{sp} vector quantity a_{sp} vector quantity a_{sp} averaged over time or a specific coordinate direction, multicomponent system, Laplace transformed dependent variable averaged quantity quantity in a mixture, per unit mass of bulk phase a_{\pm}^{4} , A_{1} , A_{2} , A_{3} rlmes $A(r)$ hypothetical binary system quantity (2.4.23), (2.4.24) vector quantity, tensor quantity A_{c} $A_{hesc}; A_{ij}; A_{ni}; A_{i'}(T); A_{i}^{0}etsA_{1,0}average valuev_{ij} over surface area S_{j}a_{3}ellipsoid semiaxis dimension; see also(3.1.0a); constant in relations (3.1.49),(A_3.7) and (4.3.43a); interfacial area perunit volume, defined by (7.2.191), (7.3.25)and (5.2.147); constants in (7.2.73),and (5.2.147); constants in (7.2.73),(7.3.50) and (7.3.139)constant in (3.3.105), (4.1.42b), (4.3.29)and (5.2.147); constant (3.1.16)eonstant in (7.2.198a)stoichiometric coefficient for species AHamaker constant (3.1.16)ronstant (7.1.63); atom fraction of ithisotope of an element in region j and liquidphase, respectively; amplitude (7.1.72b)surface area of a particlestasuAm+, Am-, Am+a_{asw}activity of solvent s in regions 1 and 2,respectively; activity of salt in waterAm$

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b_1, b_2, b_3 b_1 $b_{i'}, b_{ij}, b_{ij}, b_{i\ell}; b_1^i$	constants in relations (3.1.143f) constant in (3.3.105), (5.2.147) membrane feed channel height (Figure 7.2.3(a)); constant in equilibrium relation (3.3.81); constant in (7.1.73), constant in Freundlich isotherm (3.3.112c); constant in Langmuir isotherm (3.3.112a); constant in equation (4.1.42a)	$C_{ii} \ \overline{C}_{i}; C_{ii}^{t}; C_{i}^{t}; C_{i}^{*}; C_{ig}^{*}; C_{ig}^{*}; C_{i1}^{i}, C_{i2}^{i}$	molar concentration of species i ; an average of the molar concentration of species i in the feed and the permeate (5.4.74), (6.3.158b); total molar concentration of species i in the porous medium per unit volume (3.1.118b); nondimensional species i concentration (5.3.35j), hypothetical gas-phase species i concentration
b_{i-k}, b_k	proportionality constant in (5.2.154), equilibrium constant in (5.2.155)		(8.1.47); initial bed concentration of solute <i>i</i> in phases 1 and 2
$\begin{array}{l} \mathbf{b}_{\mathrm{m}}, \mathbf{b}_{\mathrm{m}}^{'}\\ \boldsymbol{B}\\ \mathbf{B}; \ B^{\mathrm{o}}; \ B_{i}^{\mathrm{o}}; B_{p}\end{array}$	constants in (4.3.43a,c) magnetic induction vector (3.1.19) constant, density function of the birth rate of new particles (6.2.50g), value of <i>B</i> as $r_p \rightarrow 0$; value of B^o for crystal growth rate gr_i ; duct perimeter	C_{i10}, C_{i20} $C^o_i(\pi)$	values of C_{i1} , C_{i2} at $z = 0$ liquid-phase concentration of pure solute <i>i</i> at spreading pressure π and temperature <i>T</i> providing the same surface phase concentration of <i>i</i> as the mixture
D;	(7.3.41) Biot number (2.4.25)	C_{igel}	molar species <i>i</i> concentration in gel
<i>В</i> ₁ р, В _{2р}	second virial coefficients for interaction between polymers 1 and 2 (4.1.34p)	∪ij	region <i>j</i> or location <i>j</i> or stream <i>j</i> ; <i>j</i> = <i>b</i> , bulk; <i>j</i> = <i>E</i> , extract; <i>j</i> = <i>f</i> , feed region; <i>j</i> = <i>g</i> , gas phase; <i>j</i> = <i>k</i> , <i>k</i> th phase; <i>j</i> = <i>l</i> , liquid; <i>j</i> = l' , adhering liquid phase on
с; с _С	velocity of light; gap between plates at entrance (Figure 7.3.10), stoichiometric coefficient for species C		crystal; $j = m$, membrane; $j = o$, organic; j = p, permeate, product; $j = r$, raffinate; j = R, ion exchange resin phase,
С	clearance of a solute (8.1.390)		raffinate; $j = s$, solution, solid phase or
$C_{1}, C_{2}; C_{2}(x)$	integration constants (3.3.10b); molar concentration of species 2 at location <i>x</i> molar concentration of species 2 in	$C_{ij}^t; C_{ijn}$	pore surface; $j = w$, water, mol/liter total molar concentration of species <i>i</i> in region <i>j</i> including complexed or dissociated forms: value of C_{ii} on <i>n</i> th
-21	initial mixture, mol/liter		plate/stage
$C^{(2)}_{ m A}$ $C^0_{ m A}$, $C^\delta_{ m A}$	defined in (6.3.75) molar concentration of A at $z = 0$, δ (3.1.124)	$C^0_{ij},~C^\ell_{ij},~C^\delta_{ij}$	species <i>i</i> concentrations in phase <i>j</i> at locations 0 (or initial concentration), ℓ and δ
$C_{A\ell b}, C_{A\ell i}$	molar concentration of A in phase bulk and phase interface and in liquid at gas–liquid interface (3.4.1b)	$C_{i\ell b}, C_{i\ell e}, C_{i\ell i}$	molar concentrations of species <i>i</i> in bulk solution, at the end of concentration process and at the
$C_{Awb}, C_{Awb}, C'_{Awb}$	molar concentration of A in bulk water and in water at phase interface		beginning of concentration process (6.3.173)
	(3.4.45e); critical value of C_{Awb} for maximum enhancement (5.3.53)	C'_{ig}, C'_{igf}	molar species <i>i</i> concentration per unit gas phase volume in a pore
$C_{\mathrm Bob}$, $C_{\mathrm Boi}$	molar concentration of species B in organic-phase bulk and interface, respectively	$\overline{C}_{ik}, \overline{C}_{ik}, \hat{C}_{ik}; \overline{C}_{it}$	intrinsic phase average, phase average and deviation in C_{ik} for species <i>i</i> concentration in phase <i>k</i> (6.2.24a,b),
<i>C_c; C_{Cb};C</i> D	slip (Cunningham) correction factor (3.1.215); critical value of bulk concentration of C for maximum enhancement (5.3.29b); particle drag coefficient (3.1.64) (6.3.4)	$C^d_{im}, C^H_{im}; C^p_{im}$	(6.2.28); defined by (7.1.94) species <i>i</i> concentration in membrane: for Henry's law and Langmuir species, respectively, in dual sorption model (3.3.81); membrane nore liquid
C_{FC}	molar concentration of fixed charges in	$C_{imi}, C_{imo}, C_{iob},$	molar concentrations of species i at
C'_{H1} , C'_{H2}	ion exchange resin dual mode sorption constants for species 1 and 2 (3.3.82a,b)	C_{iwi}, C_{iwb} C_{pR}, C_{pw}	various locations in Figure 3.4.11 molar protein concentrations in resin phase and aqueous solution

C _{sf} , C _{sm} , C _{sp}	molar solvent concentration in feed,	D_{im} ; D_{imo} ; D_{ip}	diffusion coefficient of <i>i</i> in membrane
	membrane and permeate,		(6.3.149); value of D_{im} for $C_{im} = 0$
	respectively		$(3.4.67b)$, D_i in a pore $(3.4.89c)$,
C_{ti} ; C_{ti} ; C_{un}	total molar concentration; C_t in a		$(6.3.145a)$; effective D_i in the pores of a
v y, vp	mixture in region <i>i</i> ; volume of particles		particle
	per unit fluid volume (7.2.176)	\overline{D}_{ilit} \overline{D}_{im}	multicomponent diffusion coefficient
	per une nulle volume (1.2.116)	D_{lk} , D_{lm}	of species pair (i, k) and (i, m) in
d. d. d. d.	diameter of tube/pipe/yessel		Maxwell Stefan approach
$u, u_h, u_i, u_{\ell m}$	hydroulic diameter (Table 2.1.9)	ת	Knudson diffusion coefficient for
	affective diameter of a malecule of real	D_{iK}	consistent diffusion coefficient for
	ellective diameter of a molecule of gas	D	species t (3.1.115c)
	species i (3.3.90a); logarithmic mean	D_{iM}	effective binary diffusivity of species <i>i</i>
	diameter (8.1.417)	0 - N	in a mixture (3.1.184), (3.1.185)
d_{i} ; d_{gr} ; d_{imp}	force-type term (3.1.178), (3.1.181);	$D_{is}; D_{is}^{0}; D_{is}^{N}$	binary diffusion coefficient for solute $i/$
	grain diameter; diameter of an		solvent <i>s</i> ; value of <i>D</i> _{<i>is</i>} at infinite dilution;
	impeller		Nernst-Planck binary diffusion
d_{ion} ; d_p ; d_w ; d_{p1} ,	mean diameter of a molecular ion;		coefficient for species <i>i</i> /solvent <i>s</i>
d_{p2}	mean diameter of a particle (6.1.4b);	D_{12}	binary diffusion coefficient for species
	wire diameter (3.1.23); diameters of		1 and 2
	particles 1 and 2	$De; (De)_{mv}$	density function of particles which
d_{32}	Sauter mean diameter of a drop or		disappear (die) (6.2.50h); see
	particle (6.4.88), (6.4.89)		(7.2.170a) and $(7.2.172)$
D	diffusion coefficient of species in	Df: DF	decontamination factor (2.2.1c):
_	countertransport through liquid		dilution factor $(6.4.106)$, $(7.2.91c)$
	membrane		
D_1 D_2 : D_2	diffusion coefficient of species A and C	ρ	charge of an electron 1.60210×10^{-19}
$D_{\rm A}, D_{\rm C}, D_{\rm B}$	respectively: dialysance in	C	coulomb
	homodialysia (9.1.290)	0	couldn't in adaptition isotherm for
D	affective diffusion coefficient (5.4.64c)	e_i	constant in ausorption isotherm for
$D_{\rm eff}$	enective diffusion coefficient (5.4.64a)		
$D_{\rm gr}$	crystal growth diffusivity (6.4.45)	en _b ,en _M ,en _{MN} ,	molecular energy in the bulk, due to
$D_p; D_p(\phi)$	diffusion coefficient for particle	en _{MP} ,en _p	intramolecular interactions, due to
	(3.1.68), (6.2.52); shear-induced		intermolecular interactions, due to
	particle diffusivity (3.1.74), (7.2.126),		interaction between molecules and
	(7.2.131a)		pores and total energy for molecules in
D_r	desalination ratio (1.4.25), (2.2.1a)		the pore (3.3.89d)
$D_{i,\text{eff}}$, $D_{i,\text{eff},r}$	effective diffusion coefficient of i in	$\boldsymbol{E}; E; E_c; E_{D_i}; E_e$	electrical force field; its magnitude
$D_{i,\text{eff},z}; D_{i,\text{eff},1}$	liquid (6.2.18), (6.3.16b); value of $D_{i,eff}$		(3.1.8), (6.1.22), (6.3.8f), extraction
	in <i>r</i> -and <i>z</i> -directions; value of $D_{i,eff}$ in		factor (8.1.281), stage efficiency
	phase/region 1		(6.4.72); electrical field strength E_c
$D_{i, eff, k}; D$	effective diffusion coefficient of <i>i</i> in		(7.3.32a); activation energy for
$\equiv i, eff, k$	phase k (6.2.33); dispersion tensor		diffusion of species <i>i</i> in polymer
	(6.2.31)		(4.3.46b); extraction factor for
Dii: Di: Dia	diffusion coefficient of species <i>i</i> in		extraction section (8.1.303)
	region i : $i = 1$ liquid: $i = s$ solvent	$E \cdot E \cdot E \rightarrow E \cdot E \cdot$	enrichment of species <i>i</i> by
D^{T} $D^{\mathrm{T}} \cdot D^{\mathrm{T}}$	thermal diffusion coefficient for	$E_{y} = E_{0}, E_{0}, E_{s}, E_{y},$ $E_{ppo} = E_{0}, e_{s}$	nervaporation (6.3.193b) narticle
$D_{\rm A}, D_{\rm B}, D_{\rm is}$	species A and B (3.1.44): for species i in	LBRS, LGrS	collection efficiency (7.2.200b): overall
	solution		column officiongy (9.1.105); point
ת י ת	binary diffusion coefficient for minture		afficiency (8.3.13); ovtraction factor for
D_{AB}, D_{BR}	of gauge A and B. diffusion and finite		the completing continue distribution for
	of portiolog due to Press in matin		atrongth in a direction (7.2, 40) must 1
	or particles due to Brownian motion		suengui in y-direction (7.3.48); particle
	(7.2.216)		collection efficiency $(7.2.219)$, $(7.2.214)$
D_{iD}, D_{iH}	diffusion coefficients in dual sorption-	$E_{IS}; E_{IS}$	inertial impaction based single fiber
-	dual transport model (3.4.78)		capture efficiency (6.3.42a); particle
D_{ie}	effective diffusion coefficient of i in a		capture efficiency by interception
	porous medium (3.1.112d)		(7.2.224)

Notation

E_{ME} , E_{MR} ; E_{MV} ; E_N	Murphree extract stage efficiency, Murphree raffinate stage efficiency (64.70), (64.71) ; Murphree vapor	$F; \hat{F}, \hat{F}_p; F$	force on a particle; value of F per unit particle mass; degrees of freedom $(4, 1, 22)$
$E_{\tau} : E_{\tau}^{1} : E_{\tau}$	efficiency (8.1.198); Newton particle separation efficiency (2.4.14a) total efficiency in solid-fluid	$F(r_p)$	probability distribution function corresponding to $f(r_p)$ (2.4.1c), crystal size distribution function (6.4.11)
1, 1, 1,	separation (2.4.4a), overall filter efficiency (6.3.45), (7.2.201); reduced efficiency of Kelsall (2.4.16a); E_T for <i>i</i> th solid-fluid separator (2.4.17c.d)	F_i, F_i^{ext}	electrostatic force on 1 gmol of a charged species in solution (6.3.8a); magnitude of external force on 1 gmol of species <i>i</i>
		F _{acrx}	acoustic radiation force in <i>x</i> -direction
f	friction factor (6.1.3a), fractional		(3.1.48)
	consumption of chemical adsorbent (5.2.19d)	$F_{\rm rad}$	radiation pressure force (3.1.47), (7.3.267)
f_2	fraction of the solute in ionized form $(i = 2)$ in RO (5.4.4)	$F^{ m BR}$	force on very small particle due to random Brownian motion (3.1.43)
$f(r); f(r_p); f(\varepsilon)$	molar density function in a continuous/semi-continuous mixture	$m{F}_{ m i}^{ m ELK}$	electrokinetic force on particle in double layer (3.1.17)
	with characteristic property r; particle	F_i^{ELS}	electrostatic force on particle <i>i</i> ,
	size probability density function	Turk	Coulomb's law (3.1.15)
	(2.4.1a), pore size distribution function	F ^{Lret} _i	London attraction force (3.1.16)
	in a membrane; defined by (7.2.222a,c)	$F_k^{\rm m}$	force on species k in mass flux \mathbf{j}_{i} force
$f_f(r_p), f_1(r_p), f_2(r_p)$	value of $f(r_p)$ for feed stream, overflow	rext	relation (3.1.202)
	fraction in a given size range (2.4.1b)	F _{net}	net external force; for gravity
f_{\cdot} f_{\cdot} f^{0}	fugacity of species A species <i>i</i> :	F drag. F iner. Fext	frictional force on a particle: inertial
JAJ JV J i	standard state fugacity of species <i>i</i> ,	p, p , p , pz	force on a particle (6.2.45): external
$f_{q}(\mathbf{gr})$	probability density function of crystal		force on a particle in <i>z</i> -direction
5800 7	growth rate (6.4.41a)	$\boldsymbol{F}_{ti}, \boldsymbol{F}_{ti}^{\text{ext}}$	total force and total external force on 1
f _{il}	fugacity of pure species <i>i</i> in liquid		gmol of species i (3.1.50)
	phase	$F_{tp}^{\text{ext}}; F_{tpx}^{\text{ext}},$	total external force on a particle
f_{m}, f_{m}	quantities characteristic of a membrane polymer (4.3.46a,d)	$F_{tpy}^{\text{ext}}; F_{tpz}^{ext}$	(3.1.59), (6.2.45); components of F_{tp}^{ext} in <i>x</i> -, <i>y</i> -and <i>z</i> -directions
$f^0_{ij}, f^0_{ig}, f^0_{il}$	standard state fugacity of species <i>i</i> in region <i>j</i> ; <i>j</i> = <i>g</i> , gas phase; <i>j</i> = ℓ , liquid	F_{TA}	force on 1 gmol of species A due to a temperature gradient (3.1.44)
	phase	${\mathcal F}$	Faraday's constant, 96 485 coulomb/
f_i^d, f_p^d	frictional coefficient for species <i>i</i> and spherical particle		gm-equivalent
$\hat{f}_{ig}, \hat{f}_{ij}, \hat{f}_{il}; \hat{f}_{ijpl}$	value of fugacity of <i>i</i> in a mixture in gas	g; g _c ; g _m	acceleration due to gravity; conversion
	phase, phase <i>j</i> and liquid phase, respec-		factor; a quantity characteristic of a
,	tively; value of \hat{f}_{ij} for a planar surface		membrane polymer (4.3.46a)
f^{a}_{io}	value of f_i^a for a sphere of equivalent	$\boldsymbol{g}_{x}^{\text{ext}}; \boldsymbol{g}_{x}^{\text{ext}}, \boldsymbol{g}_{y}^{\text{ext}},$	external body force per unit mass; its
fd fd	frictional coefficient for solute <i>i</i> and	8 _z	z directions
J im'J sm	solvent s in a membrane	ar.	intrinsic growth rate of <i>i</i> th crystal
$f_{\cdot}(M) f_{\cdot}(M)$	value of $f(r)$ where $r - M$ molecular	81	(6.4.41a)
$f_{f}(M); f_{l}(M);$	weight, for the feed mixture, liquid	G: G_	superficial mass average velocity based
$J_{\mathcal{V}}(\mathcal{V},\mathcal{J})$	fraction and the vapor fraction,	0, 0g	on empty flow cross section, G for gas
	respectively; defined by (7.1.59a),		phase
	(7.2.187), respectively	G; G _a , G _b ; G _i ; G _o	growth rate of crystal (6.4.25), (6.4.3b);
f_{M} , f_{Qm} , f_{VO}	fraction of the total metal ion		value of G under condition a, condition
	concentration in the aqueous phase present as M^{n+} (5,2.97): probability		b; factor representing contribution of species i properties to O_{i} (4.3.56a):
	present us m (0.2.57), probubility		species i properties to Q_{im} (4.5.500),

