

- Excerpts from the Preface to the 5th Edition p. xv
- Preface p. xvii
- Brief Biographies of the Authors p. xix
- No-Liability Statement p. xxi
- 1 Industrial Heating Processes p. 1
- 1.1 Industrial Process Heating Furnaces p. 1
- 1.2 Classifications of Furnaces p. 7
- 1.2.1 Furnace Classification by Heat Source p. 7
- 1.2.2 Furnace Classification by Batch or Continuous, and by Method of Handling Material into, Through, and out of the Furnace p. 7
- 1.2.3 Furnace Classification by Fuel p. 16
- 1.2.4 Furnace Classification by Recirculation p. 18
- 1.2.5 Furnace Classification by Direct-Fired or Indirect-Fired p. 18
- 1.2.6 Classification by Furnace Use p. 20
- 1.2.7 Classification by Type of Heat Recovery p. 20
- 1.2.8 Other Furnace Type Classifications p. 21
- 1.3 Elements of Furnace Construction p. 22
- 1.4 Review Questions and Projects p. 23
- 2 Heat Transfer in Industrial Furnaces p. 25
- 2.1 Heat Required for Load and Furnace p. 25
- 2.1.1 Heat Required for Heating and Melting Metals p. 25
- 2.1.2 Heat Required for Fusion (Vitrification) and Chemical Reaction p. 26
- 2.2 Flow of Heat Within the Charged Load p. 28
- 2.2.1 Thermal Conductivity and Diffusion p. 28
- 2.2.2 Lag Time p. 30
- 2.3 Heat Transfer to the Charged Load Surface p. 31
- 2.3.1 Conduction Heat Transfer p. 33
- 2.3.2 Convection Heat Transfer p. 35
- 2.3.3 Radiation Between Solids p. 37
- 2.3.4 Radiation from Clear Flames and Gases p. 42
- 2.3.5 Radiation from Luminous Flames p. 46
- 2.4 Determining Furnace Gas Exit Temperature p. 53
- 2.4.1 Enhanced Heating p. 55
- 2.4.2 Pier Design p. 56
- 2.5 Thermal Interaction in Furnaces p. 57
- 2.5.1 Interacting Heat Transfer Modes p. 57
- 2.5.2 Evaluating Hydrogen Atmospheres for Better Heat Transfer p. 60
- 2.6 Temperature Uniformity p. 63
- 2.6.1 Effective Area for Heat Transfer p. 63
- 2.6.2 Gas Radiation Intensity p. 64
- 2.6.3 Solid Radiation Intensity p. 64
- 2.6.4 Movement of Gaseous Products of Combustion p. 64
- 2.6.5 Temperature Difference p. 65
- 2.7 Turndown p. 67

- 2.8 Review Questions and Project p. 67
- 3 Heating Capacity of Batch Furnaces p. 71
- 3.1 Definition of Heating Capacity p. 71
- 3.2 Effect of Rate of Heat Liberation p. 71
- 3.3 Effect of Rate of Heat Absorption by the Load p. 77
- 3.3.1 Major Factors Affecting Furnace Capacity p. 77
- 3.4 Effect of Load Arrangement p. 79
- 3.4.1 Avoid Deep Layers p. 83
- 3.5 Effect of Load Thickness p. 84
- 3.6 Vertical Heating p. 85
- 3.7 Batch Indirect-Fired Furnaces p. 86
- 3.8 Batch Furnace Heating Capacity Practice p. 91
- 3.8.1 Batch Ovens and Low-Temperature Batch Furnaces p. 92
- 3.8.2 Drying and Preheating Molten Metal Containers p. 96
- 3.8.3 Low Temperature Melting Processes p. 98
- 3.8.4 Stack Annealing Furnaces p. 99
- 3.8.5 Midrange Heat Treat Furnaces p. 101
- 3.8.6 Copper and Its Alloys p. 102
