CONTENTS

Preface ix
Nomenclature xiii

1 Thermal Energy Storage

.1 Introduction 1
1.1.1 Utilization of Energy Storage Devices 2
1.1.2 Specific Areas of Applications of Energy Storage 2
.2 Selection of the Type of Energy to Be Stored
3 Thermal Energy Storage Units
References 9

2 Single-Blow Operating Mode: Infinite Fluid Heat Capacity and Simplified Models 10

2.1 Introduction 10
2.2 Infinite Fluid Heat Capacity
2.2.1 Negligible Temperature Gradients in the Storage Material
2.2.2 Internal Temperature Gradients in Storage Material 13
2.3 Simplified Model 17
2.4 Simplified Model Employing a Modified Heat Transfer Coefficient 27
References 29

3 Single-Blow Operating Mode: Finite Conductivity Model 30

3.1 Introduction 30
3.2 Finite Conductivity Model: Slab Configuration 31
3.3 Finite Conductivity Model: Hollow Cylinder 51
3.4 Comparison of Results for Finite Conductivity Models of Hollow Cylindrical and Slab Configurations 74
3.5 Analysis of the Effects of Finite Thermal Conductivity 75
References 83

4	**Prediction of Transient Response of Heat Storage Units with Timewise Variations in Inlet Fluid Temperature and Mass Flow Rate**	**85**
4.1	Introduction	85
4.2	Superposition: Timewise Variations in Inlet Fluid Temperature	86
4.3	Superposition: Arbitrary Initial Temperature Distribution in the Storage Material	93
4.4	Superposition: Arbitrary Variation in Fluid Mass Flow Rate	97
	References	104
5	**Basic Concepts in Counterflow Regenerators**	**105**
5.1	Introduction	105
5.2	Mathematical Model	110
5.3	Discussion of Design Parameters	113
5.4	Effect of Cycle Time on Regenerator Performance	116
5.5	Imbalance in Regenerator Performance	118
5.6	Solution of Differential Equations	123
	References	127
6	**Finite Conductivity Models of Counterflow Regenerators**	**128**
6.1	Introduction	128
6.2	Lumped Heat Transfer Coefficients	128
6.3	Further Considerations of the Effect of Checkerwork Conductivity	135
6.4	Longitudinal Conduction in the Regenerator Packing	136
6.5	Note on Numerical Solution of Equations Including Longitudinal Conduction	140
6.6	Latitudinal Conduction in the Regenerator Checkerwork	141
6.7	Relationship between the Two-Dimensional and Three-Dimensional Models	143
6.8	Possible Improvements in the Lumped Heat Transfer Coefficient	149
	References	153
7	**Nonlinear Models of Counterflow Regenerators**	**154**
7.1	Introduction	154
7.2	Mathematical Representation	155
7.3	Quasi-linearization of Nonlinear Models	158
7.4	Methods for Simulating Nonsteady-State Performance of Regenerators	159
7.5	Variable Gas Flow Problems in Regenerators	159
7.6	Radiative Heat Transfer between Gas and Solid Surface in Regenerators	164
	References	167
8	**Improved Computational Methodology for Regenerators**	**168**
8.1	Introduction	168
8.2	Open Methods: Numerical Solution of the Regenerator Equations	169
8.3	Control of Truncation Error	

8.4 Open Methods: Integral Methods for Simulation of the Regenerator 176
8.4.1 Evaluation of the K Function 179
8.4.2 Calculation of Regenerator Effectiveness 180
8.5 Closed Methods 180
8.5.1 Further Consideration of Reversal Conditions for the Symmetric Case 180
8.5.2 Development of the Closed Methods 180
8.5.3 The Method of Nahavandi and Weinstein: Symmetric Case 181
8.5.4 The Method of Nahavandi and Weinstein: Unsymmetric Case 182
8.5.5 Choice of Data Points ξ_i 183
8.5.6 The Closed Method of Iliffe 184
8.6 Numerical Acceleration of Regenerator Simulations 186
References 191

9 Parallel-Flow Regenerators 192

9.1 Introduction 192
9.2 Method of Analysis 194
9.2.1 Symmetric Regenerators: Reversal Conditions 195
9.3 The Heat Pole Method 196
9.4 Refinement of the Heat Pole Method 201
9.5 Application of the Nahavandi and Weinstein Method to Parallel-Flow Regenerators 202
9.6 Parallel-Flow Regenerator Performance 203
9.7 The Approach of Kumar 204
9.8 Unbalanced Regenerators 214
References 218

10 Transient Performance of Counterflow Regenerators

10.1 Initial Considerations 219
10.2 Response to a Step Change in Operation Conditions 221
10.3 Step Changes in Inlet Gas Temperature 222
10.3.1 Symmetric Case 222
10.3.2 Unsymmetric-Balanced Regenerators 228
10.3.3 Unbalanced Regenerators 230
10.4 Interpretation of the Relation between the Transient Performance of a Regenerator and Its Dimensionless Parameters 230
10.5 Step Changes in Gas Flow Rate 232
10.6 Further Parameterization of Transient Response 235
10.7 Thermal Inertia of Variable Gas Flow Regenerator Systems 240
10.8 Conclusions 241
References 242

11 Heat Storage Exchangers

11.1 Introduction 243
11.2 Two-Fluid Heat Exchangers 244
11.2.1 Single-Blow Operation: Mathematical Model 244
11.2.2 Transient Response Parameters 248

11.2.3 Results: Step Change in One Inlet Fluid Temperature
11.2.4 Method of Superposition for Arbitrary Variations in Inlet Fluid Temperature for a Two-Fluid Heat Storage Exchanger 263
11.3 Heat Flux and Single-Fluid Heat Storage Exchanger 266
11.3.1 Mathematical Model 266
11.3.2 Results 269
11.3.3 Methods of Superposition for Arbitrary Timewise Variations in Heat Flux 275
References 277

12 Packed Beds

12.1 Introduction 279
12.2 Mathematical Models: Single Blow 280
12.2.1 Negligible Thermal Resistance 280
12.2.2 Simplified Model 281
12.2.3 Intraparticle Conduction and Dispersion Model 290
12.3 Arbitrary Inlet Fluid and Initial Bed Conditions 294
12.3.1 Arbitrary Time Variation in Fluid Inlet Temperature 294
12.3.2 Arbitrary Variation in the Initial Temperature Distribution of the Packed Bed 296
12.3.3 Arbitrary Time Variation in Flow Rate 300
12.3.4 Periodic Operation of Packed Bed Units 300
References 301

13 Design Optimization

13.1 Introduction 302
13.2 Complex Optimization Method 303
13.3 Optimization of a Slab Heat Storage Unit for Single-Blow Operating Mode 307
13.4 Results from Optimization Study of Slab Heat Storage Units 310
13.5 Optimization of a Packed Bed Heat Storage Unit for Single-Blow Operating Mode 322
13.6 Results from Optimization Study of Packed Bed Storage Units 325
References 332

14 Heat Transfer and Pressure Drop Correlations

14.1 Introduction 333
14.2 Heat Transfer and Pressure Drop Correlations for Channel Flow 333
14.2.1 Pressure Drop Calculation 334
14.2.2 Heat Transfer Coefficient Correlation 338
14.3 Heat Transfer and Pressure Drop Correlations for Flow in Packed Beds 342
14.3.1 Pressure Drop Calculations 342
14.3.2 Heat Transfer Correlations 344
References 348

Index