density functions (7.3.79), (7.3.80)

constant

$\overline{G_c}; \overline{G_{Dr}}; \overline{G}_{D\mu}$	convective hindrance factor (3.1.113); drag factor reducing solute diffusion by hindrance (3.1.112e); function of particle volume fraction in hindered	j j ö jixo jiyo jiz	unit vector in positive <i>y</i> -direction mass flux vector of species <i>i</i> , $M_i J_i$ (3.1.98), Tables 3.1.3A, 3.1.3B, (6.2.5n); components of j_i in <i>x</i> -, <i>y</i> - and <i>z</i> -directions
	settling (4.2.61)	In	factor defined by (3.1.143g)
$\overline{G_i}$: $\overline{G_{ii}}$	partial molar Gibbs free energy of	$I_{i}, I_{i}^{*}: (I_{i})_{i}: I_{1}, I_{1}^{T}$	molar flux vector of species i (3.1.98).
- , , - ,	species <i>i</i> , ratio of solute <i>i</i> velocity to the averaged pore solvent velocity, convective hindrance factor $(=\overline{G}_c)$ (3.1.113), (3.4.89b); value of \overline{G}_i in		(3.1.99), Tables 3.1.3A, 3.1.3B; value of J_i in region k ; diffusive molar flux vector of species 1 (4.2.63); temperature gradient driven molar flux
	region j		vector of species 1 (4.2.62)
$G_r(r_p)$	grade efficiency function (2.4.4b)	J_{iz} , J_{sz} ; J_{iy}^*	<i>z</i> -components of flux vectors J_i and J_s ;
$G_{tj}; G_{crit}$	total Gibbs free energy of all molecules	·	<i>y</i> -component of flux vector J_i^*
·	in region <i>j</i> (3.3.1), (4.2.23); defined by (7.1.58e)	$J_{iz}^*, J_{jz}^*, J_{sz}^*, J_{Az}^*$	<i>z</i> -components of flux vectors J_i^* , J_j^* , J_s^* and J_A^*
Gr; $Gr(\beta_r, \sigma_v)$; Gz	Grashof number (3.1.143e); function	J_{Av}^{*t}	total molar flux of species A in y-
, , ,, ,,,	defined by (7.2.174): Graetz number	- Ay	direction (5.4.51)
	(8.1.276)	I	volume flux through membrane in
	(011210)) UZ	z-direction (3.4.60c) (6.3.155a)
h· h	membrane flow channel height		2 uncertoir (3.4.00c); (0.3.135u)
<i>n, n</i> ₀	distance between particle and collector	k: k	unit vector in positive z direction.
	(2,1,17) constant in $(4,1,0a)$ for	K , <i>K</i>	region or phase constant in (2.2.9a, c)
	(3.1.17), constant in $(4.1.3a)$ for		(2-1) (2.1.49)
	Henry's law constant, $(1/n)$ is a	1 B	$(2\pi/\lambda)$ (3.1.40)
	(C.2.21a) haidht a fliamid in a san illand	K 1. 1.	Boltzmann's constant (3.1.72), (3.3.900)
	(6.3.31a), height of liquid in a capillary	κ_a, κ_d	disconsisting respectively (4.1.77a)
1. 1. 1.	at any time <i>i</i> ; value of <i>n</i> as $i \to \infty$ (6.1.11)	1. 1.	he alread and forward receiving rate
n_{+}, n_{-}, n_{G}	$(4,1,0_2)$	κ_b, κ_f	constants (5.4.42)
1.	(4.1.9C)	1. 1.	constants (5.4.42)
n _{min}	minimum value of n	κ_{Ao}, κ_{Aw}	A in automic of coefficient of species
$H; H_{f}; H_{i};$	plate height, stack height; molar	1. 1. 1. 1.	A in organic or water phase
$\Pi_i, [\Pi_i]; \Pi_i;$	i(6,2,22) Hopry's law constants for	$\kappa_c, \kappa_g, \kappa_{xj}, \kappa_y$	(2,1,120) $(2,4,2)$
11 _{lf} , 11 _{vf}	species <i>i</i> in gas liquid equilibrium:	<i>k' k' k' k'</i>	(3.1.135), (3.4.3) values of k k k and k for equimolar
	(3 3 59) (4 1 7) (3 4 1b) (5 2 6) (5 2 7)	$\kappa_c, \kappa_g, \kappa_x, \kappa_y$	counterdiffusion (3.1.124)
	(8.1.49), $(3.4.1a)$; molar enthalpy of	ka ki ke	mass-transfer coefficients in
	liquid fraction and vapor fraction.	<i>w</i> 3, <i>v v</i>	crystallization (3.4.23a,b): liquid film
	respectively, of the feed		mass transfer coefficient $(5.3.3)$
Hall Hall	height of a transfer unit defined by	k: k: k:	mass-transfer coefficients for species <i>i</i>
	(8.1.96)	niger night nigy	in gas phase when the concentration
\mathbf{H}^{m}	magnetic field strength vector		gradient is expressed in terms of C.
$H_{\mathbb{A}}, H^{\mathrm{o}}_{\mathbb{A}}, H^{\mathrm{c}}_{\mathbb{A}};$	Henry's law constants for species A		molar concentration of species <i>i</i> in gas
H_1, H_2	(3.4.1a,b), (3.4.8); defined by $(7.1.20b)$		phase, x, mole fraction of species <i>i</i> in
HD. HM. Hs. Hsm	components of plate height (7.1.107e-i)		gas phase and similarly v. mole
\overline{H}	partial molar enthalpy of species <i>i</i>		fraction in gas phase respectively
	height of a transfer unit (6.4.85)	$k_{\pi} \cdot k'$	thermal diffusion ratio (3.1.45):
1110	(8 1 54b) $(8 1 57b)$ $(8 1 65e)$	n_T, n_T	thermal diffusion constant (4.2.64)
	(0.1.345), $(0.1.375)$, $(0.1.036)$, $(0.1.036)$, $(8.1.375)$	k . k	gas film mass-transfer coefficient on
	(0.1.2100), (0.1.21(a), (0.1.03(0)	ngp ngs	feed side and strip side of a liquid
i	unit vector in positive <i>r</i> -direction		membrane $(5 4 97a)$ $(5 4 99a)$
-	current density (3.1.108c)	kas kaik	liquid film mass_transfer coefficient on
$I I I I I I (C^+)$	ionic strength of the solution (3.1.10c)	nes, npp	feed side and strip side of a liquid
$\mathbf{I}, \mathbf{I}, \mathbf{I}_{j}, \mathbf{I}(\mathbf{C}_{isbL})$	$(4 \mid 9h)$: purity index $(1 \mid 4 \mid 2h)$ current		membrane $(54.07h)$ $(54.00h)$
	(1.1.30), purity index (1.4.30), cullent;		nembraie (3.4.370), (3.4.350),
	(1.4.2h), integral $(7.2.9c)$		(7.9.917b)
	(1.4.30); IIItegfal (1.2.80)		(1.2.21(0)

xviii			Notation
k k	rate constants for forward and	K · k · k'	moler concentration based overall
K _S + , K _S -	backward interfacial reactions	\mathbf{K}_{ijc} , \mathbf{K}_{ijx} , \mathbf{K}_{ijx}	motal concentration based overall mass-transfer coefficient for phase j
$k_{il}^{'}; \dot{k}_{i1}^{'}$	distribution ratio of species <i>i</i> between		(0.1110), <i>j</i> phase mass-transfer coefficient (8.1.60); value of k_{ijx} for equimolar counterdiffusion (8.1.62a)
	factor (1.4.1); distribution ratio defined by (2.2.19) for species <i>i</i> between streams 1 and 2	K _o , K _w	overall mass-transfer coefficient based on organic or aqueous phase, ionization product for water (5.4.41c)
k_{cR}, k_{cE}	mass-transfer coefficient in the continuous phase, raffinate based, extract based (6.4.97a,b)	K _{is} , K _{ps}	values of K for ion <i>i</i> /protein (p)-salt (s) exchange on an ion exchange resin (7.1.109d), (3.3.122b)
k _{gr} , k _{nu} ksi: ksp. ksu. ksi.:	rate constant for crystal growth and nucleation, respectively (6.4.51) mass-transfer coefficients for species <i>i</i>	K _{xE} , K _{xR}	overall mass-transfer coefficient K_x (3.4.5) based on extract phase and raffinate phase, respectively (6.4.77).
k_{imo}	in liquid phase; value of k_{il} for condition 3, condition 4, channel inlet;		(6.4.81)
k,	species <i>i</i> mass-transfer coefficient through organic filled membrane pore first-order reaction rate constant	l; l	length of a device, length of molten zone in zone melting (6.3.109b), characteristic dimension of the
k_{1m}	(5.3.7) membrane mass-transfer coefficient		separator; constant in (2.2.8a–c), length
Κ	for species 1 (4.3.1) equilibrium constant for a chemical	ℓ_{ik} , ℓ_{ki}	phenomenological coefficients (3.1.203)
Y ³⁶	reaction (3.3.68), or an ion exchange process (3.3.121i), a constant (6.3.49)	$\ell_{ m loc}$	characteristic length of a local volume corresponding to a point in volume
К [~] ; К	mole fraction based <i>K</i> for a chemical reaction (5.2.35); defined by (5.4.100) constants in membrane transport	ℓ_x, ℓ_y, ℓ_z	averaging Section 6.2.1.1 dimensions of a rectangular separator, Figure 3.2.1
$K_{Aa}, K_{Aw}; K_{AB}$	(6.3.155a,b) overall mass-transfer coefficient of	L ; L_{f} ; L^+	length of a separator, dimension of length, characteristic crystal size;
	species A based on organic or water phase; equilibrium constant (7.1.42c)		molar feed flow rate; nondimensional L (7.2.38)
K_c, K_g, K_x, K_y	overall mass-transfer coefficients (3.4.5), (3.4.6)	L_{ii}, L_{is}, L_{ss}	phenomenological coefficients for binary system (i , s) (3.1.208), (3.1.209)
K_{cE} K_{C}^{A}	K_c based on extract phase (6.4.80) equilibrium constant for ion exchange	L_{ik}, L_{ki}, L_{iT}	phenomenological coefficients (3.1.205) hydraulia transport parameter in
K _d	equilibrium constant for protein-ion exchange resin binding (4.1.77c), ionization equilibrium constant	L_p, L_p, L_p	Kedem-Katchalsky model (6.3.158a); value of L_p in perfect region; value of L_p in leaky region
K_{d1}, K_{d2}	(5.2.4) dissociation constant for solutes 1 and 2 respectively $(5.2.61a)$ $(6.3.29)$	L_T ; L_{min} ; L_{MTZ} ; LUB	separator length (= <i>L</i>); (7.1.60); Figure 7.1.5(b); (7.1.21g)
$K_{i}; K_{1}, K_{2}, K_{3}; K_{i}^{a};$ K^{∞}	equilibrium ratio of species <i>i</i> between regions 1 and 2 (1 4 1) or (3 3 61).	$m; m_B; m_i; m_1; m_1; m^0$	velocity profile constant (7.3.134); moles of B: moles of species i in
κ _i	value of K_i for species 1, 2 and 3; values of K_i in terms of activities (4.1.3); $\int_{il}^{0} \gamma_{il}^{n} / P$ in dilute solution stripping	mi	separator; moles of species <i>i</i> in separator; total number of moles of species <i>i</i> in separator
$K_{i\ell}; K_{\ell}$	(4.1.19b) overall liquid-phase mass-transfer coefficient for species <i>i</i> (7.1.5a);	$m_{ij};\ m^o_{ij};\ m_{ij}(n);$ m^a_{ij}	moles of species <i>i</i> in region <i>j</i> , total number of moles of <i>i</i> in region <i>j</i> at <i>t</i> = 0; moles of <i>i</i> in region <i>j</i> after <i>n</i> th contact;
	reaction equilibrium constant in the liquid phase based on molar concentrations (5.2,52a)	m:-	number of atoms of <i>i</i> th isotope of the element in region <i>j</i> moles of species <i>i</i> in interfacial region <i>g</i>
	concentrations (0.2.02a)	πισ	mores of species i in meridetal region o

