

H. SCOTT FOGLER

**ELEMENTS
of CHEMICAL
REACTION ENGINEERING**

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OF CHEMICAL
REACTION
ENGINEERING**

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Preface

The man who has ceased to learn ought not to be allowed to wander around loose in these dangerous days.

M. M. Coady

This book is intended for use as both an undergraduate- and graduate-level text in *chemical reaction engineering*. The level of difficulty will depend on the choice of chapters to be covered and the type and degree of difficulty of problems assigned from those at the end of each chapter. Most problems requiring significant numerical computations can be solved with a personal computer which has at least BASIC as a programming language.

The thrust of this book is to present in a clear and concise manner the fundamentals of chemical reaction engineering. First, a structure is developed that allows the reader to solve reaction engineering problems through reasoning rather than through memorization and recall of numerous equations and the restrictions and conditions under which each equation applies. In perhaps no other area of engineering is mere formula plugging more hazardous; the number of physical situations in reaction engineering that can arise appears infinite, and the chances of a simple formula being sufficient for the adequate design of a real reactor are vanishingly small. However, the algorithms presented in the text for reactor design provide a framework with which one can develop confidence through reasoning rather than memorization.

Due to the rapid addition of new information and scientific principles, a true engineer must constantly expand his or her horizons beyond simple gathering of information and engineering principles. Thus the second goal of this book is to

increase the student's lifelong learning skills by presenting heuristics and problems that encourage the student to practice certain intellectual skills. To accomplish this, we use (1) conventional problems that reinforce the student's understanding of the basic concepts and principles (included at the end of each chapter); (2) problems whose solution requires reading the literature, handbooks, or other textbooks on chemical engineering kinetics; and (3) problems that give students practice in problem definition and alternative pathways to solutions.

Another important skill fostered in this text is a critical analysis of journal articles. For the last ten years students in the graduate reactor engineering class at the University of Michigan have been required to carry out an in-depth critique of a journal article on chemical engineering kinetics. Although the students were told that choosing an article with erroneous data or reasoning was not necessary for a successful critique, it was stated that finding an error made the whole assignment much more fun. Consequently, a select number of problems at the end of chapters involve the critique of journal articles on reactor engineering which may or may not have major or minor inconsistencies. In some cases a small hint is given to guide the student in his or her analysis.

Many of the problems at the end of the various chapters were selected from those which have appeared in California Board of Registration for Civil and Professional Engineers—Chemical Engineering Examinations (PECEE) over past years. The permission for use of these problems, which, incidentally, may be obtained from the Documents Section, California Board of Registration for Civil and Professional Engineers—Chemical Engineering, 1004 6th Street, Sacramento, CA 95814, is gratefully acknowledged. (*Note:* These problems have been copyrighted by the California Board of Registration and many not be reproduced without their permission.) Additional problems are available on diskettes for use with the personal computer. Information about these interactive programs may be obtained from the author.

The strategy behind the presentation of material is the application, modification, or extrapolation of several basic ideas in chemical reaction engineering to solve a wide variety of problems. These ideas are referred to as the *Pillars of Chemical Reaction Engineering*, on which different applications rest. The pillars holding up the application of chemical reaction engineering are shown in Figure P-1.

The architecture and construction of the structure shown in Figure P-1 had many participants, most notably Professors Amundson, Aris, Smith, Levenspiel, and Denbigh. The contents of this book may be studied in virtually any order after the first four chapters, with few restrictions. A flow diagram showing possible paths is shown in Figure P-2.

In a three-hour undergraduate course at the University of Michigan approximately eight chapters are covered in the following order: Chapters 1, 2, 3, 4, Sections 5.1–5.3, 6.1–6.5, and Chapters 8, 10, 11, and parts of 13.

The reader will observe that although metric units are used primarily in this text (e.g., kmol/m³, J/mol), a variety of other units are also employed (e.g., lb/ft³).

