

Table of Contents

Preface	v
About the Editor	vii
About the Authors	ix
Acknowledgments	xvii
Chapter 1 The Nature of Nature of Ironmaking	1
1.1 Introduction	1
1.2 Structure of this Volume	1
1.3 The History of Ironmaking	2
1.3.1 Prologue	2
1.3.2 Ancient Ironmaking	2
1.3.3 The Spread and Evolution of Ironmaking in Europe	5
1.3.4 The Evolution of the Charcoal Blast Furnace	9
1.3.5 Mineral-Based Ironmaking in the 1700s and 1800s	18
1.3.6 Coke Furnace Evolution from the Late 1800s to Today	24
1.3.7 The Science of Ironmaking	32
1.3.8 Summary	33
Chapter 2 Fundamental of Iron and Steelmaking	37
2.1 Thermodynamics	37
2.1.1 Ideal gas	37
2.1.2 Thermodynamic Laws	38
2.1.3 Thermodynamic Activity	42
2.1.4 Reaction Equilibrium Constant	47
2.2 Rate Phenomena	48
2.2.1 Diffusion	48
2.2.2 Mass Transfer	50
2.2.3 Chemical Kinetics	63
2.2.4 Mixed Control	71

2.3 Properties of Gases	73
2.3.1 Thermochemical Properties	73
2.3.2 Transport Properties	79
2.3.3 Pore Diffusion	81
2.4 Properties of Molten Steel	84
2.4.1 Selected Thermodynamic Data	84
2.4.2 Solubility of Gases in Liquid Iron	85
2.4.3 Iron-Carbon Alloys	88
2.4.4 Liquidus Temperatures of Low Alloy Steels	93
2.4.5 Solubility of Iron Oxide in Liquid Iron	93
2.4.6 Elements of Low Solubility in Liquid Iron	94
2.4.7 Surface Tension	96
2.4.8 Density	99
2.4.9 Viscosity	99
2.4.10 Diffusivity, Electrical and Thermal Conductivity, and Thermal Diffusivity	100
2.5 Properties of Molten Slags	103
2.5.1 Structural Aspects	103
2.5.2 Slag Basicity	104
2.5.3 Iron Oxide in Slags	105
2.5.4 Selected Ternary and Quaternary Oxide Systems	105
2.5.5 Oxide Activities in Slags	108
2.5.6 Gas Solubility in Slags	113
2.5.7 Surface Tension	119
2.5.8 Density	122
2.5.9 Viscosity	124
2.5.10 Mass Diffusivity, Electrical Conductivity and Thermal Conductivity	125
2.5.11 Slag Foaming	126
2.5.12 Slag Models and Empirical Correlations for Thermodynamic Properties	128
2.6 Fundamentals of Ironmaking Reactions	128
2.6.1 Oxygen Potential Diagram	128
2.6.2 Role of Vapor Species in Blast Furnace Reactions	129
2.6.3 Slag-Metal Reactions in the Blast Furnace	133
2.7 Fundamentals of Steelmaking Reactions	142
2.7.1 Slag-Metal Equilibrium in Steelmaking	143
2.7.2 State of Reactions in Steelmaking	147
Chapter 3 Steel Plant Refractories	161
3.1 Classification of Refractories	161
3.1.1 Magnesite or Magnesite–Lime Group	162
3.1.2 Magnesite–Chrome Group	165
3.1.3 Siliceous Group	166
3.1.4 Clay and High-Alumina Group	168
3.1.5 Processed Alumina Group	171
3.1.6 Carbon Group	172
3.2 Preparation of Refractories	174
3.2.1 Refractory Forms	174
3.2.2 Binder Types	175