m_{ivj}	molality, moles of <i>i</i> per kilogram of	$n_{ m max}$; $n_{ m med}$, $n_{ m par}$	peak capacity (3.2.32) (6.3.26a);
	solvent in region $j: j = R$, resin; $j = w$,		refractive index of medium and
	aqueous phase		particle
$m_{F,R}$	molality of fixed charges in the resin	$\boldsymbol{n}_{p}, n_{p}; n_{py}; n_{t}$	particle number flux, (3.1.65), (3.1.66),
	phase		(3.1.68); particle flux in y-direction;
$m_p; m_{sl}$	mass of particle; solvent moles in		number of turns by gas in a cyclone
,	stationary liquid phase (7.1.104b)		(7.3.146b)
m_{ti}	total moles of all species in region <i>j</i>	N; $N(r_p)$;	total number of stages in a multistage
•	(j = f, feed; j = 1, vapor phase; j = 2,	$N(r_{\min}, r_p),$	device or in the enriching section of a
	ℓ , liquid phase)	$N(r_{p_{max}})$	cascade, anionic species in Donnan
$m_{11}(t), m_{21}(t)$	moles of species 1 and 2 in region 1 at	(p max)	dialysis, a metal species, number
	time t		concentration of molecules; numbers/
$m_{11}^{r}(t), m_{21}^{r}(t)$	values of $m_{11}(t)$ and $m_{21}(t)$ in the case		cm ³ , number of particles per unit fluid
11(), 21()	of a chemical reaction		volume in the size range of r_{\min} to r_n ;
$mo_{\rm p}^{\rm mag}$	magnetophoretic mobility (7.3.251)		value of $N(r_{\min}, r_n)$ for $r_{n_{\max}}$
$M; M_i, M_s; M_{sl}$	molecular weight, a metal species.	\tilde{N} : N_i	Avogadro's number (6.02×10^{23})
, , , , ,, ,,	number of stages in stripping section	, .	molecules/gmol): plate number for i
	of a cascade: value of M for species i.		(6.3.27a)
	for solvent s: M for coating liquid in	$N_{\Lambda}: N^{r}_{\Lambda}, N^{t}_{\Lambda}:$	molar flux of species A in a fixed
	stationary phase	N _{dil}	reference frame without and with
M.	average molecular weight of solution	1 · uii	reaction: total molar flux of species
	(3.1.56)		A in facilitated transport or counter-
<i>M</i>	magnetization of wire (3.1.23)		transport or co-transport in v-direction:
	seed mass density per unit liquid		normality of diluate solution (8.1.404)
111se	volume (6.4.40a)	$N \cdot N \cdot N \cdot N$	species i flux: N : through membrane
	suspension density of a crystal-	N_{i} N_{i} N_{i} N_{i} N_{i} N_{i}	<i>N</i> , through membrane: components of
1017, 1017a, 1017b	containing solution (2.4.2f) (6.4.18)	$ N_{ij} $	$N_{\rm i}$ in $r_{\rm r}$ $v_{\rm r}$ and $z_{\rm r}$ -directions: radial
	value of M_{π} for cases <i>a</i> and <i>b</i>	1 • 19	component of $N: N$, through surface
$Mo^{(n)}$: $Mo^{(i)}$	<i>n</i> th moment of the density function		area S : magnitude of N_i
$Mo^{(i)} Mo^{(i)}$	(2.4 lg): <i>i</i> th moment of molecular	N^p	$z_{-component}$ of species <i>i</i> flux N_{iy}
mo_{ℓ} , mo_{v}	weight density function of	1 v iz	2 -component of species i has, N_{i2}
	feed liquid and vanor respectively		$(3 \ 1 \ 112a)$
	(6.3.70)	$N : N \rightarrow N$	number of transfer units (8,1,02)
Ma ^j Ma ^j	ith moment of crystal size density	1 oj, 1 olp, 1 p	(8, 1, 96); defined in $(8, 1, 96)$; number of
MO_{fr}, MO_{gr}	functions $f(r)$ and $f(r)$		(0.1.50), defined in $(0.1.50)$, number of
MWCO	molecular weight cut off of a	N_{-} · N_{-}	flux ratio (3.1.129a): solvent flux
WWCO	monecular weight cut on of a	N_R, N_S	number density of crystals baying a
	memorane	$N_i(r_p); N_{it}$	size loss then r and growth rate gro
10. 10	number of anopies (components in a		size less than r_p and growth rate gr_i
$n; n_c$	number of sectes/ components in a		total number of crystals per unit
	system, number of contacts, stage/		(C 4 41a)
	plate number, number of positive	NT	(0.4.41C)
	charges in a metal ion, number of unit	$1N_t$	volume (6.4.10)
	bed elements; number of collectors,	AT AT	volume (6.4.10)
$m(\pi), m(\pi), \tilde{m}(\pi)$	number of channels (7.3.109)	IN _{toE} , IN _{toR}	number of transfer units based on
$n(r_p); n^*; n(r_p)$	population density function, particle		extract and rainfale phases,
	number density function (2.4.2a);	3.7	respectively (6.4.86a), (6.4.83)
	nucleation population density	INO _i	number of particles of size r_{pi} (2.4.2k)
	parameter (6.4.7); defined by	INTU	number of transfer units $(8.1.54c)$,
	(b.4.4bb)		(8.1.57C), (8.1.66D), (8.1.67d), (8.1.338)
\boldsymbol{n}_{i} ; n_{ix} , n_{iy} , n_{iz} ; \boldsymbol{n}_{ij}	mass flux vector of species i , $M_i N_i$, its		
	components in <i>x</i> -, <i>y</i> - and <i>z</i> -directions;	р	dipole moment of a dielectric particle
	\boldsymbol{n}_i through surface area \mathbf{S}_j	р	stoichiometric coefficient for product
\mathbf{n}_k	outwardly directed unit normal to the		P, kinetic order in the dependence of
	<i>k</i> -phase surface (6.2.26b–d)		nucleation rate (6.4.30a)

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$p_{\mathrm{A}}; p_{\mathrm{B}}; p_{i}, p_{j}$	partial pressures of species A, species	<i>q_{fr}</i>	fraction of light reflected (3.1.47)
	B; species <i>i</i> and species <i>j</i>	$q_i(C_{i2}), q_{i1}(C_{i2}),$	moles of species <i>i</i> in solid phase 1 per
$p_{\mathrm{A}b}; p_{\mathrm{A}i}; p_{\mathrm{B},\ell m}$	value of p_A in the gas bulk; value of p_A	$\overline{q}_{i1}; q^0_{i1}$, $q^{ m s}_{i1}$	unit mass of solid phase, cross-
	at gas-liquid interface; logarithmic		sectional average of q_{i1} , initial value of
	mean of $p_{\rm B}$ (3.1.131b)	<i>a a</i>	q_{i1} ; saturation value of q_{i1}
Pifi Piji Pipi Piv	value of p_i in feed gas, region/stream <i>j</i> ,	q_{iR}, q_{is}	indices of species <i>i</i> per unit mass of (R) or solid
\overline{n} , \overline{n}	species <i>i</i> partial pressure in bulk and		adsorbent (s)
Pib [,] Pii	particle interface, averaged over bed	(amay B	maximum molar fixed charge density
	cross section, Figures 3.4.4(a), (b)	JIIIAXA	per unit resin mass
pH; pI	indicator of hydrogen ion	$q(\mathbf{r}, \boldsymbol{\psi}, \boldsymbol{\lambda})$	probability that a molecule having
	concentration (5.2.65a); isoelectric		configuration (r, ψ, λ) does not
	point for a protein/amino acid; at $pI =$		intersect pore wall (3.3.89f)
	<i>pH</i> , net charge is zero	Q	volumetric fluid flow rate, product
pK_i	$-\log_{10} K_{di}$, (5.2.65b) for $i = 1$, (5.2.74b)		species in reaction (5.3.5), hydraulic
D D ⁽⁾ D	for $i = 2$, (6.3.29)		permeability in Darcy's law (6.1.4g,h),
$P; P^*; P_c$	total pressure, system pressure;	0.0	heat transfer rate (6.4.4/a,d)
\overline{D} , D_{-} , D_{-}	local solute permeability coefficient	$Q_c; Q_d$	flow rate of dialysate solution
$\mathbf{P}_{i}, \mathbf{P}_{j}, \mathbf{P}_{i}, \mathbf{P}_{i}$	(6.3.157b): feed pressure: total	$O_{\ell} O \cdot O_{\ell} \cdot O_{\ell}$	volumetric feed flow rate to separator.
p, p, p, r	pressure of <i>i</i> th region and permeate.	Q_p, Q_g, Q_n, Q_n $O_{\ell}, O_{\alpha}, O_{m}, O_{P},$	Darcy permeability for gas through
	respectively; gas pressure (Figure	Q_1, Q_2	packed bed; amount of heat supplied
	7.2.1(b)); gas pressure at the end of a		at a high temperature; electrical charge
	capillary of length <i>l</i> (6.1.5d)		on 1 gmol of charged species i; amount
$P^0_i(\pi); P^*_i$	equilibrium gas-phase pressure for		of heat rejected at a low temperature;
	pure <i>i</i> adsorption at spreading		volumetric flow rate at membrane
	pressure π , which is the same for a		channel inlet; electrical charge of a
	mixture (3.3.111a); pressure at		particle; excess particle flux (7.2.123),
	crossover point for solute <i>i</i> in		volumetric flow rate of product stream
$D \rightarrow D_{1} \rightarrow D_{2} D_{2}$	atmospheric pressure: pressure in the		repoiler per mole of feed: volume flow
1 atm, 1 liq, 1 1, 1 2	liquid (6,1,12): purification factors		rate of overflow: volumetric rate of
	(7.2.97)		underflow/concentrate
$Pe; Pe_i; Pe_i^m;$	Péclet number (3.1.143g), (7.3.34d); <i>Pe</i>	Q_{Am}, Q_{Bm}, Q_{im}	permeabilities of species A, B, <i>i</i> and <i>j</i> ,
$Pe_{z, eff}; Pe_{zj}$	number for dispersion of solute <i>i</i>	Q_{jm}	respectively, through membrane in gas
	(6.3.23a); pore Péclet number (6.3.145a);		permeation and pervaporation,
	$(z v_z/D_{i,\text{eff.}z})$ (7.1.18h); <i>j</i> phase Pe_z (8.1.92)		respectively
$P_i^{\text{sat}}, P_j^{\text{sat}};$	vapor pressure of pure <i>i</i> and pure <i>j</i> ,	Q_{ij}	permeability of species <i>i</i> through
$P_{iP\ell}^{\text{sat}}; P_{i, \text{ curved}}^{\text{sat}}$	respectively, at system temperature;		region j (= A, B, C, D, 1, 2) of the
	value of P_i^{sat} on a plane surface; value	0 ⁰ V	membrane
nsat	of P_i^{at} on a curved surface	Q_{im}^{in}	overall permeability of species in
P_M	molecular weight M		membrane of thickness δ
Po	amplitude of pressure wave (3.1.48)	Ogran Ogy	heat transfer rate of a solution during
P_{R}, P_{W}	pressure of resin phase and external	Crys/ Csub	crystallization and subcooling,
10 10	aqueous solution, respectively		respectively
Po, Pr	power number (6.4.976), power (3.1.47)	Q_{im0}	value of Q_{im} for $C_{im} = 0$
		Q _{sm} , Q _{sc}	solvent permeability through
q	number of variables in a problem,		membrane and cake in cake
	stoichiometric coefficient for species Q,		filtration
	heat flux in a heat exchanger attached		
	to a cooling crystallizer $(6.4.47a)$, the	r	vector of molecular position, radius
	power of M_T in expression (6.4.39a) for P^0 factor (8.1.150)		direction
	B, lactor (8.1.150)		urection

r	radial coordinate, any characterizing property of a continuous mixture	R_1, R_2	intrinsic RO rejection of the unionized species 1 and ionized species 2
$r_1, r_2; r_{1i}, r_{2o}; r_c; r_f$	radii of curvature of interface (3.3.47);	R ⁺ (R ⁻)	ion exchange resin with fixed positive (negative) charge; cation (anion) of a
	critical size of a nucleus (3.3.100b)		surface active solute
	cyclone radius: free surface radius in	R. R. R.	nermeation resistance of region $i(i - A)$
	tubular centrifuge	<i>Typtum</i> , reqd	B C D) in the membrane to species i :
$r \cdot r_i \cdot r \cdot r_i$	radius of gyration of a macromolecule.		membrane permeation resistance of
<i>'g, 'n, 'b, '</i> m	hydrodynamic viscosity based radius		species i solute i rejection required in
	(3.3.90f): radius of spherical solute		a RO membrane
	molecule (3.3.90a): radius of liquid-	Rik, Rki Rmin	phenomenological coefficients
	liquid interface in tubular centrifuge		(3.1.207); minimum reflux ratio
ro	radius of a sphere whose volume is		(8.1.170)
	equal to that of an ellipsoid (3.1.91g),	R _{obs} , R _{true} ; Re;	observed and true solute rejection in
	radial location of the center of solute	Re_L ; Re_{imp}	ultrafiltration and RO; Reynolds
	peak profile, radius of a cylindrical		number; <i>Re</i> for a plate of length <i>L</i>
	centrifuge		(3.1.143a), Table 3.1.5; <i>Re</i> for an
$r_p; r_{p,a}; r_{p1}, r_{p2};$	radius of particle, pore radius;		impeller (Table 3.1.7), (6.4.96)
$r_{p_i}; r_s; r_t; r_w$	analytical cut size (2.4.18); particles of		
	two different sizes; dimension of	S	fractional supersaturation (3.3.98b),
	for classification (2.4.8): cyclone evit		power of the ΔP dependence of $R_{c\delta}$ (6.3.138i) Laplace transform complex
	pipe radius: radius of wire		variable (5.4.35), solution volume fed
Program Train: Pro 50	maximum and minimum radius of		to bed per unit empty bed cross
1111, p,50	membrane pores or particle sizes;		section (7.1.17a), eluent/salt
_	equiprobable size		(7.1.109b), salinity (10.1.13)
$\sqrt{r_p^2}$	hydraulic mean pore radius (3.4.87)	s_{m} ; s_{mp} , s_{ms} ; s_{p}	pore surface area/membrane volume
$\overline{r}_n, \overline{r}_n, \overline{r}_n$	mean of particle size distribution		(6.3.135e); value of s_m for membrane
$P' P_{1,0}' P_{i+1,i}$	based on $f(r_n)$ and $n(r_n)$, respectively		pore volume or membrane solids
	(2.4.1e), (2.4.2g), (2.4.2h)		volume (6.3.135f,g); sedimentation
$\overline{r}_{p_{3,2}}$	Sauter mean radius of a drop, bubble	6 6	two different solvents
	or particle (6.4.89)	S ₁ , S ₂	solute transmission/sieving coefficient
<i>ra; re; re</i> $_{\rm flow}$	rate of arrival of cells; fractional water	0, 01	(6.3.141e), supersaturation ratio
D. D	recovery; value of <i>re</i> in a cell (6.3.172b)		(3.3.98c), stripping factor (8.1.135),
R; <i>R</i>	or copillary roflux ratio (2.2.5) (2.2.7)		(8.1.189b); bed/column cross-sectional
	(8 ± 137) solute rejection in reverse		area
	osmosis, solute retention in	$S_{f}, S_{k}, S_{M}, S_{j}, S_{M},$	cross-sectional area vector of feed
	ultrafiltration	S_{d_p}	entrance, <i>k</i> th feed exit and membrane
$R_c; \hat{R}_{c\delta}, \hat{R}_{cw}$	cake resistance; specific cake		surface area vector in a separator;
	resistance per unit cake thickness and		cross-sectional area of flow for <i>j</i> th
	unit cake mass, respectively (6.3.135l)	Sut Su	molar entropy of species <i>i</i> : partial
R_h ; R_i ; R'_i ; R_L	hydraulic radius (6.1.4c); solute	S_{ij} , S_{ij}	molar entropy of species <i>i</i> (3.3.17b)
	rejection/retention by membrane for	Sim; Simo	solubility coefficient of species <i>i</i> in
	species i , retention ratio for species i		membrane; value of S_{im} for $C_{im} = 0$
	(7.3.211); fraction of solute <i>i</i> in mobile	S_{∞}	value of <i>S</i> when $Pe_i^m >>1$ (6.3.145b)
	conical tube	$S_{\sigma}; \overline{S_{\sigma}}; S_1$, S_2	surface area of interfacial region
Rm: Ro: Ro	membrane resistance: resolution		(Figure 3.3.2A); molar surface area in
	between neighboring peaks (2.5.7) in		gas-solid adsorption (3.3.107); sieving
	chromatography; value of R_i at large	0.0	coefficients for species 1 and 2
	Pe_i^m	S_{tj} ; S_{mag}	total entropy for region j (3.3.3);
$R_{\rm A}$, R_i	molar rate of production of A per unit		(7 3 251)
	volume (5.3.7), (6.2.2d), for species <i>i</i>		(1.0.201)