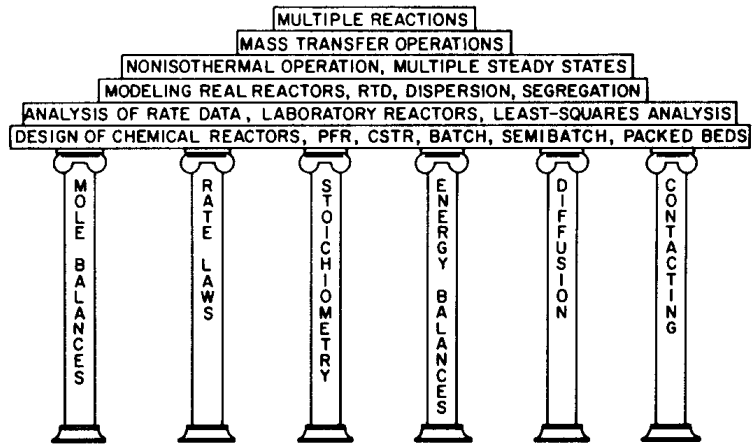


Figure P-1

This is intentional. It is our feeling that whereas most papers published in the future will use the metric system, today's engineers as well as those graduating over the next ten years will be caught in the transition between English, SI, and metric units. As a result, engineers will be faced with extracting information and reaction rate data from older literature which uses English units, as well as the current literature using metric, and should be equally at ease with both. However, all intensive laws tend often to have exceptions. Very interesting concepts take

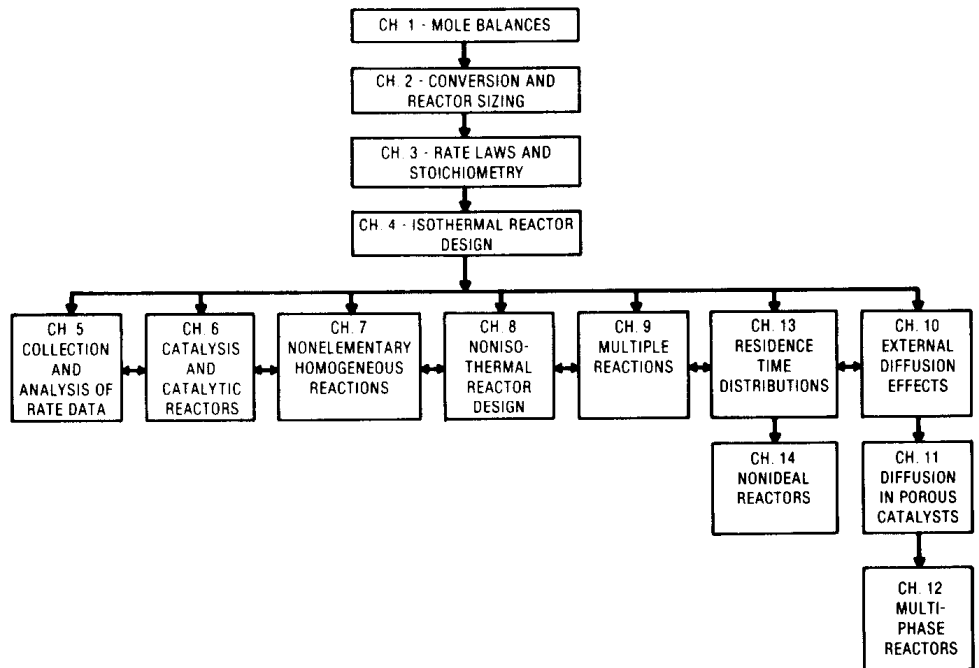


Figure P-2

orderly, responsible statements. Virtually all laws instinctively are normal thoughts. General observations become laws under experimentation.

The notes in the margins are meant to serve two purposes. One is to act as a guide or commentary as one reads through the material. Second, they identify key equations and relationships that are used to solve chemical reaction engineering problems.