3.2.3 Processing	178
3.2.4 Products	179
3.3 Chemical and Physical Characteristics of Refractories and their Relation to Service Conditions	180
3.3.1 Chemical Composition	180
3.3.2 Density and Porosity	181
3.3.3 Refractoriness	183
3.3.4 Strength	184
3.3.5 Stress-Strain Behavior	187
3.3.6 Specific Heat	188
3.3.7 Emissivity	189
3.3.8 Thermal Expansion	190
3.3.9 Thermal Conductivity and Heat Transfer	192
3.3.10 Thermal Shock	196
3.4 Reactions at Elevated Temperatures	196
3.5 Testing and Selection of Refractories	208
3.5.1 Simulated Service Tests	208
3.5.2 Post-Mortem Studies	214
3.5.3 Thermomechanical Behavior	215
3.6 General Uses of Refractories	217
3.6.1 Linings	217
3.6.2 Metal Containment, Control and Protection	219
3.6.3 Refractory Use for Energy Savings	224
3.7 Refractory Consumption, Trends and Costs	226
Chapter 4 Ironmaking Refractory Systems	229
4.1 Introduction	229
4.2 Blast Furnace Proper	229
4.3 Hearth	231
4.3.1 Refractory Materials	231
4.3.2 Discussion	234
4.3.3 Wear Mechanisms	237
4.3.4 Design Considerations	237
4.3.5 Summary	240
4.4 Bosh, Belly and Stack	240
4.4.1 Refractory Materials	241
4.4.2 Ceramic Properties	244
4.4.3 Wear Mechanisms	244
4.4.4 Design Considerations	247
4.5 Gunning Materials	248
4.6 Taphole and Casthouse	249
4.6.1. Taphole Materials	249
4.7 Hot Blast Stoves	251
4.7.1 General	251
4.7.2 Basis for Selection of Refractory and Insulating Materials	252
4.7.3 Selection of Refractory and Insulating Materials	254

Chapter 5 Production and Use of Industrial Gases for Iron and Steelmaking	259
5.1 Industrial Gas Uses	259
5.1.1 Introduction	259
5.1.2 Oxygen Uses	260
5.1.3 Nitrogen Uses	262
5.1.4 Argon Uses	263
5.1.5 Hydrogen Uses	264
5.1.6 Carbon Dioxide Uses	264
5.2 Industrial Gas Production	265
5.2.1 Introduction	265
5.2.2 Atmospheric Gases Produced by Cryogenic Processes	266
5.2.3 Atmospheric Gases Produced by PSA/VSA/VPSA Membranes	270
5.2.4 Hydrogen Production	273
5.2.5 Carbon Dioxide Production	273
5.3 Industrial Gas Supply System Options and Considerations	274
5.3.1 Introduction	274
5.3.2 Number of Gases	274
5.3.3 Purity of Gases	275
5.3.4 Volume of Gases	275
5.3.5 Use Pressure	275
5.3.6 Use Pattern	275
5.3.7 Cost of Power	275
5.3.8 Backup Requirements	275
5.3.9 Integration	275
5.4 Industrial Gas Safety	275
5.4.1 Oxygen	276
5.4.2 Nitrogen	276
5.4.3 Argon	276
5.4.4 Hydrogen	277
5.4.5 Carbon Dioxide	277
Chapter 6 Steel Plant Fuels and Water Requirements	279
6.1 Fuels, Combustion and Heat Flow	279
6.1.1 Classification of Fuels	279
6.1.2 Principles of Combustion	280
6.1.3 Heat Flow	294
6.2 Solid Fuels and Their Utilization	297
6.2.1 Coal Resources	298
6.2.2 Mining of Coal	304
6.2.3 Coal Preparation	307
6.2.4 Carbonization of Coal	309
6.2.5 Combustion of Solid Fuels	309
6.3 Liquid Fuels and Their Utilization	312
6.3.1 Origin, Composition and Distribution of Petroleum	313
6.3.2 Grades of Petroleum Used as Fuels	315
6.3.3 Properties and Specifications of Liquid Fuels	316

6.3.4 Combustion of Liquid Fuels	319
6.3.5 Liquid-Fuel Burners	319
6.4 Gaseous Fuels and Their Utilization	320
6.4.1 Natural Gas	321
6.4.2 Manufactured Gases	321
6.4.3 Byproduct Gaseous Fuels	324
6.4.4 Uses for Various Gaseous Fuels in the Steel Industry	326
6.4.5 Combustion of Various Gaseous Fuels	328
6.5 Fuel Economy	331
6.5.1 Recovery of Waste Heat	332
6.5.2 Minimizing Radiation Losses	334
6.5.3 Combustion Control	334
6.5.4 Air Infiltration	335
6.5.5 Heating Practice	336
6.6 Water Requirements for Steelmaking	336
6.6.1 General Uses of Water in Steelmaking	336
6.6.2 Water-Related Problems	339
6.6.3 Water Use by Steelmaking Processes	340
6.6.4 Treatment of Effluent Water	347
6.6.5 Effluent Limitations	353
6.6.6 Boiler Water Treatment	363
Chapter 7 Manufacture of Metallurgical Coke and Recovery of Coal Chemicals	381
7.1 Introduction	381
7.1.1 Carbon as a Reducing Agent	381
7.1.2 Chemical Effects of Coking	381
7.1.3 Kinds of Coke	382
7.1.4 Important Properties of Metallurgical Coke	382
7.1.5 Methods of Manufacturing Metallurgical Coke	382
7.1.6 Products of Coal Carbonization	383
7.1.7 Recovery of Coal Chemicals	384
7.2 Coals for Metallurgical Coke Production	384
7.2.1 Selecting Coals for Quality Coke	384
7.2.2 Preparation of Coal Charge for Byproduct Ovens	395
7.3 Metallurgical Coke Production Processes	401
7.3.1 The Beehive Process for Carbonizing Coal	401
7.3.2 The Byproduct Process for Carbonizing Coal	403
7.4 General Design and Operating Principles of Modern Byproduct Ovens	409
7.4.1 Principal Oven Components	409
7.4.2 Accessory Oven Equipment	421
7.4.3 Coke Quenching	428
7.4.4 Charging and Pushing Schedules	430
7.4.5 Instrumentation and Control	431
7.4.6 Pushing Emissions Control Systems	433
7.4.7 Coke Screening and Handling	436
7.4.8 Refractory Materials Used in Coke Battery Construction	438
7.4.9 Coke Oven Repair Work	441