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$S_{\rm obs}$; $S_{\rm true}$	observed solute transmission/sieving	$u_{i}; u_{k}; u_{ij}; u_{il}; u_{io};$	mass fraction of impurity species <i>i</i> ;
	coefficient; true value of S	u_{is} ; u_{ilb}	mass fraction of species k; mass
$Sc; Sc_c$	Schmidt number (3.1.143a); Sc for		fraction of species i in region j (1.3.5)
	continuous phase		or <i>j</i> th stream (2.1.20); value of u_i in
$Sh; Sh_c, Sh_D; Sh_p;$	Sherwood number (3.1.143a); <i>Sh</i> for		melt; value of u_i initially in the solid;
Sh_z	continuous phase and dispersed		value of u_i in the recrystallized solid;
	phase, respectively; Sh in a packed bed		value of u_{i1} in the bulk melt
<i>Qi</i>	(7.2.218a); Sh at location z (7.2.64)	$u_o; u_{rc}; u_{ro}$	mass fraction of solute in the solution
St	Stanton number (3.1.143g), Stokes		charged for crystallization; $u_c/(1 - u_c)$;
	number (6.3.41)	m	$u_o/(1 - u_o)$ (6.4.47b)
	times huselthrough times times for sut	u_i^m	ionic mobility (3.1.108j)
$l; l_{br}; l_{c}; l_{res}; l_{\sigma}$	time; breakthrough time; time for cut	u_{iEn}, u_{iRn}	mass fraction of species <i>t</i> in extract and
	point in the chromatographic		rannate streams, respectively, from
	separator output (2.5.1); residence		stage n
	(Time: 2.2.0.4)	ur _{ig} , ur _{is}	defined by (8.1.349) and (8.1.350)
4 +, 4 + 4 +,	(Figure 3.3.2A)	<i>ur_{ij}</i>	weight of solute <i>i</i> per unit weight of $\frac{1}{22}$
$t_i; t_1, t_2;$	nondimensional time variable for $f(0, 2, 12)$, unlike for t^+ for	II. II	phase <i>J</i> (9.1.32)
$t; t_1, t_2, t_3$	species t (6.3.12); value for t_i for	$\boldsymbol{U}_{ij}, \boldsymbol{U}_{p}$	migration velocity vector for species i
	species 1, 2 (3.2.9), (3.2.20);		(3.1.84b); particle velocity vector
	breakthrough time (7.1.15c); value of t	U_i	averaged velocity vector of <i>i</i> th
in .0	for species 1, 2 and 3		molecules due to all forces
$t_i^{\text{m}}, t_i^{\text{o}}$	times when species i appears and		defined by (3.1.103)
	disappears, respectively, from a	U_{ix}, U_{iy}, U_{iz}	components of migration velocity of
	chromatographic separator output		species $i \ln x$ -, y - and z -directions,
t_{im}, t_{is}	transport number of <i>i</i> in membrane or	rr (rr)k îr	(3.1.82)
	solution (3.1.108d)	$U_{ik}; \langle U_{ik} \rangle^{\kappa}; U_{ik}$	value of U_i in the <i>k</i> th phase/region;
t_{s_1}, t_{s_2}	time required for solvents, s_1 , s_2 (3.2.24)		average of U_{ik} in the <i>k</i> th phase/region;
$t_{R_i}; t_{R_M}; t_{R_o}$	retention time for species i in capillary	wint wint wint	defined as a fluctuation by (6.2.28)
	electrophoresis (6.3.18a), (7.1.99d);	$U_p^{\mathrm{int}}; U_{px^i}^{\mathrm{int}}; U_{pr_p}^{\mathrm{int}}$	internal particle velocity vector
	retention time for the mobile phase;		(6.2.50d); its component in the
	retention time based on $v_{z,avg}$ (7.3.207)		direction of the internal coordinate x ;
$I; I_1; I_2; I_c$	absolute temperature; temperature of		internal particle velocity vector for all
	cooled plate; temperature of the		particles of size r_p
	heated plate; critical temperature	$\boldsymbol{U}_{pt}; U_{pr}; U_{prt};$	terminal velocity vector of particle
$T_{f}, T_{g}, T_{i}, T_{p}$	feed temperature; glass transition	U_{pzt}, U_{pyt}	(3.1.62); radial particle velocity;
	temperature of a glassy polymer; value		terminal value of U_{pr} ; value of U_{pt} in
	of absolute temperature T of region i;		<i>z</i> -direction (6.3.1), (7.2.211),
	product temperature		y-direction $(7.3.154)$
$T_{C}; T_{H}, T_{L}; T_{R}$	temperature of condenser; two	* * L	
	temperatures in supercritical	$\boldsymbol{v}, \boldsymbol{v}_t; \boldsymbol{v}^*, \boldsymbol{v}_t^*; \boldsymbol{v}^{ op},$	mass averaged velocity vector of a
	extraction; reboiler temperature	\boldsymbol{v}_t^{reg} ; \boldsymbol{v}_{tj} , \boldsymbol{v}_{tj}^*	fluid (also v_t); molar average velocity
T_{cf}, T_{ci}, T_{mi}	temperature of cooling fluid, critical		vector of a fluid (also \boldsymbol{v}_t^*);
	temperature of species <i>i</i> ; melting		nondimensional \boldsymbol{v} (6.3.39); reference
_	temperature for species <i>i</i>		\boldsymbol{v}_t values of \boldsymbol{v}_t and \boldsymbol{v}_t^* on surface area \boldsymbol{S}_j
$T_{\rm sat}$	temperature at which the solution is		(2.1.1), (2.1.2)
—	saturated	v _i ; v _{ij}	averaged velocity vector of <i>i</i> th
I _{sol}	temperature of the solution due to		species; value of \boldsymbol{v}_i on surface area \boldsymbol{S}_j
m 1	undergo crystallization	int	(2.1.1)
Ih	dimensionless group (3.1.46b)	$v_k; v_{kz}; v_k^{\text{int}}$	velocity of region <i>k</i> ; <i>z</i> -component of
			velocity \boldsymbol{v}_k of region k ; mass average
и	number of fundamental dimensions		velocity of the interface of two
	(Section 3.1.4.1)	r	phases
<i>u_c</i>	mass fraction of solute in the	\boldsymbol{v}_p	particle diffusion velocity relative to
	crystallized solution on a solid-free basis		that of the fluid phase (3.1.43)

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$ \begin{matrix} v_{ci}^{*}; v_{Ci}^{*}; v_{o}; v^{\mathrm{o}}; \\ v_{Ci}^{*+}; v_{og} \end{matrix} $	average velocity of liquid zone carrying species i (7.3.208); concentration wave velocity of species i (7.1.12a); velocity of micelles, superficial velocity (3.1.176), in a packed bed (6.1.4a);	$ \begin{array}{l} V_k; \ V_b \ \ V_\ell^p; \ V_o; \\ V_o^t; V^o \end{array} $	volume of region k ; liquid volume; specific pore volume of a microporous adsorbent (4.1.64a); volume of organic solvent; total amount of V_o (6.3.99); sample volume
V _r ; V _s ; V _{so} ; V _{tw} ; V _{tz} ; V _{vz}	amplitude of square-wave velocity (7.1.72a); nondimensional concentration wave velocity (7.1.105o); superficial velocity for gas phase radial velocity; shell-side velocity (3.1.175), volume flux of solvent/ permeate (7.2.71); value of v_s at	V _M ; V _p ; V _s ; V _{Sℓ} ; V _{sp}	 (7.1.101b) mobile-phase volume in a column (7.1.99g); volume of a particle, cumulative permeate volume (7.2.87); stationary adsorbent-phase volume in a column; suspension volume; stationary liquid-phase volume;
	membrane channel inlet; tangential fluid velocity in wall region (7.3.134); same as v_{z} ; vapor velocity in <i>z</i> -direction (6.3.47a)	$\overline{V}_s; \overline{V}_t; V_w; V_\sigma$	mobile-phase volume present inside the pores of a particle (7.1.110c) partial molar volume of solvent; averaged partial molar volume
$v_x, v_y; v_{yw}; v_{ywf}$	local convective velocity in <i>x</i> -direction, <i>y</i> -direction; value of v_y at wall; value of <i>y</i> at feed entrance (7.2.39)	$V \cdot V$	(3.1.56); volume of water; volume of interfacial region, Figure 3.3.2A initial volume of feed solution: final
$v_z; v_{zmax};$	v_{yw} at least entrance (7.2.35) velocity of fluid in <i>z</i> -direction;	v _{fi} , v _{fe}	volume of solution
$v_{z, \operatorname{avg}}; v_{z, \operatorname{avg}, f}$	maximum value of v_z , averaged value of v_z over flow cross section; value of	V_{f0} ; V_{fR} ; V_{N_i} ; V_{R_i}	volume of feed solution at time $t = 0$; volume of retentate; net retention
v_{∞}	$v_{z,avg}$ at feed location (6.1.5f) uniform gas velocity far away from object		volume for species <i>i</i> (7.1.99j), retention volume for species <i>i</i> (7.1.99e,f),
$v_{fr}; v_{i, \mathrm{eff}}^+$	velocity of freezing interface in zone	•	(7.1.99h)
	melting (6.3.110c); nondimensional velocity of species <i>i</i> in capillary	$V_{ m cap}^{ m tex};V_{ m eff};$ $V_{ m channel}$	volumetric ion exchange capacity of packed bed; liquid filled centrifuge
$v_z^{\mathrm{AA}}; v_{zH}, v_{zL}$	velocity of interface AA between	$\overline{V}_{ m AY}$	partial molar volume of electrolyte AY
	direction (4.2.52): interstitial gas	\overline{V}_{ic}	value of \overline{V}_i for a crystal of i
	velocity at high-pressure feed step and	V_{im}	molar volume of species <i>i</i> at its normal
	low-pressure purge step, respectively		boiling point
	(7.1.53a,b)	V _{ij}	value of V_i in region j
$v_{\rm EOF}; v_{\rm EOF,z}$	in <i>z</i> -direction	VCR	(6.4.98) (6.4.98)
V_i V_i V_h : V_d : V_f :	volume of a region, volume of	W: Warns: Wi: Wso	mass of adsorbent, quantity defined by
$V_h; \hat{V}_a; \dot{V}; \overline{V}$	separator, volume of feed solution/ eluent passed, volume of a sphere (3.3.52a) voltage between electrodes;		(5.2.54); mass of crystals formed at any time, mass of solute <i>i</i> charged; mass of solution charged to the crystallizer
	volume of buffer; volume of the	$w_{ii}; w_{ti}; w_{tz}; w_{ti}^{s};$	mass flow rate of species <i>i</i> through S_i
	dialysate solution; volume of feed	w_{tE}, w_{ER}	(2.1.4); total mass flow rate through S_j
	solution; hydrodynamic volume of a macromolecule/protein (3.3.90f);		(2.1.5); total mass flow rate in <i>z</i> -direction; total solids flow rate in <i>j</i> th
	adsorbed monolayer phase volume/ weight of adsorbent (3.3.114b): radial		stream (2.4.3a); w_{tj} for j = extract, E , w_{tj} for i = raffinate, R
	volume flow rate of solution (Figure 7.1.6); defined by (7.1.18i)	<i>w_E</i> , <i>w_M</i> , <i>w_R</i>	weight of mixture at <i>E</i> , <i>M</i> and <i>R</i> , respectively
$\tilde{V}_c; V_i; \overline{V_i}; V_j$	critical molar volume of a species;	$w^{l}; w^{s}; w^{s}_{p}(r_{p});$	mass of stationary liquid phase used as
	molar volume of pure species <i>i</i> ; partial molar volume of species <i>i</i> ; volume of	wa	coating; mass of particles per unit of fluid volume (2.4.2e); mass of a solid
	region $j: j = 1$, stationary phase; $j = 2$, mobile phase		particle of size r_p (2.4.2e); waist size of a light beam

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<i>W</i> , <i>W</i> _A	width of rectangular channel walls, molar transfer rate of species A	$x_{s,lm}$	defined by (3.1.137) molar density of fixed charges in
W	total reversible work done	Λ	electrically charged system
<u></u>	(3.1.25a b)	X., X.,	mole ratio of species <i>i</i> in region <i>i</i>
W. W. W.	band width of the chromatographic	$\Lambda_{ij}, \Lambda_{ijn}$	(132) or stream $i(222d)$ X, for
vv _{bi} , vv _{ij} , vv _{tj}	output of species i (Figure 2.5.2) molar		(1.3.2) of stream $f(2.2.2u)$, A_{ij} for
	flow rate of species <i>i</i> (Figure 2.5.2), molar flow rate of species <i>i</i> through \mathbf{s} (2.1.7)	\mathbf{v}^{a}	shundance ratio of isotone <i>i</i> in region <i>i</i>
	now rate of species <i>i</i> through S_j (2.1.7),	Λ_{ij}	(1.2.7)
			(1.3.7)
147 147	S_j (2.1.0) moler rate of permeation of species		coordinate direction normal to gas
vv _{tAm} , vv _{tBm}	A and P through mombrane	<i>y</i> , <i>y</i> _f	liquid liquid liquid or mombrono
W. W. W	molar flow rate of feed liquid fraction		fluid interface, feed gas mole fraction
vv _{tf} , vv _{tl} , vv _{tv}	and vanor fraction respectively		(Figure 7.1.14)
W. W.	total molar flow rate of bottoms	V. V. V. V.	mole fraction of species <i>i</i> and A in
v tlb, v tld	product and distillate product from a	Ϋ́υ ΥΑν ΥΗν ΥL	vanor/gas phase respectively fluid
	distillation column		mole fraction (7.1.62b) gas_phase
W. W. W.	total molar flow rate of streams $i = 1$ $i = 1$		mole fractions defined by
<i>t</i> ₁ , <i>t</i> ₂ , <i>t</i> _p	2 and $i = \text{permeate}$		(7 1 54a)
W_{t}^{t}	total molar flow rate of stream <i>i</i> for	$v_{A}^{*}, v_{A}^{*'}, v_{A}$	hypothetical gas-phase mole fraction
- ijn	stage <i>n</i> in enriching section of cascade	JA'J 'J um	of species A in equilibrium with x_{Ab} .
We	Weber number, $(\rho_c v_c^2 d_n/\gamma)$ (6.4.91)		nondimensional <i>v</i> -coordinate (5.3.5i).
			<i>y</i> -coordinate of limiting trajectory
x, x_{Δ}	coordinate direction, mole fraction of		(7.3.263a)
	species A in liquid phase	VAb, VAi	bulk gas mole fraction of species A,
$x_{\rm A}^*$	hypothetical liquid phase mole		value of y_A at a two-phase interface
	fraction of species A in equilibrium	$Y_{ij}, Y_{iR}, Y_2, Y_{2,f}$	segregation fraction of species <i>i</i> in
	with y_{Ab}	ý ý	region j (1.3.8a), segregation fraction of
x_{Ab}, x_{Ai}	bulk liquid mole fraction of species A,		solute <i>i</i> in retentate in a membrane
	value of x_A at a two-phase interface		process (6.4.107), defined by (7.2.19)
$x_{i}, x_{ij}, x_{i\sigma}, x_{i,j}$	mole fraction of species <i>i</i> , value of x_i (<i>i</i>		and (7.2.20)
	= A,B, 1, 2, <i>s</i> (solvent), etc.) in region <i>j</i>	$Y_{11}(t), Y_{21}(t)$	segregation fraction of species 1 and 2
	or stream j (j =1, 2, f (feed), g = gas, l =		in region 1 at time t
	liquid, p = permeate, R = resin, s =	Y^a_{ij} , \dot{Y}_{ij} , \dot{Y}_{rj}	segregation fraction for an isotopic
	solution, $v =$ vapor, $w =$ water), x_{ij}		mixture (1.3.9a), of species i stream j
	where $j=\sigma$, the surface adsorbed phase,		(2.2.12), of particles of size r in stream j
	mole fraction of species i in region j		(2.4.5)
	when molecular formula is substituted		
	for species <i>i</i>	z , $z_{ m cr}$ (or $z_{ m crit}$), z_{H} ,	coordinate direction, critical distance
$x_{iE}, x_{iE}^*, x_{iE}^e$	mole fraction of species <i>i</i> in extract	z_L , z_{AA} , z_{BB}	(7.2.133), characteristic locations at
	phase, value of x_{iE} in equilibrium with		pressures P_H and P_L (7.1.55e), vertical
	x_{iR} , value of x_{iE} if both streams leave		coordinates of interfaces AA and BB,
	stage in equilibrium		respectively
x _{ilb} , x _{ild}	bulk value of x_{il} , mole fraction of i in	z_{HL} , z_{HS}	height of the liquid level of a dilute
	liquid product from reboiler in a		suspension, height of sludge layer
	distillation column, x_{il} in liquid	z^+ , z^+_i	nondimensional z-coordinate (Figure
	product from condenser at the top of a		3.2.2), (6.3.12), value of z^+ for center of
	distillation column		mass of concentration profile of
$x_{iR}, x_{iR}^*, x_{iR}^e$	mole fraction of species <i>i</i> in raffinate		species <i>i</i> (3.2.22a,b)
	phase, value of x_{iR} in equilibrium with	z_{lpha} , z_{eta} , $z_o(C_{i2})$	<i>z</i> -coordinate locations of regions α and
	x_{iE} , value of x_{iR} if both streams leave		β , respectively, defined by (7.1.17e,f)
,	stage in equilibrium	$Z_i, Z_{i,eff}, Z_p$	electrochemical valence of species <i>i</i> ,
x_{jp}, x_{jp}, x_{ip}	mole traction of species <i>j</i> in feed and		effective charge on ion i due to the
	permeate, respectively, mole fraction		diffuse double layer ($\langle Z_i \rangle$ (6.3.31a),
	(Figure 7.2.1(b))		value of Z_i for a protein