Approximately three years after my first book, *The Elements of Chemical Kinetics and Reactor Calculations*, was published, I decided to revise and expand the programmed learning approach of the text. I asked Professor Lee Brown, whose research interests are kinetics and catalysis, to join me in rewriting the book, as he had used my programmed text in his course. I had always been impressed with the penetrating problems posed by Lee, which could not be solved by mere formula plugging. Dr. Brown later left the academic life for industry, and his limited time prevented him from participating to the extent that we originally expected. However, Dr. Brown collaborated in Chapters 13 and 14 (which are of joint authorship), provided material for Chapters 3, 6, and 8, and gave a critical reading of the entire book.

There are so many colleagues and students who contributed to this book that it would require another chapter to thank them all in an appropriate manner. Unfortunately, since Prentice-Hall has already requested a page reduction, this is not possible. However, certain people cannot go unacknowledged. The first is Neal Amundson, "The Chief," who I am sure is unaware of the various ways in which he has touched the author's career. Three of my colleagues at Michigan have, at different times and in different ways, been very important to the author personally and professionally. This book is dedicated to them: Guiseppe Parravano, Joe Martin, and Don Katz. I am also indebted to Max Peters and Octave Levenspiel, who first spawned my interest in chemical reaction engineering; Klaus Timmerhaus, who provided early guidance and a model to follow; Rane Curl, Uzi Mann, Erdogan Gulari, and Johannes Schwank, for their many insights and stimulating discussions; and certainly to Lee Brown for his friendship, penetrating questions, and artful presentation of material. Two other colleagues, Bob Kabel at Penn State and R. S. Shankar at I.I.T. Bombay, provided not only comments on the prepublication manuscript but also problems found at the ends of some chapters. To my colleagues in the department, thank you for your support and confidence, and for generating an atmosphere that spawns creativity and scholarship in teaching and research. J. S. Schultz was instrumental in helping to create such an atmosphere. A number of graduate and undergraduate students also contributed to the material in the book, primarily Abhaya Datye, T. Y. Hsieh, and Steve Le Blanc. Tim Nolan, Herb Alvord, Don DiMassi, Sunil Rege, and Greg McCabe helped proofread the final draft manuscript. Bruce Pynnonen was instrumental in helping to proofread the galley proof, and Tia Badalamente was invaluable in proofreading the page proofs. I would also like to thank Barbara Zeiders and her staff at Service to Publishers for their patient and outstanding job in taking the final manuscript through the final page proofs.

My wife Janet, family Peter, Robert, and Kristin, and parents, Ralph and Anne, contributed greatly to the support necessary to complete a task such as this. Many people contributed to typing portions of the original manuscript, including, in the early stages, Diana Delonnay and Jill Taber. However, this book would never have been completed were it not for Susan Montgomery, an alumna of my undergraduate chemical reaction course. Susan typed, retyped, edited, pasted, proofread, and commented on the entire book many times in addition to handling the many details associated with putting the manuscript in final form.

H.S.F.

Ann Arbor
February 1986

Contents

PREFACE	xvii
CHAPTER 1: MOLE BALANCES	1
1.1 DEFINITION OF THE RATE OF REACTION, $-r_A$	2
1.2 THE GENERAL MOLE BALANCE EQUATION	6
1.3 BATCH REACTORS	8
1.4 CONTINUOUS-FLOW REACTORS	10
1.4.1 Continuous-Stirred Tank Reactor	10
1.4.2 Tubular Reactor	11
1.5 INDUSTRIAL REACTORS	15
SUMMARY	19
QUESTIONS AND PROBLEMS	20
SOME THOUGHTS ON PROBLEM SOLVING	23
SUPPLEMENTARY READING	27
CHAPTER 2: CONVERSION AND REACTOR SIZING	28
2.1 DEFINITION OF CONVERSION	28
2.2 DESIGN EQUATIONS	29
2.2.1 Batch Systems	29
2.2.2 Flow Systems	31