- 3.8.7 High-Temperature Batch Furnaces, 1990 F to 2500 F p. 103
- 3.8.8 Batch Furnaces with Liquid Baths p. 108
- 3.9 Controlled Cooling in or After Batch Furnaces p. 113
- 3.10 Review Questions and Project p. 114
- 4 Heating Capacity of Continuous Furnaces p. 117
- 4.1 Continuous Furnaces Compared to Batch Furnaces p. 117
- 4.1.1 Prescriptions for Operating Flexibility p. 118
- 4.2 Continuous Dryers, Ovens, and Furnaces for <1400 F (<760 C) p. 121
- 4.2.1 Explosion Hazards p. 121
- 4.2.2 Mass Transfer p. 122
- 4.2.3 Rotary Drum Dryers, Incinerators p. 122
- 4.2.4 Tower Dryers and Spray Dryers p. 124
- 4.2.5 Tunnel Ovens p. 124
- 4.2.6 Air Heaters p. 127
- 4.3 Continuous Midrange Furnaces, 1200 to 1800 F (650 to 980 C) p. 127
- 4.3.1 Conveyorized Tunnel Furnaces or Kilns p. 127
- 4.3.2 Roller-Hearth Ovens, Furnaces, and Kilns p. 129
- 4.3.3 Shuttle Car-Hearth Furnaces and Kilns p. 129
- 4.3.4 Sawtooth Walking Beams p. 130
- 4.3.5 Catenary Furnace Size p. 135
- 4.4 Sintering and Pelletizing Furnaces p. 137
- 4.4.1 Pelletizing p. 138
- 4.5 Axial Continuous Furnaces for Above 2000 F (1260 C) p. 139
- 4.5.1 Barrel Furnaces p. 139
- 4.5.2 Shaft Furnaces p. 142
- 4.5.3 Lime Kilns p. 142

- 4.5.4 Fluidized Beds p. 143
- 4.5.5 High-Temperature Rotary Drum Lime and Cement Kilns p. 144
- 4.6 Continuous Furnaces for 1900 to 2500 F (1038 to 1370 C) p. 144
- 4.6.1 Factors Limiting Heating Capacity p. 144
- 4.6.2 Front-End-Fired Continuous Furnaces p. 152
- 4.6.3 Front-End-Firing, Top and Bottom p. 153
- 4.6.4 Side-Firing Reheat Furnaces p. 153
- 4.6.5 Pusher Hearths Are Limited by Buckling/Piling p. 155
- 4.6.6 Walking Conveying Furnaces p. 158
- 4.6.7 Continuous Furnace Heating Capacity Practice p. 160
- 4.6.8 Eight Ways to Raise Capacity in High-Temperature Continuous Furnaces p. 162
- 4.6.9 Slot Heat Losses from Rotary and Walking Hearth Furnaces p. 165
- 4.6.10 Soak Zone and Discharge (Dropout) Losses p. 166
- 4.7 Continuous Liquid Heating Furnaces p. 168
- 4.7.1 Continuous Liquid Bath Furnaces p. 168
- 4.7.2 Continuous Liquid Flow Furnaces p. 170
- 4.8 Review Questions and Projects p. 172
- 5 Saving Energy in Industrial Furnace Systems p. 175
- 5.1 Furnace Efficiency, Methods for Saving Heat p. 175
- 5.1.1 Flue Gas Exit Temperature p. 177
- 5.2 Heat Distribution in a Furnace p. 182
- 5.2.1 Concurrent Heat Release and Heat Transfer p. 182
- 5.2.2 Poc Gas Temperature History Through a Furnace p. 184
- 5.3 Furnace, Kiln, and Oven Heat Losses p. 185
- 5.3.1 Losses with Exiting Furnace Gases p. 185
- 5.3.2 Partial-Load Heating p. 187
- 5.3.3 Losses from Water Cooling p. 187
- 5.3.4 Losses to Containers, Conveyors, Trays, Rollers, Kiln Furniture, Piers, Supports, Spacers, Boxes, Packing for Atmosphere Protection, and Charging Equipment, Including Hand Tongs and Charging Machine Tongs p. 188