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Greek letters		$\gamma_{1}, \gamma_{2}, \gamma_{3}, \gamma_{4}, \gamma^{12};$	factors/parameters in plate height
α $\alpha_f, \alpha_l, \alpha_v$	constant in (3.1.215), separation factor between two species 1 and 2 in capillary electrophoresis (6.3.27e) parameters for feed, liquid fraction,	yu, yu, yu	(7.1.1071-1); interfacial tension between two bulk phases 1 and 2; interfacial tension between phases <i>S</i> and <i>L</i> , <i>L</i> and <i>G</i> , <i>S</i> and <i>G</i> , respectively (S = solid, L = liquid, G = gaseous)
	vapor fraction in a continuous chemical mixture described by a Γ distribution function (4.1.33f),	$\dot{\gamma}; \dot{\gamma}_w$ $\gamma_{il}^{\infty}; \gamma_{il, u}^{\infty}$	shear rate (3.1.74), (6.1.31); wall shear rate infinite dilution activity coefficient for
$a_{ij}; a_{ij}^{hf}, a_{ij}^{ft}, \ a_{ij}^{ht}; a_{ijn}$	(6.5.71) separation factor between two species <i>i</i> (<i>i</i> = 1, A, <i>s</i> (solvent)) and regions <i>j</i> (<i>j</i> = 2, B (species), <i>i</i>), value of α_{ij} between two streams (2.2.3), (2.2.4),		species i in the liquid; activity coefficient of species i in liquid phase on a mass fraction basis at infinite dilution (6.3.83)
a _{in}	(2.2.2a); value of a_{ij} for <i>n</i> th plate multicomponent separation factor between species <i>i</i> and <i>n</i> (1.6.6)	Γ^{E}_{is}	molar excess surface concentration of species i/cm^2 of pore surface area (3.1.117a)
$lpha^{'} lpha^{*}_{ m AB}; lpha^{ m evap}_{ij}; lpha^{ m perm*}_{ij}$	separation factor of Sandell (1.4.15) value of α_{AB} under ideal condition of zero pressure ratio (6.3.198), (8.1.426);	$\Gamma_{i\sigma}$; $\Gamma^E_{i\sigma}$	surface concentration of species <i>i</i> (3.3.34); algebraic surface excess of species <i>i</i> (3.3.40b), (5.2.145a)
	value of α_{ij} for evaporation only (6.3.180); ideal separation factor in vapor permeation (6.3.180)	$\delta; \delta(x), \delta(z), \ \delta(z^+); \delta_c$	falling film thickness; delta function in x -, z - and z ⁺ -directions (3.2.14b); cake layer thickness
β	defined by (2.2.8a,b), exponent in (3.3.89a), indicator of macromolecular shape for a given r_g (3.3.90e), constant in (3.1.215), defined by (7.1.52b),	$\begin{array}{l} \delta_{g}; \delta_{i}; \delta_{\ell}; \\ \delta_{m}; \delta_{s}; \delta_{\ell} \end{array}$	thickness of gas film; solubility parameter of species <i>i</i> , characteristic thickness of concentration profile (7.3.202); thickness of liquid film; membrane thickness, pore length;
$\beta_f, \beta_\ell, \beta_v$	(7.2.58), (7.2.138) compressibility of fluid (3.1.48), parameters for feed, liquid fraction and vapor fraction in a continuous	$\delta_{A}, \delta_{B}, \delta_{C}$	sorbed surface phase thickness (3.1.118b); thickness of liquid film from phase interface to reaction interface (5.3.22) membrane thickness in regions A. B. C
$\frac{\beta_i; \beta_p; \beta_A, \beta_B;}{\overline{R} \cdot \overline{R}}$	chemical mixture (4.1.33f), (6.3.71) exponent in (3.3.112c), parameter (7.2.18), compressibility of particle	$\delta_1, \delta_2, \delta_n$	of a membrane (Figure 6.3.35(b)) thickness of layer 1, layer 2, layer n in a
<i>Ρ</i> , <i>Ρ</i> _c	(3.1.48); defined by (7.1.52a); coefficient of volume expansion (6.1.9); a parameter (6.4.129); coefficient of thermal expansion of solution density (7.3.233)	$\Delta C; \Delta E_s; \Delta G; \\ \Delta G_t; \Delta H_s; \Delta P; \\ \Delta S; \Delta T$	composite membrane molar supersaturation (3.3.98a); activation energy for crystal growth rate (3.4.29); Gibbs free energy change, e.g. for forming a crystal (3.3.100a); change in Gibbs free energy for all molecules;
$\gamma;\gamma_{cr};\gamma_{\rm A};\gamma_{\rm R};\gamma_{\rm R_2}$	surface tension, interfacial tension, pressure ratio (6.3.197), (6.4.123), (8.1.426), parameter (7.1.18f); critical surface tension for a polymer; Damkohler number ($k_b \partial_m^2/D_A$)	AH	enthalpy of solution of a gas species in a polymer; pressure difference $(P_f - P_p)$, etc.; selectivity index (7.2.93); extent of supercooling (3.3.98d), temperature difference $(T_2 - T_1)$ host of errotalization
	(5.4.100); $(D_A k_1 / k_\ell^2)$ (5.3.11); defined by (5.3.35j)	ΔH^{crys}_{crys} ΔG^0 , ΔH^0 , ΔS^0	standard Gibbs free energy change, enthalpy change and entropy change
$\gamma_f, \gamma_\ell, \gamma_\nu$	fraction (4.1.33f), (6.3.69)	$\Lambda d_{a} \cdot \Lambda r_{a} \cdot \Lambda w^{s}$	for a reaction
Yi Yip Yij Yjf	activity coefficient for species <i>i</i> , dimensionless steric correction factor; value of γ_i in feed stream, in phase <i>j</i> ; value of γ_j in feed stream (species <i>j</i>)		two consecutive sieves; $(\Delta d_p/2)$ or the net growth in size of all seed crystals (6.4.40i); mass of crystals retained on a sieve of given size