2.3	APPLICATIONS OF THE DESIGN EQUATIONS	33
2.4	REACTORS IN SERIES	37
2.5	SOME FURTHER DEFINITIONS	47
	SUMMARY	49
	QUESTIONS AND PROBLEMS	51
	SOME THOUGHTS ON PROBLEM SOLVING	56
	SUPPLEMENTARY READING	57
CHAPTER 3: RATE LAWS AND STOICHIOMETRY		59
3.1	BASIC DEFINITIONS	59
3.1.1	The Reaction Rate Constant	60
3.1.2	The Reaction Order	63
3.1.3	Elementary Reactions and Molecularity	65
3.1.4	Reversible Reactions	67
3.1.5	Nonelementary Reactions	68
3.2	PRESENT STATUS OF OUR APPROACH TO REACTOR SIZING AND DESIGN	69
3.3	STOICHIOMETRIC TABLE	70
3.3.1	Batch Systems	71
3.3.2	Constant-Volume Reaction Systems	73
3.3.3	Flow Systems	76
3.3.4	Volume Change with Reaction	77
3.4	REACTIONS WITH PHASE CHANGE	86
	SUMMARY	89
	QUESTIONS AND PROBLEMS	92
	SOME THOUGHTS ON PROBLEM SOLVING	99
	SUPPLEMENTARY READING	103
CHAPTER 4: ISOTHERMAL REACTOR DESIGN		105
4.1	DESIGN STRUCTURE FOR ISOTHERMAL REACTORS	106
4.2	SCALE-UP OF LIQUID-PHASE BATCH REACTOR DATA TO THE DESIGN OF A CSTR	106
4.2.1	Batch Operation	108
4.2.2	Design of CSTRs	112
4.3	TUBULAR FLOW REACTORS	121
4.4	PRESSURE DROP IN REACTORS	126
4.4.1	Flow through a Packed Bed	126
4.4.2	Pressure Drop and the Rate Law	130
4.4.3	Pressure Drop in Pipes	135

Contents	ix
4.5 REVERSIBLE REACTIONS	136
4.5.1 Role of Nitric Oxide in Smog Formation	138
4.6 UNSTEADY-STATE OPERATION OF REACTORS	142
4.6.1 Startup of a CSTR	143
4.6.2 Semibatch Reactors	144
4.6.3 Reactive Distillation	152
4.7 RECYCLE REACTORS	154
SUMMARY	158
QUESTIONS AND PROBLEMS	159
SOME THOUGHTS ON PROBLEM SOLVING	175
SUPPLEMENTARY READING	178
 CHAPTER 5: COLLECTION AND ANALYSIS OF RATE DATA	 179
5.1 BATCH REACTOR DATA	180
5.1.1 Differential Method of Rate Analysis	180
5.1.2 Gas-Phase Reactions with Total Pressure as the Measured Variable	182
5.1.3 Integral Method	189
5.2 METHOD OF INITIAL RATES	195
5.3 METHOD OF HALF-LIVES	197
5.4 LEAST-SQUARES ANALYSIS	199
5.4.1 Linearization of the Rate Law	199
5.4.2 Nonlinear Analysis	200
5.4.3 Weighted Least-Squares Analysis	201
5.5 DIFFERENTIAL REACTORS	203
5.6 EVALUATION OF LABORATORY REACTORS	206
5.6.1 Integral (Fixed-bed) Reactor	206
5.6.2 Stirred Batch Reactor	207
5.6.3 Stirred Contained Solids Reactor (SCSR)	208
5.6.4 Continuous-Stirred Tank Reactor (CSTR)	208
5.6.5 Straight-through Transport Reactor	209
5.6.6 Recirculating Transport Reactor	210
5.6.7 Summary of Reactor Ratings	211
5.7 EXPERIMENTAL DESIGN	211
5.7.1 Finding the Rate Law	211
5.7.2 Experimental Planning	213
SUMMARY	216
QUESTIONS AND PROBLEMS	218
SOME THOUGHTS ON PROBLEM SOLVING	225
SUPPLEMENTARY READING	229