- 5.3.5 Losses Through Open Doors, Cracks, Slots, and Dropouts, plus Gap Losses from Walking Hearth, Walking Beam, Rotary, and Car-Hearth Furnaces p. 188
- 5.5 Saving Fuel in Batch Furnaces p. 195
- 5.3.6 Wall Losses During Steady Operation p. 192
- 5.3.7 Wall Losses During Intermittent Operation p. 193
- 5.4 Heat Saving in Direct-Fired Low-Temperature Ovens p. 194
- 5.6 Saving Fuel in Continuous Furnaces p. 196
- 5.6.1 Factors Affecting Flue Gas Exit Temperature p. 196
- 5.7 Effect of Load Thickness on Fuel Economy p. 197
- 5.8 Saving Fuel in Reheat Furnaces p. 198
- 5.8.1 Side-Fired Reheat Furnaces p. 198
- 5.8.2 Rotary Hearth Reheat Furnaces p. 198
- 5.9 Fuel Consumption Calculation p. 201
- 5.10 Fuel Consumption Data for Various Furnace Types p. 202

- 5.11 Energy Conservation by Heat Recovery from Flue Gases p. 204
- 5.11.1 Preheating Cold Loads p. 204
- 5.11.2 Steam Generation in Waste Heat Boilers p. 209
- 5.11.3 Saving Fuel by Preheating Combustion Air p. 212
- 5.11.4 Oxy-Fuel Firing Saves Fuel, Improves Heat Transfer, and Lowers NO_x p. 231
- 5.12 Energy Costs of Pollution Control p. 233
- 5.13 Review Questions, Problems, Project p. 238
- 6 Operation and Control of Industrial Furnaces p. 243
- 6.1 Burner and Flame Types, Location p. 243
- 6.1.1 Side-Fired Box and Car-Bottom Furnaces p. 243
- 6.1.5 Roof Firing p. 245
- 6.1.2 Side Firing In-and-Out Furnaces p. 244
- 6.1.3 Side Firing Reheat Furnaces p. 245
- 6.1.4 Longitudinal Firing of Steel Reheat Furnaces p. 245
- 6.2 Flame Fitting p. 246
- 6.2.1 Luminous Flames Versus Nonluminous Flames p. 246
- 6.2.2 Flame Types p. 247
- 6.2.3 Flame Profiles p. 247
- 6.3 Unwanted NO_x Formation p. 247
- 6.4 Controls and Sensors: Care, Location, Zones p. 251
- 6.4.1 Rotary Hearth Furnaces p. 253
- 6.4.2 Zone Temperature in Car Furnaces p. 261
- 6.4.3 Melting Furnace Control p. 264
- 6.5 Air/Fuel Ratio Control p. 264
- 6.5.1 Air/Fuel Ratio Control Must Be Understood p. 264
- 6.5.2 Air/Fuel Ratio Is Crucial to Safety p. 265
- 6.5.3 Air/Fuel Ratio Affects Product Quality p. 270
- 6.5.4 Minimizing Scale p. 271
- 6.6 Furnace Pressure Control p. 272
- 6.6.1 Visualizing Furnace Pressure p. 272
- 6.6.2 Control and Compensating Pressure Tap Locations p. 273
- 6.6.3 Dampers for Furnace Pressure Control p. 276
- 6.7 Turndown Ratio p. 278
- 6.7.1 Turndown Devices p. 279
- 6.7.2 Turndown Ranges p. 280
- 6.8 Furnace Control Data Needs p. 281
- 6.9 Soaking Pit Heating Control p. 283
- 6.9.1 Heat-Soaking Ingots--Evolution of One-Way-Fired Pits p. 283
- 6.9.2 Problems with One-Way, Top-Fired Soak Pits p. 286
- 6.9.3 Heat-Soaking Slabs p. 288
- 6.10 Uniformity Control in Forge Furnaces p. 290
- 6.10.1 Temperature Control Above the Load(s) p. 290
- 6.10.2 Temperature Control Below the Load(s) p. 291
- 6.11 Continuous Reheat Furnace Control p. 293

- 6.11.1 Use More Zones, Shorter Zones p. 293
- 6.11.2 Suggested Control Arrangements p. 295