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$\begin{aligned} \Delta_{i_{i_{i}}} \Delta_{i_{i_{i}}}} \Delta_{i_{i_{i}}} \Delta_{i_{i_{i}}} \Delta_{i_{i_{i}}} \Delta_{i_{i_{i}}}} \Delta_{i_{i_{i}}} \Delta_{i_{i_{i}}}} D_{i_{i_{i}}} D_{i_{i_{i}}} D_{i_{i_{i}}} D_{i_{i_{i}}}} D_{i_{i_{i}}} D_{i_{i_{i}}}} D_{i_{i_{i}}} D_{i_{i_{i}}}} D_{i_{i_{i}}}} D_{i_{i_{i}}}} D_{i_{i_{i}}}} D_{i_{i_{i}}}} D_{i_{i_{i}}}} D_{i_{i_{i}}}} D_{i_{i_{i}}} D_{i_{i_{i}}}} D_{i_{i_{i}}} D_{i_{i_{i}}}} D_{i_{i}}} D_{i_{i}}}} D_{i_{i}}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}}} D_{i_{i}}}} D_{i_{i}}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}} D_{i_{i}}}} D_{i_{i}}}} D_{i_{i}}}} D_{i_{i}}} D_{i_{i}}}} D_{i_{i}}}} D_{i_{i}}}} D_$	Δχ Δν Δζ	lengths of a small rectangular volume	A	cut (2.2.10a) stage cut fraction of
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$\Delta z_L, \Delta z_H$	element in three coordinate directions,	0	adsorbent sites occupied (3.3.112a),
$\begin{aligned} \Delta q_{ij}^{1} \Delta q_{ij} \Delta q_$		defined by (7.1.53a,b)		contact angle, gas-liquid-solid system
$ \Delta v_{-x} \Delta \pi $ cations and anions, respectively released during binding isomotic pressure difference $(x_{7} - x_{7})$ θ_{i} (2.2.10b). Langmuir isotherm (5.3.104) (2.2.10b). Langmuir isotherm (7.1.136), nondimensional mobile phase concentration (4.5.1); potential difference between two phases $\theta_{ab} \ \theta_{ad}$ (2.2.10b). Langmuir isotherm (7.1.136), nondimensional mobile phase concentration (6.4.31); potential difference between two phases $\theta_{ab} \ \theta_{ad}$ (2.2.10b). Langmuir isotherm (7.1.136), nondimensional mobile phase concentration (6.4.31); potential difference between two phases (6.4.16); reciprocal Debye length (3.1.17); distribution coefficient of species <i>i</i> and <i>k</i> , $x_{1} \times k_{1} \times k_{2} \times k_{2} \times k_{2}$ (3.1.6); reciprocal Debye length (3.1.17); distribution coefficient of species <i>i</i> distribution coefficient of species <i>i</i> and (3.1.16); reciprocal Debye length (3.1.17); distribution coefficient of species <i>i</i> and (3.1.16); reciprocal Debye length (3.1.17); distribution coefficient of species <i>i</i> distribution coefficient of solute <i>i</i> between regions 1 and 2 (1.4.1), its tennard-lones force constant of a particle; electrical constant of a region B (Figure 6.3.35(b)); value of fractional area of defects in glassy skin region B (Figure 6.3.25(b)); value of fractional area of defects in glassy skin region B (Figure 6.3.25(b)); value of fractional area of defects in glassy skin region B (Figure 6.3.25(b)); value of fractional dreas of defects in glassy skin region B (Figure 6.3.25(b)); value of fractional fraces (2.2.22); nondimensional variable (2.5.5), n (for species 1 and 2, (5.3.109)) (7.3.30); (7.3.30); (7.3.30); (7.3.30); (7.3.30); (7.3.30); (7.3	$\Delta \mu_i^0; \varDelta v_1, \varDelta v_+,$	$\mu_{i1}^0 - \mu_{i2}^0$, number of water molecules,		(Figure 3.3.16), contact angle between
$ \begin{aligned} & e_{ij} & \Delta_{pi} & \Delta_{pi}, & \Delta_{pi} & \Delta_{pi}, & \Delta_{pi} & \Delta_{pi}, & \Delta_{pi} & \Delta_{pi}, & \Delta_{p$	Δv_{-} , $\Delta \pi$	cations and anions, respectively		membrane surface and liquid
$ \begin{split} & pressure difference (x_{f} - x_{f}) & b_{i} \\ & component cut or spaces i \\ & in crystallizer (6.4.24); change in \\ & saturation concentration due to \Delta T \\ & (6.4.31); potential difference between \\ & two phases & b_{ab} & b_{bd} \\ \hline & C_{1.136a}, nondimensional \\ & mobile phase concentration \\ & defined by (8.1.328) \\ \hline & V^{i} & defined by (8.1.328) \\ \hline & V^{i} & defined by (8.1.328) \\ \hline & V^{i} & defined py (8.1.328) \\ \hline & V^{i} & V^{i} & defined py (8.1.328) \\ \hline & V^{i} & V^{i} & V^{i} & V^{i} \\ \hline & V^{i} \\ \hline & V^{i} \\ \hline & V^{i} & V^{i$		released during binding; osmotic	0	(6.3.140)
$ \begin{split} \Delta \rho_{i}^{*} \Delta \rho_{i} \Delta \rho_{$		pressure difference $(\pi_f - \pi_p)$	θ_i	component cut for species <i>i</i>
$ \begin{split} & fight equation of the statistication the statistication of the statistication of the statistication t$	$\Delta \rho_i; \Delta \rho_{i,sat}; \Delta \phi$	mass concentration change of species i		(2.2.10b), Langmuir isotherm
$ \begin{aligned} & \text{defined by (B.1.328)} \\ \nabla^{1} & \text{defined by (B.1.328)} \\ \nabla^{1} & \text{defined by (B.1.328)} \\ \nabla^{1} & \text{def operator in internal coordinates } x_{i}^{l}, \\ y^{l} \text{ and } x^{l} \\ & \text{K}_{Aa}; & \mathcal{K}_{a}; \\ & \text{defined by (B.1.328)} \\ \nabla^{1} & \text{def operator in internal coordinates } x_{i}^{l}, \\ y^{l} \text{ and } x^{l} \\ & \text{K}_{Aa}; & \mathcal{K}_{a}; \\ & \text{detribution coefficient of species (A and k, respectively, in the distillation column top product (B.1.224)} \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the fluid (= e_{x_{i},x_{i}}) \\ & \text{deterrical permittivity of the ded or particle (electrical permittivity of mombrane, pellet, bead or particle (electrical permittivity of vacuum; prorsity of spacer in spiral-wound module (3.1.70), prorsity of vacuum; prorsity of spacer in spiral-wound module (3.1.70), prorsity of tractional area of defects in glassy kin region B (Figure 6.3.35(b)); value of fractional neembrane (cos start of a particle) electrical permittivity of vacuum; prossity of spacer in spiral-wound module (3.1.70), prossity of tractional neembrane (3.3.87), wound module (3.1.70), prossity of traction al region C (1.4.10), (2.2.2e) \\ & \text{K}_{ip}, \pi_{ip}^{i} \\ & \text{region B (Figure 6.3.35(b)); value of fraction al queuos phase (6.3.10a) \\ & \text{region C (1.4.10), (2.2.2e)} \\ & \text{K}_{ip}, \pi_{ip}^{i} \\ & impurity distribution coefficient$		In crystallizer (6.4.24); change in AT		(7.1.36a), nondimensional
$ \begin{aligned} & (1,1,10) \\ $		(6.4.51); potential difference between		(7.1.18b)
$\begin{split} & \sum_{k_{1}} \sum_{k_{2}} \sum_{k_{2}} \sum_{k_{3}} $		two phases	And And	component cut for species i and k
∇^1 del operator in internal coordinates x', y' and z'top product (8.1.224)εvoid volume fraction in a packed bed, electrical permittivity of the fluid (= ε _φ ε _φ) phase angle; fractional cross-sectional area of membrane which is defective ε _φ : ε _φ : ε _φ distribution coefficient of species i distribution coefficient of species i particle; delectrical constant of a marking/µfs/µs particle; delectrical permittivity of vacuum; porosity of spacer in spiral- wound module (3.1.170), porosity of clean filterκ _{ij} , κ _{ij} , κ _{ij} k _{ij} , κ _{ij} effective value of κ _{ij} when there is no reaction area of defects in glassy skin region CK _{ij} , κ _{ij} k _{ij} , κ _{ij} effective value of signet and queues phase (6.3.101a)K _{ij} , κ _{ij} k _{ij} , κ _{ij} k _{ij} , κ _{ij} effective value of k _{ij} when there is no reaction of particle; celectrical permittivity of vacuum; porosity of spacer in spiral- wound module (3.1.170), porosity of region CK _{ij} , κ _{ij} k _{ij} , κ _{ij} effective value of k _{ij} when there is no reaction area of defects in glassy skin region CK _{ij} , κ _{ij} k _{ij} effective value of k _{ij} when there is no reaction area of defects in glassy skin region CK _{i,koc} (r)Ioal equilibrium partition constant (6.3.101a) ξ_i zeta (electrokinetic) potential (3.1.11) (3.1.46), intrinsic viscosity x _{ij} , κ_{jj} , κ_{jj} , κ_{jj} ($1.4.10$, $(2.2.22)$, nondimensional variable (2.3.11), $(5.3.14b)$, $(5.3.14b)$, $(5.3.14b)$ Hender by (3.2.45b) ξ_i zeta (electrokinetic) potential (3.1.17) species i (3.3.10) impurity ratio for th	$\Delta_{\mathbf{P}}$	defined by (8.1.328)	чи) ^с ки	respectively, in the distillation column
$ \begin{aligned} y^i \text{ and } z^i \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$	∇^{i}	del operator in internal coordinates x^{i} ,		top product (8.1.224)
$ \begin{split} \kappa_{\lambda\alpha}; \kappa_{d}; \kappa_{i} & \text{distribution coefficient of species} \\ \kappa_{\lambda\alpha}; \kappa_{d}; \kappa_{i} & \text{A between aqueous and organic} \\ electrical permittivity of the fluid (= e_{0,C_{0}}) & \text{Phases (3.4.16); reciprocal Debye} \\ e_{a^{i}} e_{b} & \text{phase angle; fractional cross-sectional} & \text{of species } i \\ \text{dielectric constant of a fluid, porsity} & \kappa_{11}, \kappa_{11}^{N} & \text{distribution coefficient of species } i \\ \text{between regions 1 and 2 (1.4.1), its} \\ \text{Lennard-Jones force constant for} & \text{Nerrst limit (3.3.78), (3.3.79)} \\ \text{species } volume fraction of phase k in \\ a multiphase system & \epsiloned solution and feed side of the membrane; partition coefficient of solute i between regions 1 and 2 (1.4.1), its \\ \text{Dermst limit (3.3.78), (3.3.79)} \\ \text{species } volume fraction of phase k in \\ a multiphase system & \epsiloned solution and feed side of the membrane; partition coefficient of solute i between regions 0 and 1 the membrane (3.3.87) \\ \text{vacuum; prosity of membrane, pellet, bead or \\ particle; electrical constant for \\ vacuum; prosity of spacer in spiral- \\ wound module (3.1.170), porsity of \\ vacuum; prosity of spacer in spiral- \\ wound module (3.1.170), porsity of \\ reaction al area of defects in glassy skin \\ region C & (5.3.56)); value of \\ fractional area of defects in glassy skin \\ region C & (5.3.56)); value of \\ ractional area of defects in glassy skin \\ region C & (3.4.58) \\ \kappa_{ip} \kappa_{ip}^{*} & (3.3.89) \\ \epsilon_{12} & (1.4.10), (2.2.2e) & \kappa_{ip} & \kappa_{ip} \cdot \kappa_{in} \\ \tauatable (3.2.11), (6.3.14b), (6.3.114) \\ variable (3.2.11), (6.3.14b), (6.3.114) \\ variable (3.2.11), (6.3.14b), (6.3.114) \\ variable (3.2.11), (6.3.44b), (6.3.114) \\ variable (3.2.11), (6.3.44b), (6.3.114) \\ variable (3.2.11), (6.3.44b), (6.3.114) \\ risy eff a the difficut or efficient in zone melting for species i (3.4.25), in portices i (3.4.25) \\ risy efficition (1.4.30); intrusic viscosity \\ variable (3.2.11), (6.3.44b), (6.3.114) \\ risy efficition (0.5.116a) \\ risy control (3.3.09); its value for polymer \\ i(7.1.110f); current utilization factor \\$		y^i and z^i		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$			$\kappa_{Ao}; \kappa_d; \kappa_i$	distribution coefficient of species
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	3	void volume fraction in a packed bed,		A between aqueous and organic
$\begin{split} \epsilon_{qi} \epsilon_{b} & \text{phase angle; fractional cross-sectional length (3.1.17); distribution coefficient of a fluid, porosity of particle deposit on filter media; Lennard-Jones force constant for species i obtained fraction of phase k in \kappa_{l1}, \kappa_{l1}^N distribution coefficient of species i between regions 1 and 2 (1.4.1), its Nernst limit (3.3.78) (3.3.79) species i; volume fraction of phase k in \kappa_{gj}; \kappa_{ij}; \kappa_{ij} manultiphase system a multiphase system porosity of membrane, pellet, bead or particle; dielectrical constant of a species i (distribution coefficient of solute i between tween two particle; dielectrical constant of a species i (distribution and feed side of the membrane; partiticle; dielectrical constant of a species i, volume fraction of phase k in \kappa_{gj}; \kappa_{ij}^{\prime} wound module (3.1.170), prosity of spacer in spiral-wound module (3.1.170), prosity of spacer in spiral-wound module (3.1.170), prosity of class skin region B (Figure 6.3.35(b)); value of fractional membrane cross section in region C (1.4.10), (2.2.2e) (1.4.10), (2.3.17), (7.3.38), (7.3.48), (1.5.34b), (6.3.114), \kappa_{is}, \text{eff} effective partition coefficient in zone methrace (3.2.5), \eta for species i (3.2.25); \kappa_{ik} distribution coefficient of i in ton exchange system (3.3.115) (1.4.30) (1.4.30; (1.4.30)) (1.4.32); (7.1.100; current utilization factor (8.1.406) (1.4.30; (1.4.30)) (3.2.26); \kappa_{in}^{m} distribution coefficient of and an equeous two-phase extraction; protein distribution coefficient of and coefficient of (1.4.30) (2.2.2e) (3.2.26); \kappa_{in}^{m} distribution coefficient of salt, molal defined by (3.2.29) (3.2.26); \kappa_{in}^{m} distribution coefficient of salt, molal basis (4.1.3.40)$		electrical permittivity of the fluid $(= \varepsilon_0 \varepsilon_d)$		phases (3.4.16); reciprocal Debye
area of membrane which is defectiveof species i \mathcal{E}_{ab} \mathcal{E}_{k} dielectric constant of a fluid, porosity κ_{11} , κ_{11}^{N} distribution coefficient of species i \mathcal{E}_{ab} \mathcal{E}_{k} \mathcal{E}_{ab} \mathcal{E}_{k} \mathcal{E}_{ab} \mathcal{E}_{k} \mathcal{E}_{ab} \mathcal{E}_{k} \mathcal{E}_{ab} \mathcal{E}_{k} \mathcal{E}_{ab} \mathcal{E}_{p} \mathcal{E}_{pi} \mathcal{E}_{pi} porosity of membrane, pellet, bead or particle; electrical constant of a particle; electrical constant of a particle; electrical constant of a particle; electrical constant of a particle; electrical permittivity of vacuum; porosity of spacer in spiral- wound module (3.1.170), porosity of clean filter \mathcal{E}_{ij} , \mathcal{E}_{ij} $\mathcal{E}_{$	$\varepsilon_a; \varepsilon_b$	phase angle; fractional cross-sectional		length (3.1.17); distribution coefficient
$ \begin{split} \vec{e}_{d} \in \vec{e}_{d} \in \vec{e}_{d} & \text{dielectric constant of a fluid, porosity } \\ \vec{e}_{l} \in \vec{e}_{d} \in \vec{e}_{d} & \text{distribution coefficient of species } i \\ \text{of particle deposit on filter media;} \\ \text{Lennard-Jones force constant for} \\ \text{species } i; volume fraction of phase k in \\ a multiphase system \\ \text{porosity of membrane, pellet, bead or \\ particle; dielectrical constant of a \\ multiphase system (delettric all constant of a \\ particle; dielectrical constant of a \\ particle; dielectrical constant of a \\ vacuum; porosity of spacer in spiral- \\ wound module (3.1.170), porosity of \\ clean filter \\ region B (Figure 6.3.35(b)); value of \\ region C \\ clean filter \\ (1.4.10), (2.2.2e) \\ \vec{e}_{12} \\ \text{enrichment factor for species 1 and 2 } \\ \vec{e}_{12} \\ \text{enrichment factor for species 1 and 2 } \\ \vec{e}_{12} \\ \text{enrichment factor for species 1 and 2 } \\ \vec{r}_{14} ; \eta_i , \eta_j ,$		area of membrane which is defective	N	of species <i>i</i>
$ \begin{aligned} & \int \operatorname{particle} \operatorname{deposit} \operatorname{on} \operatorname{hlter} \operatorname{media}; & \operatorname{between} \operatorname{regions} 1 \operatorname{and} 2 (14.1), \operatorname{its} \\ & \operatorname{Lennard-Jones} \operatorname{force constant} \operatorname{for} \\ & \operatorname{species} i, \operatorname{volume} \operatorname{fraction} \operatorname{of} \operatorname{phase} k \operatorname{in} \\ & \operatorname{a} \operatorname{multiphase} \operatorname{system} \\ & \operatorname{a} \operatorname{multiphase} \operatorname{system} \\ & \operatorname{a} \operatorname{multiphase} \operatorname{system} \\ & \operatorname{particle}; \operatorname{delectrical} \operatorname{constant} \operatorname{of} \operatorname{a} \\ & \operatorname{vacuum}; \operatorname{porosity} \operatorname{of} \operatorname{spacer} \operatorname{in} \operatorname{spiral} \\ & \operatorname{wound} \operatorname{module} (3.1.170), \operatorname{porosity} \operatorname{of} \\ & \operatorname{clean} \operatorname{filter} \\ & \operatorname{region} \operatorname{fractional} \operatorname{area} \operatorname{of} \operatorname{defects} \operatorname{in} \operatorname{glassy} \operatorname{skin} \\ & \operatorname{region} \operatorname{fractional} \operatorname{membrane} \operatorname{cross} \operatorname{section} \operatorname{in} \\ & \operatorname{region} \operatorname{fractional} \operatorname{membrane} \operatorname{cross} \operatorname{section} \operatorname{in} \\ & \operatorname{region} \operatorname{C} \\ & (1.4.10), (2.2.2e) \\ & \kappa_{i_D} \\ & (1.4.10), (2.2.2e) \\ & \kappa_{i_D} \\ & \kappa_{i_D} \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{species} 1 \operatorname{and} 2 \\ & \kappa_{i_D} \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{particle} \operatorname{collected} (7.3.37), \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{particle} \\ & (3.1.11a) \\ & \kappa_{i_D} \\ & \kappa_{i_D} \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{particle} \\ & (2.2.22), \operatorname{nondimensional} \\ & \kappa_{i_D} \\ & \kappa_{i_D} \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{resoin} \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{ratio} (3.1.14), \\ & \kappa_{i_D} \\ & \operatorname{recycle} \operatorname{ratio} \operatorname{ord} \operatorname{region} f (1.4.3a); \\ & \operatorname{inpurity} \operatorname{ratio} \operatorname{region} f (1.4.3a); \\ & \operatorname{inpurity} \operatorname{ratio} \operatorname{recycle} \operatorname{ratio} \operatorname{region} f (1.4.3a); \\ & \operatorname{recycle} \operatorname{ratio} r$	ε_d ; ε_i ; ε_k	dielectric constant of a fluid, porosity	κ_{i1} , κ_{i1}^{N}	distribution coefficient of species <i>i</i>
$ \begin{aligned} & \text{peritis limit } (3.5.73), (5.5.73) \\ & \text{species } i \text{ volume fraction of phase } k \text{ in } \\ & \kappa_{ij}; \kappa_{ij}; \kappa_{im} \\ & \text{a multiphase system} \\ & \text{porosity of membrane, pellet, bead or \\ & \text{particle; electrical constant of a \\ & \text{particle; electrical permittivity of } \\ & \text{vacuum; porosity of spacer in spiral-} \\ & \text{wound module } (3.1.170), \text{porosity of } \\ & \text{clean filter} \\ & \text{vacuum; porosity of spacer in spiral-} \\ & \text{wound module } (3.1.170), \text{porosity of } \\ & \text{clean filter} \\ & \text{region B (Figure 6.3.35(b)); value of \\ & \text{fractional area of defects in glassy skin } \\ & \text{region B (Figure 6.3.35(b)); value of \\ & \text{fractional membrane cross section in } \\ & \text{region C } \\ & \text{enrichment factor for species 1 and 2 } \\ & \kappa_{ip} \\ & \text{clear filter} \\ & \text{vacuus (l.4.10), (2.2.2e)} \\ & \kappa_{i,loc}(\mathbf{r}) \\ & \text{local equilibrium partition coefficient in zone \\ & \text{fraction of particle collected } (7.3.37), \\ & \text{region C } \\ & \text{zeta (electrokinetic) potential (3.1.11a)} \\ & \pi_{ip} \\ & \text{fraction of particles collected } (7.3.37), \\ & \text{region C } \\ & \text{variable } (3.2.11), (6.3.14b), (6.3.114), \\ & \kappa_{is}, \kappa'_{is} \\ & \text{fign tribuition coefficient in zone \\ & \text{fraction of particles collected } (7.3.37), \\ & \text{recycle ratio } (2.2.22), \text{ nondimensional } \\ & \text{variable defined by } (3.2.17) \\ & \text{species } i (3.3.25); \\ & \kappa_{in} \\ & \text{intribution coefficient of } i \text{ intrins} \\ & \text{variable defined by } (3.2.17) \\ & \text{species } i \text{ nodvent extraction } \\ & \text{spirity distribution coefficient of } i \text{ into } \\ & \text{spirity distribution coefficient of } i \text{ intrins} \\ & \text{variable defined by } (3.2.25); \\ & \kappa_{in} \\ & \text{intribution coefficient in the \\ & \text{distribution coefficient in the } \\ & \text{distribution coefficient in the } \\ & \text{distribution coefficient in the } \\ & \text{distribution coefficient of salt, molal \\ & \text{defined by } (3.2.29) \\ & \text{basis } (4.1.340) \\ $		of particle deposit on filter media;		between regions 1 and 2 (1.4.1), its
$ \begin{aligned} speckes i, volume fraction of priase vin kij (kij kij) \\ a multiphase system \\ a multiphase system \\ porosity of membrane, pellet, bead or particle; dielectrical constant of a particle; dielectrical constant of a vacuum; porosity of spacer in spiral-wound module (3.1.170), porosity of clean filter kij; kij (ji) (3.3.89a) \\ clean filter kij (ji) (ji) (ji) (ji) (ji) (jii) $		Lennard-Jones force constant for		Nerrist limit (3.3.78), (3.3.79)
$ \begin{aligned} \epsilon_{mi} \epsilon_{pi} \epsilon_{0i} \epsilon_{0$		a multiphase system	$\kappa_{if}, \kappa_{ij}, \kappa_{im}$	feed solution and feed side of the
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	E 'E 'Eo'Eo	porosity of membrane pellet head or		membrane: partition/distribution
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	<i>cm;cp;c0;c0</i>	particle: dielectrical constant of a		coefficient of solute <i>i</i> between two
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		particle; electrical permittivity of		immiscible phases; κ_{ii} for feed
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		vacuum; porosity of spacer in spiral-		solution and the membrane (3.3.87),
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		wound module (3.1.170), porosity of		(3.3.89a)
$\begin{split} \varepsilon_{\mathrm{B}; \ \mathcal{E}_{\mathrm{C}}} & \mbox{fractional area of defects in glassy skin} & \mbox{region B (Figure 6.3.35(b)); value of } & \kappa_{io} & \mbox{partition coefficient of i between an organic and an aqueous phase (6.3.101a) & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fractional membrane cross section in region C } & \mbox{fraction} & \mbo$		clean filter	$\kappa_{ij}^{'},\kappa_{ij}^{''}$	effective value of κ_{ij} when there is no
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\varepsilon_{\rm B}; \varepsilon_{\rm C}$	fractional area of defects in glassy skin		reaction or there is reaction
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		region B (Figure 6.3.35(b)); value of	κ_{io}	partition coefficient of <i>i</i> between an
$ \begin{aligned} & \operatorname{region C} & (6.3.101a) \\ & \operatorname{enrichment factor for species 1 and 2} & \kappa_{ip} & \kappa_{im} \text{ at permeate-membrane interface} \\ & (1.4.10), (2.2.2e) & (3.4.58) \\ & \kappa_{i,loc}(\mathbf{r}) & \operatorname{local equilibrium partition constant} \\ & & (3.3.89g) \\ & & \kappa_{is}, \kappa_{is}' & \operatorname{impurity distribution coefficient} \\ & & (6.3.109a) \\ & & & \kappa_{is}, \kappa_{is}' & \operatorname{impurity distribution coefficient} \\ & & (6.3.109a) \\ & & & \kappa_{is}, \kappa_{is}' & \operatorname{impurity distribution coefficient} \\ & & (6.3.109a) \\ & & & \kappa_{is}, \kappa_{is}' & \operatorname{impurity distribution coefficient in zone} \\ & & & fraction of particles collected (7.3.37), & & & \\ & & & (7.3.38), (7.3.46), \operatorname{intrinsic viscosity} & \kappa_{iE} & & & \\ & & & & (6.3.119a) \\ & & & & & (7.3.38), (7.3.46), \operatorname{intrinsic viscosity} & \kappa_{iE} & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & $		fractional membrane cross section in		organic and an aqueous phase
$ \begin{split} \varepsilon_{12} & \text{enrichment factor for species 1 and 2} & \kappa_{ip} & \kappa_{im} \text{ at permeate-membrane interface} \\ & (1.4.10), (2.2.2e) & (3.4.58) \\ & \kappa_{i,\text{loc}}(\mathbf{r}) & \text{local equilibrium partition constant} \\ & \zeta & \text{zeta (electrokinetic) potential (3.1.11a)} & (3.3.89g) \\ & \kappa_{is}, \kappa_{is}' & \text{impurity distribution coefficient} \\ & \eta & \text{recycle ratio (2.2.22), nondimensional} & (6.3.109a) \\ & \text{variable (3.2.11), (6.3.14b), (6.3.114),} & \kappa_{is,\text{eff}}' & \text{effective partition coefficient in zone} \\ & \text{fraction of particles collected (7.3.37),} & \text{melting for species i (6.3.119a)} \\ & (7.3.38), (7.3.46), \text{intrinsic viscosity} & \kappa_{iE} & \text{distribution (partition) coefficient for} \\ & \eta^+ & \text{variable (2.5.5), } \eta \text{ for species i (3.2.25);} & \kappa_{iR} & \text{distribution coefficient in aqueous} \\ & (\eta_i; \eta_i, \eta_{iF}, \eta_{iF}) & \text{impurity ratio for region j (1.4.3a);} \\ & \text{impurity ratio for ith species in region j} & \kappa_{p_1}; \kappa_{p1}^0 & \text{protein partition coefficient in aqueous} \\ & (1.6.4); \text{ defined by (1.4.4); intrinsic} \\ & \text{viscosity (3.3.90f); its value for polymer} \\ & interface \\ & \langle \eta_i \rangle; \langle \eta_i^2 \rangle & \text{first moment of } C_i(\eta_i, t_i^+) (3.2.26); & \kappa_{salt}^m & \text{distribution coefficient of salt, molal} \\ & \text{defined by (3.2.29)} & \text{basis (4.1.34o)} \\ \end{split}$		region C		(6.3.101a)
$ \begin{aligned} & (1.4.10), (2.2.2e) \\ & (3.4.58) \\ & ($	ε_{12}	enrichment factor for species 1 and 2 $(1,4,10)$ $(2,2,2\pi)$	κ_{ip}	κ_{im} at permeate-membrane interface
$ \zeta \qquad \text{zeta (electrokinetic) potential (3.1.11a)} \qquad (3.3.89g) \\ \kappa_{is}, \kappa_{is}' \qquad \text{impurity distribution coefficient} \\ \eta \qquad \text{recycle ratio (2.2.22), nondimensional} \\ variable (3.2.11), (6.3.14b), (6.3.114), \\ \kappa_{is}, \text{eff} \qquad \text{effective partition coefficient in zone} \\ fraction of particles collected (7.3.37), \\ (7.3.38), (7.3.46), intrinsic viscosity \\ \eta_i; \eta_j; \eta_{ij}; \eta_{j'}, \qquad \text{variable defined by (3.2.17)} \\ \eta^+ \qquad \text{variable defined by (3.2.17)} \\ \eta_i; \eta_j; \eta_{ij}; \eta_{j}, \\ \eta_{iF} = \qquad \text{impurity ratio for region } j (1.4.3a); \\ \text{impurity ratio for region } j (1.4.3a); \\ \text{impurity ratio for ith species in region } j \\ (1.6.4); defined by (1.4.4); intrinsic \\ viscosity (3.3.90f); its value for polymer \\ i (7.1.110f); current utilization factor \\ (8.1.406) \\ \langle \eta_i \rangle; \langle \eta_i^2 \rangle \qquad \text{first moment of } C_i(\eta_i, t_i^+) (3.2.26); \\ \kappa_{alt} = \begin{pmatrix} \kappa_{alt} \\ m_{alt} \\ m_{al$		(1.4.10), (2.2.2e)	16. a. (1 4)	(3.4.38)
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	7	zeta (electrokinetic) potential (3 1 11a)	$\kappa_{i, \text{loc}}(\mathbf{r})$	(3 3 89g)
$ \eta \qquad \text{recycle ratio (2.2.22), nondimensional variable (3.2.11), (6.3.14b), (6.3.114), $\kappa_{is,\text{eff}}' = ffective partition coefficient in zone fraction of particles collected (7.3.37), (7.3.38), (7.3.46), intrinsic viscosity κ_{iE} distribution (partition) coefficient for variable defined by (3.2.17) $$ species i in solvent extraction $$ distribution coefficient of i in ion $$ impurity ratio for region j (1.4.3a); $$ rechange system (3.3.115) $$ protein partition coefficient in aqueous (1.6.4); defined by (1.4.4); intrinsic $$ viscosity (3.3.90f); its value for polymer $$ i (7.1.110f); current utilization factor $$ (8.1.406) $$ first moment of $C_i(\eta_i, t_i^+)$ (3.2.26); $$ κ_{salt}^m $$ distribution coefficient of salt, molal basis (4.1.340) $$ basis (4.1.340 $$ basis (4.1.340) $$ basis (4.1.340) $$ basis (4.1.340 $$ basis (4.1.340) $$ basis (4.1.340 $$ basis (4.1.340) $$ basis (4.1.340 $$ basis (4.1.3$	2	Zeta (electrolaticae) potentiai (o.i.i.i.a)	Kie, K.	impurity distribution coefficient
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	η	recycle ratio (2.2.22), nondimensional	15/ 15	(6.3.109a)
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	1	variable (3.2.11), (6.3.14b), (6.3.114),	$\kappa'_{is eff}$	effective partition coefficient in zone
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		fraction of particles collected (7.3.37),	loj chi	melting for species i (6.3.119a)
$ \begin{array}{cccc} \eta^+ & \mbox{variable defined by (3.2.17)} & \mbox{species } i \mbox{ in solvent extraction} \\ \eta_i, \eta_j, \eta_{ij}, \eta_{jj}, \eta_{ij}, \eta_{j}', & \mbox{variable (2.5.5)}, \eta \mbox{ for species } i \mbox{ (3.2.25); } & \kappa_{iR} & \mbox{ distribution coefficient of } i \mbox{ in jurity ratio for region } j \mbox{ (1.4.3a);} & \mbox{ exchange system (3.3.115)} \\ mpurity ratio for ith species \mbox{ in region } j & \kappa_{p_1}; \kappa_{p_1}^0 & \mbox{ protein partition coefficient in aqueous} \\ (1.6.4); \mbox{ defined by (1.4.4); intrinsic} & \mbox{ two-phase extraction; protein} \\ & \mbox{ viscosity (3.3.90f); its value for polymer} & \mbox{ distribution coefficient in the} \\ & i \mbox{ (7.1.110f); current utilization factor} \\ & \mbox{ (8.1.406)} & \mbox{ interface} \\ & \end{tabular} \\ $		(7.3.38), (7.3.46), intrinsic viscosity	κ_{iE}	distribution (partition) coefficient for
$ \begin{array}{ll} \eta_{i}, \eta_{j}, \eta_{ij}, \eta_{j}', \\ \eta_{i}, \eta_{j}, \eta_{ij}, \eta_{j}', \\ \eta_{i}, \eta_{i}, \eta_{i}, \eta_{i}', \\ \eta_{i}, \eta_{i}, \eta_{i}', \\ \eta_{i}, \eta_{i}, \eta_{i}', \eta_{i}', \\ \eta_{i}, \eta_{i}', \eta_{i}', \eta_{i}', \\ \eta_{i}, \eta_{i}', \eta_{$	η^+	variable defined by (3.2.17)		species <i>i</i> in solvent extraction
$[\eta]; [\eta]_i; \eta_{iF}$ impurity ratio for region j (1.4.3a);exchange system (3.3.115)impurity ratio for i th species in region j $\kappa_{p_1}; \kappa_{p_1}^0$ protein partition coefficient in aqueous(1.6.4); defined by (1.4.4); intrinsictwo-phase extraction; proteinviscosity (3.3.90f); its value for polymerdistribution coefficient in the i (7.1.110f); current utilization factorabsence of a charge gradient at $(8.1.406)$ interface $\langle \eta_i \rangle; \langle \eta_i^2 \rangle$ first moment of $C_i(\eta_i, t_i^+)$ (3.2.26); κ_{salt}^m defined by (3.2.29)basis (4.1.340)	$\eta_i; \eta_j; \eta_{ij}; \eta'_j,$	variable (2.5.5), η for species <i>i</i> (3.2.25);	κ_{iR}	distribution coefficient of <i>i</i> in ion
impurity ratio for <i>i</i> th species in region j $\kappa_{p_1}; \kappa_{p_1}^{o}$ protein partition coefficient in aqueous(1.6.4); defined by (1.4.4); intrinsictwo-phase extraction; proteinviscosity (3.3.90f); its value for polymerdistribution coefficient in the i (7.1.110f); current utilization factorabsence of a charge gradient at(8.1.406)interface $\langle \eta_i \rangle; \langle \eta_i^2 \rangle$ first moment of $C_i(\eta_i, t_i^+)$ (3.2.26); κ_{salt}^m defined by (3.2.29)basis (4.1.340)	$[\eta]; [\eta]_i; \eta_{iF}$	impurity ratio for region j (1.4.3a);	0	exchange system (3.3.115)
$(1.6.4)$; defined by $(1.4.4)$; intrinsictwo-phase extraction; proteinviscosity $(3.3.90f)$; its value for polymerdistribution coefficient in the i $(7.1.110f)$; current utilization factorabsence of a charge gradient at $(8.1.406)$ interface $\langle \eta_i \rangle; \langle \eta_i^2 \rangle$ first moment of $C_i(\eta_i, t_i^+)$ $(3.2.26);$ κ_{salt}^m defined by $(3.2.29)$ basis $(4.1.340)$		impurity ratio for <i>i</i> th species in region j	$\kappa_{p_1}; \kappa_{p_1}^0$	protein partition coefficient in aqueous
viscosity (3.3.901); its value for polymerdistribution coefficient in the absence of a charge gradient at interface i (7.1.110f); current utilization factor (8.1.406)absence of a charge gradient at interface $\langle \eta_i \rangle; \langle \eta_i^2 \rangle$ first moment of $C_i(\eta_i, t_i^+)$ (3.2.26); κ_{salt}^m distribution coefficient of salt, molal basis (4.1.340)		(1.6.4); defined by (1.4.4); intrinsic		two-phase extraction; protein
$\langle \eta_i \rangle; \langle \eta_i^2 \rangle \qquad \begin{array}{ll} \text{first moment of } C_i(\eta_i, t_i^+) \text{ (3.2.26);} & \kappa_{\text{salt}}^m & \text{distribution coefficient of salt, molal} \\ \text{defined by (3.2.29)} & \text{basis (4.1.340)} \end{array}$		viscosity (3.3.901); its value for polymer i (7.1.110f); current utilization factor		absence of a charge gradient at
$\langle \eta_i \rangle; \langle \eta_i^2 \rangle$ first moment of $C_i(\eta_i, t_i^+)$ (3.2.26); κ_{salt}^m distribution coefficient of salt, molal basis (4.1.340)		(1.1.1.101), current utilization factor (8.1.406)		absence of a charge gradient at
defined by (3.2.29) basis (4.1.340)	$\langle n \rangle : \langle n^2 \rangle$	first moment of $C_i(n, t^+)$ (3.2.26).	κ^m	distribution coefficient of salt, molal
	<u> </u>	defined by (3.2.29)	san	basis (4.1.340)