CHAPTER 6: CATALYSIS AND CATALYTIC REACTORS	231
6.1 CATALYSTS	231
6.1.1 Definitions	231
6.1.2 Catalyst Properties	233
6.2 STEPS IN A CATALYTIC REACTION	235
6.2.1 Adsorption Isotherms	238
6.2.2 Surface Reaction	244
6.2.3 Desorption	245
6.2.4 The Rate-Limiting Step	245
6.3 SYNTHESIZING A RATE LAW, MECHANISM, AND RATE-LIMITING STEP	246
6.3.1 Is the Adsorption of Cumene Rate Limiting?	249
6.3.2 Is the Surface Reaction Rate Limiting?	253
6.3.3 Is the Desorption of Benzene Rate Limiting?	254
6.3.4 Summary of the Cumene Decomposition	255
6.4 DESIGN OF REACTORS FOR GAS-SOLID REACTIONS	258
6.4.1 Basic Guidelines	258
6.4.2 The Design Equation	258
6.5 HETEROGENEOUS DATA ANALYSIS FOR REACTOR DESIGN	261
6.5.1 Deducing a Rate Law from the Experimental Data	262
6.5.2 Finding a Mechanism Consistent with Experimental Observations	264
6.5.3 Evaluation of the Rate-Law Parameters	265
6.5.4 Reactor Design	268
6.6 CATALYST DEACTIVATION	273
6.6.1 Deactivation by Sintering or Aging	274
6.6.2 Deactivation by Coking or Fouling	276
6.6.3 Deactivation by Poisoning	276
6.6.4 Temperature-Time Trajectories	280
6.6.5 Effect of Deactivation on Selectivity	282
6.6.6 Determining the Order of Deactivation	284
6.7 MOVING-BED REACTORS	288
SUMMARY	294
QUESTIONS AND PROBLEMS	296
SOME THOUGHTS ON PROBLEM SOLVING	310
SUPPLEMENTARY READING	314
CHAPTER 7: NONELEMENTARY HOMOGENEOUS REACTIONS	316
7.1 FUNDAMENTALS	317
7.1.1 Active Intermediates	317
7.1.2 Pseudo-Steady-State Hypothesis (PSSH)	319

Contents	xi
7.2 SEARCHING FOR A MECHANISM	320
7.2.1 General Considerations	321
7.2.2 Hydrogen Bromide Reaction	324
7.3 ENZYMATIC REACTION FUNDAMENTALS	328
7.3.1 Definitions and Mechanisms	328
7.3.2 Michaelis-Menten Equation	331
7.3.3 Batch Reactor Calculations	334
SUMMARY	336
QUESTIONS AND PROBLEMS	337
SOME THOUGHTS ON PROBLEM SOLVING	345
SUPPLEMENTARY READING	348
CHAPTER 8: NONISOTHERMAL REACTOR DESIGN	349
8.1 RATIONALE	349
8.2 THE ENERGY BALANCE	351
8.2.1 First Law of Thermodynamics	351
8.2.2 Evaluating the Work Term	352
8.2.3 Dissecting the Molar Flow Rates to Obtain the Heat of Reaction	353
8.2.4 Dissecting the Enthalpies	355
8.2.5 Relating $\Delta H_R(T)$, $\Delta H_R(T_R)$, and ΔC_p	356
8.2.6 Constant or Mean Heat Capacities	358
8.2.7 Variable Heat Capacities	358
8.2.8 Heat Added to the Reactor, \dot{Q}	361
8.3 NONISOTHERMAL CONTINUOUS-FLOW REACTORS AT STEADY STATE	362
8.3.1 Application to the CSTR	363
8.3.2 Adiabatic Tubular Flow Reactor	372
8.3.3 Steady-State Tubular Flow Reactor with Heat Exchange	379
8.4 EQUILIBRIUM CONVERSION	383
8.4.1 Adiabatic Temperature and Equilibrium Conversion	384
8.4.2 Optimum Feed Temperature	387
8.5 UNSTEADY-STATE OPERATION	388
8.5.1 The General Equation	389
8.5.2 Unsteady Operation of Plug-Flow Reactors	390
8.5.3 Unsteady CSTR Operation	392
8.5.4 Batch Reactors	393