- 6.11.3 Effects of (and Strategies for Handling) Delays p. 301
- 6.12 Review Questions p. 306
- 7 Gas Movement in Industrial Furnaces p. 309
- 7.1 Laws of Gas Movement p. 309
- 7.1.1 Buoyancy p. 309
- 7.1.2 Fluid Friction, Velocity Head, Flow Induction p. 311
- 7.2 Furnace Pressure; Flue Port Size and Location p. 313
- 7.3 Flue and Stack Sizing, Location p. 319
- 7.3.1 The Long and Short of Stacks p. 319
- 7.3.2 Multiple Flues p. 320
- 7.4 Gas Circulation in Furnaces p. 322
- 7.4.1 Mechanical Circulation p. 322
- 7.4.2 Controlled Burner Jet Direction, Timing, and Reach p. 323
- 7.4.3 Baffles and Bridgewalls p. 324
- 7.4.4 Impingement Heating p. 324
- 7.4.5 Load Positioning Relative to Burners, Walls, Hearth, Roofs, and Flues p. 326
- 7.4.6 Oxy-Fuel Firing Reduces Circulation p. 333
- 7.5 Circulation Can Cure Cold Bottoms p. 334
- 7.5.1 Enhanced Heating p. 334
- 7.6 Review Questions p. 337
- 8 Calculations/Maintenance/Quality/Specifying A Furnace p. 341
- 8.1 Calculating Load Heating Curves p. 341
- 8.1.1 Sample Problem: Shannon Method for Temperature-Versus-Time Curves p. 343
- 8.1.2 Plotting the Furnace Temperature Profile, Zone by Zone on Figs. 8.6, 8.7, and 8.8 p. 348
- 8.1.3 Plotting the Load Temperature Profile p. 357
- 8.1.4 Heat Balance--to Find Needed Fuel Inputs p. 366
- 8.2 Maintenance p. 378
- 8.2.1 Furnace Maintenance p. 378
- 8.2.2 Air Supply Equipment Maintenance p. 380
- 8.2.3 Recuperators and Dilution Air Supply Maintenance p. 380
- 8.2.4 Exhortations p. 381
- 8.3 Product Quality Problems p. 381
- 8.3.1 Oxidation, Scale, Slag, Dross p. 381
- 8.3.2 Decarburization p. 388
- 8.3.3 Burned Steel p. 389
- 8.4.2 Applying Burners p. 391
- 8.3.4 Melting Metals p. 389
- 8.4 Specifying a Furnace p. 390
- 8.4.1 Furnace Fuel Requirement p. 390
- 8.4.3 Furnace Specification Procedures p. 392
- 8.5 Review Questions and Project p. 396

- 9 Materials in Industrial Furnace Construction p. 397
- 9.1 Basic Elements of a Furnace p. 397
- 9.1.1 Information a Furnace Designer Needs to Know p. 397
- 9.2 Refractory Components for Walls, Roof, Hearth p. 398
- 9.2.1 Thermal and Physical Properties p. 398
- 9.2.2 Monolithic Refractories p. 400
- 9.2.3 Furnace Construction with Monolithic Refractories p. 403
- 9.2.4 Fiber Refractories p. 403
- 9.3 Ways in Which Refractories Fail p. 404
- 9.4 Insulations p. 405
- 9.5 Installation, Drying, Warm-Up, Repairs p. 406
- 9.6 Coatings, Mortars, Cements p. 407
- 9.7 Hearths, Skid Pipes, Hangers, Anchors p. 407
- 9.7.1 Hearths p. 408
- 9.7.2 Skid Pipe Protection p. 408
- 9.7.3 Hangers and Anchors p. 411
- 9.8 Water-Cooled Support Systems p. 414
- 9.9 Metals for Furnace Components p. 416
- 9.9.1 Cast Irons p. 417
- 9.9.2 Carbon Steels p. 418
- 9.9.3 Alloy Steels p. 420
- 9.10 Review Questions, Problem, Project p. 421
- Glossary p. 425
- References and Suggested Reading p. 457
- Index p. 461