λ	Debye length $(3.1.10b)$, mean free path of a gas molecule $(3.1.114)$ filter	$\pi;\pi$	constant (3.1416); osmotic pressure,
$m{\lambda}; \lambda_{x_2} \ \lambda_{z_i} \ \lambda_i; \lambda_+; \ \lambda; \lambda_i^o$	coefficient (7.2.187), parameter for a dialyzer (8.1.399), parameter for a distillation plate/stage (8.3.38), latent heat of vaporization/condensation molecular conformation coordinate (3.3.89c); electrode spacings (7.3.18);	$\pi_f; \pi_i; \pi_p, \pi_w$	osmotic pressure of feed solution; spreading pressure in adsorption of solute <i>i</i> from a solution (4.1.63a); osmotic pressures of permeate solution and the solution at the membrane wall, respectively
	retention parameter for species i (7.3.213), ionic equivalent conductance of ion i (3.1.108r); value	π_1, π_2	osmotic pressure of solution in regions 1 and 2
	of λ_i for a cation; value of λ_i for an anion; value of λ_i at infinite dilution (Table 3.A.8)	$\rho; \rho_b; \rho_c; \rho_e; \\ \rho_f; \rho_{fm}; \rho_i; \rho_{ij}$	fluid density; bulk density of the packed bed; density of continuous phase (also fluid density at critical
λ_1 , λ_2	defined by (5.4.100)		point); electric charge density per unit
Λ	equivalent conductance of a salt		volume; density of feed fluid; moles/
	(an electrolyte) (3.1.108s)		fluid volume; mass concentration of species i (also density of solute i
$\mu;\mu_0;\mu_{\rm dr}$	dynamic fluid viscosity; value of μ at		(3.3.90b)); value of ρ_i in region j (1.3.4)
	inlet; viscosity of drop fluid	$\rho_{\ell};\rho_{p};\rho_{pg};$	density of liquid (melt); mass density
μ_C, μ_D	dispersed phases respectively	$\rho_s; \rho_t; \rho_{tj}$	of particle material; particle mass
u^m_{max}	electroosmotic mobility (6.3.10c)		material: total density of fluid: total
$\mu_{i}, \mu_{i}^{0}, \mu_{i}^{m}$	species <i>i</i> chemical potential and its		mass density of mixture in region <i>i</i>
$\mu_{i,\text{eff}}^{m};\mu_{\text{ion, g}}^{m}$	standard state value; ionic mobility of		(1.3.5)
, i ch i long	ion <i>i</i> (3.1.108m); effective value of μ_i^m (6.3.8d,g); ionic mobility of ion in gas	$\rho_v; \rho_{i1}, \rho_{if}$	density of vapor phase; mass concentration of species <i>i</i> in
- 0	phase		crystallizer outlet solution and feed
$\mu_{ij}; \mu_{ijn}; \mu_{ij}^{ee}$	value of μ_i in region <i>j</i> ; value of μ_{ij} for		solution, respectively
	plate/stage <i>n</i> ; value of μ_{ij} in a system with electrical charge (3.3.27)	$ \rho_{i\ell}; \rho_{ip}; \rho_{p,r_p} $	mass density of species i in liquid (melt); mass density of crystals of
$\mu_{ij\mathrm{Pl}}$	value of μ_{ij} for a planar interface		species <i>i</i> ; mass density contribution of portiolog of give <i>x</i> to $x + dx$ (6.2.55)
$\mu_{i}(M) = \mu_{i}(M)$	(3.3.30) chemical potential of species of	0:0 0	particles of size r_p to $r_p + \alpha r_p$ (6.2.55) density of resin particle, reduced
$\mu_{\ell}(\mathcal{W}), \mu_{v}(\mathcal{W})$	molecular weight <i>M</i> in liquid and vapor phases, respectively, in	<i>PR</i> ; <i>P</i> 1; <i>P</i> 2	density of fluid (= ρ/ρ_c); density of liquids 1 and 2
	continuous chemical mixtures	$\rho_{dR};\rho_{pR}$	fluid resistivity; particle resistivity
$\mu_0^m, \mu_p^m, \mu_s^m; \mu_\infty$	magnetic permeabilities of vacuum, particle and solution, respectively;	$\rho_{\rm avg}; \rho_{\rm isat}$	average gas density $(6.1.5e)$; mass density of solute <i>i</i> in solution at
	chemical potential of a crystal	_ =	saturation
······································	linemetic sizes sites a stanial location	ρ_{ik}, ρ_{ik}	intrinsic phase average and phase
$v; v(z); v_0$	kinematic viscosity; v at axial location z : v at inlet	0	average, respectively, or ρ_{ik} (6.2.24a,b)
<i>D</i> .	z, v at finet stoichiometric coefficient for species i	$\rho_{ik, \text{avgi}}$	p_{ik} (0.2.24a) mass density of solute <i>i</i> in solution
01	in any chemical reaction	$ \mathcal{P}_i $	averaged over flow cross section
$v_{ m A}$, $v_{ m Y}$	moles of ions A and Y produced by		(6.2.16b)
	AV	σ	electrical conductivity of the solution
		-	(3.1.108q), particle sticking probability
ξ	extent of separation for a binary system	σ_i	standard deviation of any profile
	(1.4.16), (2.2.11), (6.3.105)		(3.2.21a,b), Lennard–Jones parameter,
$\xi_{12},\xi_{r_{p_1},r_{p_2}}$	extent of separation for components 1		ionic equivalent conductance
1 2	and 2 in particle classification (2.4.9), for particles of size r_{p_1} and r_{p_2} (2.4.6)		(3.1.108r), solute <i>i</i> reflection coefficient through membrane (6.3.157a,b)

