Scaling Analysis in Modeling Transport and Reaction Processes



A Systematic Approach to Model Building and the Art of Approximation

William B. Krantz

CONTENTS

	Preface Acknowledgments			
1	Introduction			
	1.1 1.2	Motivation for Using Scaling Analysis 1 Organization of the Book 5		
2	Systematic Method for Scaling Analysis			
	2.1 2.2 2.3 2.4 2.5	Introduction 7 Mathematical Basis for Scaling Analysis 7 Order-of-One Scaling Analysis 8 Scaling Alternative for Dimensional Analysis 13 Summary 18		
3	Applications in Fluid Dynamics			
		•		
4	Applications in Heat Transfer			
	4.1 4.2 4.3	Introduction 145 Steady-State Heat Transfer with End Effects 146 Film and Penetration Theory Approximations 153		

4.4	Small Biot Number Approximation 159	
4.5	Small Peclet Number Approximation 163	
4.6	Boundary-Layer or Large Peclet Number Approximation 167	
4.7	Heat Transfer with Phase Change 173	
4.8	Temperature-Dependent Physical Properties 180	
4.9		83
4.10		0.7
4.11	Summary 193	
4.E	Example Problems 196	
4.P	Practice Problems 224	
App	lications in Mass Transfer	252
5.1	Introduction 252	
5.2	Film Theory Approximation 253	
5.3	The state of the s	
5.4		
5.5	Small Peclet Number Approximation 261	
	Small Damköhler Number Approximation 266	
5.6	Large Peclet Number Approximation 269	
5.7	Quasi-Steady-State Approximation 273	
	Membrane Permeation with Nonconstant Diffusivity 277	
5.9	Solutally Driven Free Convection Due to Evapotranspiration 281	
	Dimensional Analysis for a Membrane-Lung Oxygenator 287	
	Summary 293	
5.E	Example Problems 297	
5.P	Practice Problems 336	
Appl	lications in Mass Transfer with Chemical Reaction	360
6.1	Introduction 360	
6.2	Concept of the Microscale Element 362	
6.3	Scaling the Microscale Element 364	
6.4	Slow Reaction Regime 371	
6.5	Intermediate Reaction Regime 371	
6.6	Fast Reaction Regime 372	
6.7	Instantaneous Reaction Regime 373	
6.8	Scaling the Macroscale Element 377	
6.9	Kinetic Domain of the Slow Reaction Regime 380	
6.10	Diffusional Domain of the Slow Reaction Regime 381	
6.12	Implications of Scaling Analysis for Reactor Design 381	
	Mass-Transfer Coefficients for Reacting Systems 387	
	Design of a Continuous Stirred Tank Reactor 390	
	Design of a Packed Column Absorber 394	
	Summary 397	
6.P	Practice Problems 399	

7 Ap	plicat	ions i	n Process Design	414
7.1 7.2 7.3 7.4 7.5 7.6 7.F	Pull Pull The Flu Sur	sed Si ermall id-Wa nmary	f a Membrane Lung Oxygenator 415 ingle-Bed Pressure-Swing Adsorption 424 y Induced Phase-Separation Process 438 II Aerosol Flow Reactor for Hydrogen Production 448	
Append	lix A	Sign	Convention for the Force on a Fluid Particle	480
Append	lix B	Gen	eralized Form of the Transport Equations	482
		B.1 B.2 B.3 B.4 B.5	Continuity Equation 482 Equations of Motion 482 Equations of Motion for Porous Media 483 Thermal Energy Equation 483 Equation of Continuity for a Binary Mixture 484	
Appendix C		Con	tinuity Equation	486
			Rectangular Coordinates 486 Cylindrical Coordinates 487 Spherical Coordinates 487	
Appendix D		Equ	ations of Motion	489
		D.1 D.2 D.3	Rectangular Coordinates 489 Cylindrical Coordinates 490 Spherical Coordinates 492	
Append	lix E	Equ	ations of Motion for Porous Media	494
		E.1 E.2 E.3	Rectangular Coordinates 494 Cylindrical Coordinates 494 Spherical Coordinates 495	
Appendix F		Thermal Energy Equation		496
		F.1 F.2 F.3	Rectangular Coordinates 496 Cylindrical Coordinates 497 Spherical Coordinates 497	
Append	lix G	Equ	ation of Continuity for a Binary Mixture	499
		G.1	Rectangular Coordinates 499	

	G.2 Cylindrical Coordinates 500G.3 Spherical Coordinates 502		
Appendix H	Integral Relationships		
	 H.1 Leibnitz Formula for Differentiating an Integral 504 H.2 Gauss Ostrogradskii Divergence Theorem 504 		
Notation		506	
Index		515	