7.5 Preheating, Stamp Charging and Briquetting of Coals	442
7.5.1 Coal Preheating	443
7.5.2 Stamp Charging	445
7.5.3 Briquette Blending	447
7.6 Some Proprietary Designs of Modern Byproduct Coke Ovens	449
7.6.1 Introduction	449
7.6.2 Koppers Designs	453
7.6.3 Wilputte Designs	464
7.6.4 Thyssen Still Otto Designs	467
7.7 Recovery of Coal Chemicals	496
7.7.1 Collection of Volatile Products from Ovens	496
7.7.2 Recovery of Crude Coal Tar	497
7.7.3 Recovery of Ammonia	503
7.7.4 Recovery of Ammonia as Ammonium Sulfate	506
7.7.5 Recovery of Ammonia as Anhydrous Ammonia	509
7.7.6 Recovery of Phenol	510
7.7.7 Recovery of Coke Oven Light Oil	511
7.7.8 Hydrogen Sulfide Removal	520
7.7.9 Coke Plant Wastewater	529
7.7.10 Uses of Coke, Coke Oven Gas and Coal Chemicals	530
7.8 Recent Developments in Cokemaking	532
7.8.1 Introduction	532
7.8.2 Jewell Thompson Non-Recovery Cokemaking with Heat Recovery and Power Generation	532
7.8.3 The Single Chamber System (SCS)	534
7.8.4 Calderon Cokemaking	537
7.8.5 Antaeus Energy Cokemaking Process	537
7.8.6 TSOA/PACTI Non-Recovery Cokemaking	540

Chapter 8 Iron Ores **547**

8.1 The Nature and Occurrence of Iron Ores	547
8.1.1 Iron Bearing Materials	547
8.1.2 Geology of Iron Ore Deposits	549
8.1.3 Definition of the Term Ore	551
8.1.4 Iron Ore Reserves	552
8.2 Major Iron Ore Deposits	553
8.2.1 Iron Ore Deposits of the United States	553
8.2.2 Iron Ores of Canada	560
8.2.3 Iron Ores of Mexico	563
8.2.4 Iron Ores of South America	564
8.2.5 Iron Ore Deposits of Western Europe	574
8.2.6 Iron Ore Deposits of Eastern Europe	575
8.2.7 Iron Ore Deposits of Middle East and Asia	576
8.2.8 Iron Ore Deposits of Africa	580
8.2.9 Iron Ore Deposits of Oceania	582
8.3 Discovery and Mining of Iron Ores	586
8.3.1 Discovery Methods	586
8.3.2 Mining of Iron Ores	588

8.4 Beneficiation of Iron Ores	592
8.4.1 Introduction	592
8.4.2 High Grade Merchant Ores	592
8.4.3 Low Grade Merchant Ores	593
8.4.4 Primary Ores	596
8.4.5 Concentration Plant Flowsheets	600
8.5 Agglomeration Processes	603
8.5.1 Sintering	607
8.5.2 Pelletizing	610
8.5.3 Nodulizing	615
8.5.4 Briquetting	615
8.6 Transportation of Iron Ores	615
8.6.1 North America	615
8.6.2 International Iron Ore Trade and Transportation	617
8.7 Iron Ore Quality	618
8.7.1 Sinter Feed	618
8.7.2 Blast Furnace Lump Ores	628
8.7.3 Blast Furnace Pellets	629
8.7.4 Direct Reduction Pellets, Lump Ore and Fine Ores	631
8.7.5 Trends in Iron Ore Production by Type	638
Chapter 9 The Blast Furnace Facility and Equipment	643
9.1 Introduction	643
9.2 Furnace Proper	645
9.2.1 Foundation	645
9.2.2 Support Structure	645
9.2.3 Hearth	646
9.2.4 Tuyere Band	653
9.2.5 Bosh	654
9.2.6 Belly and Stack	657
9.3 Charging System	663
9.3.1 Stockhouse	663
9.3.2 Top Charging Equipment	665
9.4 Blast Furnace Gas System	672
9.4.1 Top Openings	672
9.4.2 Gas Cleaning Equipment	673
9.5 Hot Blast Generation	676
9.5.1 Stoves	676
9.5.2 Air System	680
9.5.3 Tuyere Injectants	684
9.6 Raw Material Receiving	684
9.6.1 Receipt of Blast Furnace Raw Materials	684
9.6.2 Car Dumper	685
9.6.3 Ore Yard and Ore Bridges	685
9.6.4 Trestle and Stockhouse	687
9.7 Casthouse	687
9.7.1 Tapping the Furnace	687