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;		evt evt evt	e de l'extre
$\sigma_p; \sigma_v, \sigma_v^\iota; \sigma_x, \sigma_y$	steric factor for protein SMA model	$\phi_i^{\text{ext}};\phi_{i\alpha}^{\text{ext}},\phi_{i\beta}^{\text{ext}}$	value of ϕ or ϕ^{ext} for any species <i>i</i> ;
	(3.3.122d); specific volume based	a â asat	values of ϕ_i^{cx} in regions α and β
	deposit in inter $(7.2.172)$, $(7.2.189)$;	$\Phi; \Phi_{ig}; \Phi_i$	so efficient of species <i>i</i> in a mixture in
Gan' Ga	standard deviations (7.3.173) everage of σ_1 and σ_2 (3.1.91b).		coefficient of species <i>i</i> in a mixture in gas phase; value of $\hat{\sigma}_{i}$ for pure <i>i</i> at P^{sat}
o_{AB}, o_{ix}	standard deviations (7.3.12a)		at system temperature
$\sigma_i^+; \overline{\sigma}_m$	nondimensional standard deviation of	$\phi_i^{\text{tot}}; \phi_i^*; (\phi_i^*)$;	defined by $(3.2.4)$; defined by $(3.2.5b)$.
1	a profile (3.2.21a,b); average electrical	$\phi_i^+; (\phi_i^+)$	defined by $(3.2.6)$; defined by $(3.2.9)$
	conductivity of the ionic and electronic		and (6.3.14a)
	species in a mixed conducting	ϕ_{ti}^{ext}	$\sum \phi_i^{\text{ext}}$, summation over different
	membrane		external forces (3.2.4)
σ_{ti} , σ_{zi} ; σ^+_{zi} ; σ_{Vi}	standard deviation in the output		
	profile of species <i>i</i> in <i>t</i> -coordinate and	χ, χ_p, χ_s	volume suspectibility of fluid, particle
	z-coordinate, respectively (2.5.3),		and the solution
	(6.3.18c,b); nondimensionalized σ_{zi}	χ_{ij}, χ_{ip}	Flory interaction parameter between
	(6.3.16D); standard deviation in		species t and j and species t and
	volume now units (7.1.1020)		porymer
$\tau; \tau_m; \tau_w; \tau_{wc}$	tortuosity factor; value of τ for porous	W :W	molecular orientation coordinate
, <i>m</i> , <i>w</i> , <i>w</i>	membrane; wall shear stress (7.2.118);	1 /1	vector (3.3.89c); extent of facilitation of
	τ_w in cake region (7.2.136a)		flux (5.4.58) (5.4.59a), selectivity
$ au_{yx}$, $ au_{yz}$	components of tangential stress τ_y in		(7.2.92)
	x- and z -directions (6.1.24)	ψ_k	any property or characteristic of the
			<i>k</i> th phase
ϕ ; ϕ_{A} , ϕ_{B}	potential of any external force field	ψ_s, ψ_v	shape factor for particle surface and
	(also ϕ^{ext}), angle in spherical polar		volume (Example 2.4.1), $(2.4.2e)$
	coordinate system, ennancement		(3.4.26), $(6.4.15)$, $(6.4.19)$
	fraction profile in suspension	$\psi_{\rm As}$	electrical potential in the double layer
	houndary layer (7.2, 109): enhancement	Ψ_{el}	nhase average of w in the <i>k</i> th nhase
	factors for species A and B	\ <i>\k</i> /	$(6.2.25a) = \psi_{kaya}$
$\phi_c; \phi_D, \phi_s$	volume fraction of solids in cake;	$\langle \psi_k \rangle^k$	intrinsic phase average of ψ in the <i>k</i> th
, c. , D,, i 3	volume fraction of continuous,		phase (6.2.25b) = $\psi_{k,avgi}$
	dispersed phase (Table 3.1.7), (6.4.88);		-
	volume fraction of particles and solids	ω	angular velocity, solute permeation
	in a suspension		parameter (6.3.158b), sign of fixed
$\phi_j;\phi_m$	electrical potential of phase <i>j</i> ; defined		charge in (3.3.30b)
	in (7.1.107h)	0	
$\varphi_{i\ell}; \varphi_{im}; \varphi_m; \phi_m; \phi_m; \phi_m; \phi_m; \phi_m; \phi_m; \phi_m; \phi$	volume fraction of species i in liquid	$\Omega_{D,AB}$	quantity in diffusion coefficient
$\varphi_p, \varphi_{p\ell}$	membrane: polymer volume fraction		expression (3.1.510)
	in membrane: voltage drop over a		
	cell pair in electrodialysis; volume	Superscripts	
	fraction of polymer in liquid	<i>a</i> ; <i>b</i> ; Br	activity based; bottom/stripping
	phase		section of a column; Brownian motion
ϕ_N	correction factor for nonequimolar	d, drag	drag
	counterdiffusion (3.1.136b)	eff; eph; ext	effective; electrophoretic; external
ϕ_0	arbitrary value of centrifugal potential	ft; G	between the feed stream and the tails
	at $r = 0$ (3.1.6d)	1.6	stream; gas phase
ϕ_w	volume fraction of water in resin,	nf	between the heads stream and the feed
Å	particle volume fraction at wall	ht	stream he heads stream and the taile
φ_{\max}	instantaneous reaction maximum	111	stream
	narticle volume fraction	<i>i</i> : iner: int	species <i>i</i> : inertial: internal
		<i>.,</i> mor, m	species of mortal, merilar

L	liquid phase	in; ion	at inlet; ionic species
m	magnetic, mobility, based on molal	j	region/phase j , where $j = 1, 2, E, f, g, l$,
	quantities, maximum number		ℓ m, o, p, R, s, t, v, w, T, σ
Ν	related to Nernst-Plank equation	k (species k
_	(3.1.106)	<i>l</i> , liq; loc; <i>l</i> ; <i>l</i> ; <i>L</i>	liquid phase; local; adhering liquid
0, o	location $z = 0$, standard state, infinite		phase on crystal; low; at end of
	dilution, original quantity		separator of length L
00, OV	(7.1.101c), overall	<i>m</i> ; <i>mc</i> ; max; min	membrane phase; micellar; maximum;
p	pore, pure species		minimum
Р	mole fraction based in Henry's law	M	mixture, molecular weight based,
r	quantity in a system with recycle or		metallic species
	reflux, for the case of a chemical	ME, MR	Murphree based on extract phase,
	reaction		raffinate phase
S	related to solids only in solid-fluid	n, (n+1), (n-1)	stage number n , $(n + 1)$ and $(n - 1)$,
	separation, at saturation, scrubbing	N T	respectively
C		N; nu	metallic species; nucleation
S 1 T	solid phase	<i>o</i> ; obs; <i>og; ol</i> ; out	organic phase; observed; overall gas
<i>t</i> , 1	total value, top/enriching section of a		phase based; overall liquid phase
- 0	column, mermai amusion	w and D	based; at outlet
VC X S	vapor inquid mole fraction based leastion $z = \int dz = \int dz$	p; pa; P	dominant particle, ploquer interface
<i>x, 0</i>	infinite dilution condition	r: r r . D	radial direction: related to particles of
<i>i</i>	aquimolar counterdiffusion case first	r, r_{p_1}, r_{p_2}, π	size r or r ; ion exchange resin phase
	derivative feed side of membrane		size r_1 of r_2 , for exchange resimplicase,
//	permeate side of membrane	c	solvent surface integration step in
1	nondimensional quantity	3	crystallization surface adsorption site
*	hypothetical quantity		salt/eluent counterion strinning
	nypouletieur qualitity		suit/ ciucin counterion, suipping
			section stage number
		s ⁺ s ⁻ se	section, stage number forward and reverse surface reaction:
Subscripts		s ⁺ , s ⁻ ; se	section, stage number forward and reverse surface reaction; seed crystal
Subscripts atm; b	atmospheric; bulk phase value, bottom	s ⁺ , s ⁻ ; se S	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase
Subscripts atm; b	atmospheric; bulk phase value, bottom product stream from a column,	s ⁺ , s ⁻ ; se S t; tOE; tOR	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column;
Subscripts atm; b	atmospheric; bulk phase value, bottom product stream from a column, backward reaction	s ⁺ , s ⁻ ; se S t; tOE; tOR	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract
Subscripts atm; <i>b</i> A,B,C	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C	s ⁺ , s ⁻ ; se S t; tOE; tOR	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on
Subscripts atm; <i>b</i> A,B,C <i>c</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration,	s ⁺ , s ⁻ ; se S t; tOE; tOR	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase
Subscripts atm; <i>b</i> A,B,C <i>c</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity	s ⁺ , s ⁻ ; se S t; tOE; tOR tj	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a
Subscripts atm; b A,B,C c d	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation,	s ⁺ , s ⁻ ; se S t; tOE; tOR tj	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{1}, f_{2}$ for two feed
Subscripts atm; b A,B,C c d	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate	s ⁺ , s ⁻ ; se S t; tOE; tOR tj	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{1}, f_{2}$ for two feed streams entering separator, $j = 1, 2$ for
Subscripts atm; b A,B,C c d D	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species	s ⁺ , s ⁻ ; se S t; tOE; tOR tj	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{11}f_{22}$ for two feed streams entering separator, $j = 1,2$ for product streams rich in species 1 and
Subscripts atm; b A,B,C c d D	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase	s ⁺ , s ⁻ ; se S t; tOE; tOR tj	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{1}, f_{2}$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively
Subscripts atm; b A,B,C c d D e	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total
Subscripts atm; b A,B,C c d D e eff; ex; ext	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T ν;w	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1 f_2$ for two feed streams entering separator, $j = 1,2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous
Subscripts atm; b A,B,C c d D e eff; ex; ext f; fr	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> , <i>fr</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> , <i>fr</i> <i>g</i> ; <i>gr</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based,
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where <i>i</i> = 1, 2, 3, A, B, <i>M</i> , <i>s</i> ,	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> , <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where $i = 1, 2, 3, A, B, M, s$, phase interface, <i>i</i> th module/tube/stage	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y Y	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{11}f_2$ for two feed streams entering separator, $j = 1,2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction as in species AY
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where $i = 1, 2, 3, A, B, M, s$, phase interface, <i>i</i> th module/tube/stage <i>i</i> th species in <i>j</i> th stream, $j = f$ for a	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y Y z	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{11}f_2$ for two feed streams entering separator, $j = 1,2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction as in species AY coordinate direction
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i> <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where <i>i</i> = 1, 2, 3, A, B, <i>M</i> , <i>s</i> , phase interface, <i>i</i> th module/tube/stage <i>i</i> th species in <i>j</i> th stream, <i>j</i> = <i>f</i> for a single feed stream, <i>j</i> = <i>f</i> ₁ , <i>f</i> ₂ for two feed	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y Y z 1, 2	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction as in species AY coordinate direction species 1 and species 2, phase 1 and
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i> <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where <i>i</i> = 1, 2, 3, A, B, <i>M</i> , <i>s</i> , phase interface, <i>i</i> th module/tube/stage <i>i</i> th species in <i>j</i> th stream, <i>j</i> = <i>f</i> for a single feed stream, <i>j</i> = f_1, f_2 for two feed streams entering separator, <i>j</i> = 1,2 for	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y Y z 1, 2	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1 f_2$ for two feed streams entering separator, $j = 1,2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction as in species AY coordinate direction species 1 and species 2, phase 1 and phase 2
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i> <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where <i>i</i> = 1, 2, 3, A, B, <i>M</i> , <i>s</i> , phase interface, <i>i</i> th module/tube/stage <i>i</i> th species in <i>j</i> th stream, <i>j</i> = <i>f</i> for a single feed stream, <i>j</i> = f_1 , f_2 for two feed streams entering separator, <i>j</i> = 1,2 for product streams rich in species 1 and	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y Y z 1, 2 3, 4	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_1, f_2$ for two feed streams entering separator, $j = 1, 2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction as in species AY coordinate direction species 1 and species 2, phase 1 and phase 2 species 3 and species 4, phases 3 and 4
Subscripts atm; <i>b</i> A,B,C <i>c</i> <i>d</i> <i>D</i> <i>e</i> eff; ex; ext <i>f</i> ; <i>fr</i> <i>g</i> ; <i>gr</i> <i>H</i> ; hex <i>i</i> <i>i</i>	atmospheric; bulk phase value, bottom product stream from a column, backward reaction species A, B and C based on molar concentration, continuous phase, cake, critical quantity diffusive, dialysate phase, dissociation, distillate drag related, Henry's law species related, dispersed phase enriching section effective value; exit location; external feed side, feed based; during formation of drop, size based gas phase; growth based high; heat exchanger species <i>i</i> , where <i>i</i> = 1, 2, 3, A, B, <i>M</i> , <i>s</i> , phase interface, <i>i</i> th module/tube/stage <i>i</i> th species in <i>j</i> th stream, <i>j</i> = <i>f</i> for a single feed stream, <i>j</i> = f_1, f_2 for two feed streams entering separator, <i>j</i> = 1,2 for product streams rich in species 1 and species 2, respectively	s ⁺ , s ⁻ ; se S t; tOE; tOR tj true; T v;w x y Y z 1, 2 3, 4 α, β	section, stage number forward and reverse surface reaction; seed crystal location <i>S</i> , stationary phase total, top product stream in a column; transfer units (overall) based on extract phase; transfer units (overall) based on raffinate phase total quantity in <i>j</i> th stream, $j = f$ for a single feed stream, $j = f_{1},f_{2}$ for two feed streams entering separator, $j = 1,2$ for product streams rich in species 1 and 2, respectively true value; thermal diffusive, total vapor phase, volumetric; aqueous phase, water liquid mole fraction based, coordinate direction gas phase mole fraction based, coordinate direction as in species AY coordinate direction species 1 and species 2, phase 1 and phase 2 species 3 and species 4, phases 3 and 4 phase α and phase β

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Abbreviations and acronyms		HFCLM	hollow fiber contained liquid membrane
Å	angstrom	HGH	human growth hormone
AEM	anion exchange membrane	HGMS	high-gradient magnetic separation
atm	atmosphere	НК	heavy key
avg	average	HPCE	high-performance capillary
AVLIS	atomic vapor laser isotope separation		electrophoresis
BET	Brunauer-Emmet-Teller	HPLC	high-performance liquid
bar	10 ⁵ pascal	III DO	chromatography
barrer	unit for permeability coefficient of	HPTFF	high-performance tangential-flow
	gases through membrane,		filtration
	$cm^{3}(STD)$ cm	IEF	isoelectric focusing
	$1 \text{barrer} = 10^{-10} \frac{\text{cm}^2 (311)^2 \text{cm}^2}{\text{cm}^2 \circ \text{cm}^2 \text{cm}^2}$	ILM	immobilized liquid membrane
	cilis-ciling	IMAC	immobilized metal affinity
Btu	British thermal unit		chromatography
CAC	continuous annular chromatograph	ITM	ion transport membrane
CACE	counteracting chromatographic	ITP	isotachophoresis
GIUE	electronhoresis	LDF	linear driving force approximation
CCFP	countercurrent electrophoresis	LK	light key
CD(s)	cyclodextrin(s)	LLC	liquid-liquid chromatography
CDI	canacitive deionization	LM	logarithmic mean
CE	capillary electrophoresis	LRV	log reduction value
CEC	capillary electrochromatography	LSC	liquid-solid adsorption
CEDI	continuous electrodeionization		chromatography
CEM	cation exchange membrane	LTU	length of transfer unit
CED	computational fluid dynamics	mAB	monoclonal antibody
CFE	continuous free-flow electrophoresis	MBE	moving boundary electrophoresis
CGC	countercurrent gas centrifuge	ME	multiple effect
CHO	Chinese hamster ovary	MEKC	micellar electrokinetic
CHOPs	Chinese hamster ovary cell proteins		chromatography
cm Hg	pressure indicated in the height of a	MEUF	micellar enhanced ultrafiltration
ciii 11g	column of mercury	MSA	mass-separating agent
CMC	critical micelle concentration	MSC	molecular sieve carbon
CMS	carbon molecular sieve	MSF	multistage flash
CSC	continuous-surface chromatography	MSMPR	mixed suspension, mixed product
CSTR	continuous stirred tank reactor		removal
CSTS	continuous stirred tank separator	MTZ	mass-transfer zone
CV	control volume	NEA	nitrogen-enriched air
CZE	canillary zone electronhoresis	OEA	oxygen-enriched air
ED	electrodialysis	PAC	powdered activated carbon
ELM	emulsion liquid membrane	PBE	population balance equation
EOF	electroosmotic flow	PSA	pressure-swing adsorption
ESA	energy-separating agent	psia	pound force per square inch absolute
FACS	fluorescence-activated cell sorting	psig	pound force per square inch gauge
FFE	free-flow electrophoresis	RO	reverse osmosis
FFF	field-flow fractionation	SCF	supercritical fluid
FFM	free-flow magnetophoresis	SEC	size exclusion chromatography
GAC	granular activated carbon	SLM	supported liquid membrane
GLC	gas-liquid chromatography	SMA	steric mass action
GPC	gel permeation chromatography	SMB	simulated moving bed
HDPs	high-density particles	SPs	structured packings
HETP	height of an equivalent theoretical	TDS	total dissolved solids
	nlate	TFF	tangential-flow filtration
	Parto	TOC	total organic carbon