8.6	NONADIABATIC REACTOR OPERATION: OXIDATION OF SULFUR DIOXIDE EXAMPLE	397
8.6.1	Manufacture of Sulfuric Acid	397
8.6.2	Catalyst Quantities	401
8.6.3	Reactor Configuration	401
8.6.4	Operating Conditions	402
8.7	MULTIPLE STEADY STATES	412
8.7.1	Heat-Removed Term, $R(T)$	413
8.7.2	Heat of Generation, $G(T)$	413
8.7.3	Ignition-Extinction Curve	415
8.7.4	Steady-State Bifurcation Analysis	419
	SUMMARY	425
	QUESTIONS AND PROBLEMS	426
	SOME THOUGHTS ON PROBLEM SOLVING	445
	SUPPLEMENTARY READING	450
	 CHAPTER 9: MULTIPLE REACTIONS	 452
9.1	CONDITIONS FOR MAXIMIZING THE DESIRED PRODUCT IN PARALLEL REACTIONS	454
9.1.1	Maximizing S for One Reactant	455
9.1.2	Maximizing S for Two Reactants	457
9.2	MAXIMIZING THE DESIRED PRODUCT IN SERIES REACTIONS	461
9.3	STOICHIOMETRIC TABLE FOR MULTIPLE REACTIONS	465
9.4	HYDRODEALKYLATION OF MESITYLENE	471
9.4.1	Description of the Reacting System	471
9.4.2	Optimization of Xylene Production in a Packed-Bed Reactor	475
9.5	NONISOTHERMAL CHEMICAL REACTIONS	479
9.6	WHAT IF THE PROCEDURE IN TABLE 9-2 CAN'T BE APPLIED?	481
	SUMMARY	491
	QUESTIONS AND PROBLEMS	494
	SUPPLEMENTARY READING	508
	 CHAPTER 10: EXTERNAL DIFFUSION EFFECTS IN HETEROGENEOUS REACTIONS	 509
10.1	MASS-TRANSFER FUNDAMENTALS	510
10.1.1	Definitions	510
10.1.2	Molar Flux	511
10.1.3	Fick's First Law	513

Contents	xiii
10.2 BINARY DIFFUSION	514
10.2.1 Evaluating the Molar Flux	517
10.2.2 Boundary Conditions	517
10.2.3 Modeling Diffusion without Reaction	523
10.2.4 Temperature and Pressure Dependence of D_{AB}	523
10.2.5 Modeling Diffusion with Chemical Reaction	523
10.3 EXTERNAL RESISTANCE TO MASS TRANSFER	524
10.3.1 Mass-Transfer Coefficient	525
10.3.2 Mass Transfer to a Single Particle	528
10.3.3 Mass-Transfer-Limited Reactions in Packed Beds	532
10.3.4 Mass-Transfer-Limited Reaction on Surfaces of Metals	539
10.4 WHAT IF . . . ? (PARAMETER SENSITIVITY)	544
SUMMARY	549
QUESTIONS AND PROBLEMS	550
SOME THOUGHTS ON PROBLEM SOLVING	558
SUPPLEMENTARY READING	559
 CHAPTER 11: DIFFUSION AND REACTION IN POROUS CATALYSTS	 560
11.1 DIFFUSION AND REACTION IN SPHERICAL CATALYST PELLETS	561
11.1.1 Effective Diffusivity	561
11.1.2 Derivation of the Differential Equation Describing Diffusion and Reaction	562
11.1.3 Writing the Equation in Dimensionless Form	565
11.1.4 Solution to the Differential Equation for a First-Order Reaction	567
11.2 INTERNAL EFFECTIVENESS FACTOR	569
11.3 FALSIFIED KINETICS	572
11.4 OVERALL EFFECTIVENESS FACTOR	574
11.5 ESTIMATION OF DIFFUSION- AND REACTION-LIMITED REGIMES	577
11.5.1 Wiesz-Prater Criterion for Internal Diffusion	577
11.5.2 Mears' Criterion for External Diffusion	579
11.6 MASS TRANSFER AND REACTION IN A PACKED BED	580
11.7 DETERMINATION OF LIMITING SITUATIONS FROM REACTION DATA	586
SUMMARY	587
QUESTIONS AND PROBLEMS	588
SUPPLEMENTARY READING	595

