

# Contents

	<i>Preface</i>	<i>xi</i>
1	<i>Introduction</i>	<i>1</i>
2	<i>Types of Process Models</i>	<i>6</i>
	2.1 Basic Classifications of Mathematical Models	10
	2.2 Fundamental Features of Models	10
	2.3 Ordinary Differential Equations	14
	2.4 Difference Equations	20
	2.5 Differential-Difference Equations	25
	2.6 Partial Differential Equations	26
	2.7 Integral Equations	29
	2.8 Integro-Differential Equations	36
	2.9 Summary	37
3	<i>The Laplace Transform</i>	<i>46</i>
	3.1 General Development	46
	3.2 Input and Transfer Functions	70
	3.3 Relationship of the Laplace Transform to the State Space Representation	88
	3.4 Discrete System Equations and the z-Transform	92
	3.5 Numerical Inversion Methods	104
	3.6 Examples of Applications of the Laplace Transform	115

<b>4</b>	<b><i>Elements of Probability Theory</i></b>	<b>149</b>
4.1	The Concept of a Random Variable	150
4.2	Joint Distributions	154
4.3	Conditional Probabilities	158
4.4	Properties of Random Variables	160
4.5	Generating and Characteristic Functions	167
4.6	Common Probability Distributions	175
4.7	Transformations of Random Variables	184
4.8	The Central Limit Theorem	187
<b>5</b>	<b><i>Stochastic Mathematical Models</i></b>	<b>197</b>
5.1	Discrete State, Discrete Time Stochastic Processes	201
5.2	Discrete State, Continuous Time Stochastic Processes	213
5.3	Continuous State Stochastic Processes	225
5.4	Characterization of Stochastic Processes	237
5.5	Mathematical Modeling of Stochastic Dynamic Systems	263
5.6	Deterministic vs. Stochastic Models	280
<b>6</b>	<b><i>Residence Time Distribution Theory</i></b>	<b>289</b>
6.1	Fundamental Definitions	290
6.2	Residence Time Distribution Studies	294
6.3	Typical Deterministic Flow System Models	297
6.4	Moments of Deterministic Residence Time Distribution Models	309
6.5	Stochastic Flow System Models	312
6.6	Staged Models with Internal Backmixing	315
6.7	Moments of the Backflow Cell Model and Comparison to Continuous Models for Systems with Axial Mixing	320
6.8	Stochastic Mixing Models for Chemical Reactors	326

<b>7</b>	<b><i>Parameter Estimation</i></b>	<b>339</b>
7.1	Model Forms for Parameter Estimation	342
7.2	Parameter Estimation Using Moments	359
7.3	Parameter Estimation Using Transfer Functions with Deterministic Inputs	373
7.4	Parameter Estimation Using Transfer Functions with Stochastic Inputs	378
7.5	Algorithms for Parameter Estimation in Algebraic Models	382
7.6	Algorithms for Parameter Estimation in Ordinary Differential Equations	386
7.7	Algorithms for Parameter Estimation in Partial Differential Equations	401
<b>8</b>	<b><i>Design of Experiments for Parameter Estimation</i></b>	<b>419</b>
8.1	Accuracy of Parameter Estimates	420
8.2	Design of Experiments for Parameter Estimation	430
8.3	Design of Experiments for Model Discrimination	446
<b>9</b>	<b><i>Process Identification: Linear Systems</i></b>	<b>454</b>
9.1	Further Linear Theory	455
9.2	Controllability, Observability, and Minimum Realizations	458
9.3	The Algorithm of Ho and Kalman	471
9.4	Exact Linear System Realizations	476
9.5	Suboptimal Realizations	485
9.6	Minimum Partial Realizations	486
9.7	Comparison with Other Identification Methods	493
9.8	Nonlinear System Modeling	499
9.9	The Adsorption Column with Axial Diffusion	500

<b>10</b>	<i>Process Identification : Nonlinear Systems</i>	<i>505</i>
10.1	The Wiener Identification Theory	506
10.2	Use of Two-Level Inputs	516
10.3	Identification via a Finite Volterra Series	527
10.4	Slurry Flow in an Ore-Crushing Rod Mill	532
10.5	Summary	534
	<i>Index</i>	<i>539</i>