9.7.2	Casthouse Emissions	691
9.7.3	Slag Disposal	693
9.7.4	Hot Metal Transportation	693
9.8	Instrumentation and Control	695
9.8.1	Evolution of Process Control	695
9.8.2	Typical Computer Process Control System Architecture	695
Chapter 10 The Manufacture of Pig Iron in the Blast Furnace		699
10.1	Production and Types of Pig Iron	699
10.1.1	Introduction	699
10.1.2	Types of Grades of Pig Iron	699
10.2	Outline of the Blast Furnace Process	703
10.2.1	Blast Furnace Proper	703
10.2.2	Description of the Charge Materials	703
10.3	Chemistry of the Blast Furnace Process	707
10.3.1	Production of Heat and Reduction of Iron	707
10.3.2	Reduction of Manganese, Phosphorus and Silicon	708
10.3.3	Elimination of Sulfur	709
10.3.4	Reaction of Less-Abundant Elements	710
10.3.5	Blast Furnace Material and Energy Balance	712
10.4	Operation of the Furnace	713
10.4.1	Blowing-in	713
10.4.2	Routine Operations	717
10.4.3	Sampling the Iron	717
10.4.4	Charging the Furnace	718
10.4.5	Operation of the Stoves	720
10.4.6	Blast Furnace Irregularities	721
10.4.7	Fanning	723
10.4.8	Back Drafting	724
10.4.9	Banking	724
10.4.10	Blowing-in from Bank	726
10.4.11	Blowing-out/Raking-out	727
10.4.12	Blowing-down	727
10.4.13	Draining the Salamander	728
10.5	The Blast Furnace Burden	728
10.6	Modern Techniques for Improving Blast Furnace Operating Performance	733
10.6.1	Beneficiated Charge Material	733
10.6.2	High Hot-Blast Temperatures	734
10.6.3	Fuel Injection	734
10.6.4	Oxygen Enrichment of the Blast	735
10.6.5	High Pressure Operation	736
10.6.6	Improved Burden Distribution	736
Chapter 11 Direct Reduction and Smelting Processes		741
11.1	Introduction	741
11.2	Historical Development and Background	741
11.2.1	Definition and Terms	743

11.2.2 DRI Quality	744
11.2.3 Special Precautions	745
11.3 Direct Reduction Processes with Reducing Gas Generated Externally from the Reduction Furnace	746
11.3.1 Methods to Produce Reducing Gas	746
11.3.2 Shaft Furnace Processes	749
11.3.3 Fluidized Bed Process	755
11.4 Direct Reduction Process with Reducing Gas Generated from Hydrocarbons in the Reduction Furnace	760
11.4.1 Kiln Processes	760
11.4.2 Shaft and Hearth Processes	766
11.5 Reduction Smelting Processes	769
11.5.1 COREX Process	770
11.5.2 DIOS	771
11.5.3 AISI Direct Steelmaking	772
11.5.4 Hismelt	772
11.5.5 ROMELT	773
11.5.6 Cyclone Converter Furnace (CCF)	773
11.6 Inactive Process of Historical and Academic Interest	774
11.6.1 Höganäs Process	774
11.6.2 Wiberg-Soderfors Process	775
11.6.3 Sumitomo Dust Reduction Process (SDR)	775
11.6.4 Sumitomo Pre-Reduction Method Process (SPM)	775
11.6.5 Kawasaki Process	775
11.6.6 Armco Process	775
11.6.7 Nippon Steel Process	776
11.6.8 High Iron Briquette Process (HIB)	776
11.6.9 Plasmared Process	776
11.7 Future Developments	777