CHAPTER 12: MULTIPHASE REACTORS	596
12.1 SLURRY REACTORS	597
12.1.1 Rate of Gas Absorption	599
12.1.2 Transport to Catalyst	599
12.1.3 Diffusion and Reaction in the Catalyst Pellet	600
12.1.4 The Rate Law	600
12.1.5 Determining the Limiting Step	600
12.1.6 Slurry Reactor Design	609
12.2 TRICKLE BED REACTORS	610
12.2.1 Fundamentals	611
12.2.2 Limiting Situations	614
12.2.3 Evaluating the Transport Coefficients	614
SUMMARY	622
QUESTIONS AND PROBLEMS	622
SUPPLEMENTARY READING	627
CHAPTER 13: DISTRIBUTIONS OF RESIDENCE TIMES FOR CHEMICAL REACTORS	629
13.1 GENERAL CHARACTERISTICS	629
13.1.1 Residence-Time Distribution Function	632
13.2 MEASUREMENT OF THE RESIDENCE-TIME DISTRIBUTION	633
13.2.1 Pulse Input	633
13.2.2 Positive-Step Tracer Experiment	638
13.2.3 Negative-Step Tracer Experiment	639
13.3 CHARACTERISTICS OF THE RTD	640
13.3.1 Integral Relationships	640
13.3.2 Mean Residence Time	642
13.3.3 Other Moments of the RTD	644
13.3.5 Normalized RTD Function $E(\theta)$	647
13.3.5 Internal-Age Distribution $I(t)$	647
13.3.6 RTDs and Chemical Reaction Rates	650
13.4 THE RTD IN IDEAL REACTORS	651
13.4.1 RTDs in Batch and Plug-Flow Reactors	651
13.4.2 Single CSTR RTD	651
13.4.3 The RTD in CSTRs in Series	653
13.4.4 Plug Flow-CSTR Series RTD	656
13.4.5 Laminar Flow Reactor	659

Contents	xv
13.5 RTDs IN REAL REACTOR SYSTEMS	661
13.5.1 Tubular Reactor RTDs	661
13.5.2 RTDs in a Continuous-Stirred Tank	665
13.5.3 Tests on Some Fluidized Beds	666
13.6 REACTOR MODELING WITH THE RTD	668
13.7 MICROMIXING: THE SEGREGATION MODEL	669
13.7.1 Segregation Model	669
13.7.2 Analysis of Reactors with Completely Segregated Mixing	670
SUMMARY	673
QUESTIONS AND PROBLEMS	674
SUPPLEMENTARY READING	679
CHAPTER 14: ANALYSIS OF NONIDEAL REACTORS	680
14.1 THE BASIC IDEA	680
14.1.1 Mathematical Tractability	681
14.1.2 Physical Realism	681
14.1.3 The Model Must Have at Most Two Parameters	681
14.2 MODELING REAL REACTORS WITH COMBINATIONS OF IDEAL REACTORS	682
14.2.1 Real CSTR Modeled with an Exchange Volume	682
14.2.2 Real CSTR Modeled Using Bypassing and Dead Space	685
14.3 TESTING A MODEL AND DETERMINING ITS PARAMETERS	686
14.3.1 Two CSTRs with Interchange	687
14.3.2 Tracer Use to Determine Parameters in CSTR-with-Deadspace-and-Bypass Model	692
14.4 MODELS OF TANK REACTORS	696
14.5 MODELS OF TUBULAR REACTORS	697
14.5.1 Nonideality in Tubular Reactors	697
14.5.2 Dispersion Model	697
14.6 MAXIMUM MIXEDNESS	707
14.7 USING THE RTD VERSUS THE NEED FOR A MODEL	712
SUMMARY	712
QUESTIONS AND PROBLEMS	714
SUPPLEMENTARY READING	719