

Contents

Introduction	9
1. Where this book was created and by whom	9
2. About iron and steel	14
2.1 Definitions of metallurgy and ironmaking	14
2.2 Iron, steel and their manufacture	14
3. A bit of history	20
Annex	33
Recommended literature	37
Part I Raw Materials and Their Preparation	38
4. Ores	40
4.1 Requirements on the iron ore quality	46
4.2 Iron ore deposits, production and consumption	46
5. Sintering	50
5.1 Fundamentals of the process	50
5.2 Thermal and chemical processes	55
5.3 Types of sinter	58
5.4 Sinter capacities and operating parameters of a modern sinter plant	58
5.5 Sinter properties and requirements on its quality	60
5.6 Sintering and environment	62
6. Pelletizing	64
6.1 Process and equipment for formation of green pellets	70
6.2 Chemistry of firing of pellets	72
6.3 Gangue composition and pellet basicity	74
6.4 Requirements on the pellet production and quality	76
7. Briquetting	82
8. Coals	89
8.1 Relevant definitions	89
8.2 Coal deposits, production and consumption	89
8.3 Coal origin, ranking, types and properties	92
9. Cokemaking	98
9.1 Methods for solid fuel conversion	98
9.2 Conventional coking process	98
9.3 Functions of coke in the blast furnace	103
9.4 Coke properties	106
9.5 Coke quality and requirements on its characteristics	110
9.6 Trends in coke functions and coke quality indexes	112

9.7	Alternative cokemaking technologies	117
9.8	Problems and solutions. Outlook	122
10.	Environmental aspects	128
10.1	Introduction	128
10.2	Sinter plant	129
10.3	Coking plant	137
	Annex I-1	144
	Annex I-2	147
	Recommended literature and Web resources	148

Part II Blast Furnace Process..... 150

11.	An outline of the process	151
12.	Blast furnace design and facilities	155
12.1	Blast furnace profile and facilities.....	155
12.2	Evaluation of blast furnace dimensions	160
13.	Movement of materials and gases	164
13.1	Fluid mechanics of the blast furnace (general considerations)	164
13.2	Material motion	165
13.3	Gas motion	170
13.4	Streaming conditions in critical zones (cohesive zone, deadman and drainage zone)	174
14.	Decomposition of materials	178
14.1	Moisture and hydrated water of the burden. Volatile matters of coke.....	178
14.2	Decomposition of carbonates	179
15.	Reduction processes	181
15.1	Thermodynamic fundamentals of oxide reduction	181
15.1.1	<i>General principles</i>	181
15.1.2	<i>Oxygen potential</i>	182
15.2	Reduction of iron.....	184
15.2.1	<i>Schemes and classification of iron oxide reduction</i>	184
15.2.2	<i>Indirect reduction of iron oxides</i>	185
15.2.3	<i>Direct reduction of iron oxides</i>	188
15.2.4	<i>Thermodynamic comparison of direct and indirect reduction and minimum carbon consumption</i>	189
15.2.5	<i>Rist diagram</i>	191
15.2.6	<i>Low temperature reduction</i>	192
15.2.7	<i>Effect of accompanying oxides on oxygen removal from iron oxides</i> ..	194
15.3	Reduction of accompanying elements.....	196
15.3.1	<i>Reduction of silicon</i>	197
15.3.2	<i>Reduction of manganese</i>	198

15.3.3	<i>Reduction of phosphorus</i>	199
15.3.4	<i>Reduction of chromium</i>	199
15.3.5	<i>Reduction of titanium</i>	200
15.4	Circulating elements in the blast furnace	200
15.4.1	<i>Zinc</i>	201
15.4.2	<i>Lead</i>	204
15.4.3	<i>Alkali metals</i>	205
15.5	Kinetics of iron oxide reduction.....	208
15.5.1	<i>Reduction in the solid state</i>	208
15.5.2	<i>Reduction in the liquid state</i>	210
16.	Oxidising processes.....	214
16.1	Raceway	214
16.2	Gas composition and temperature in the raceway.....	218
16.3	Re-oxidation of elements in the raceway and their subsequent reduction	225
17.	Formation of metal and slag.....	228
17.1	Carburisation of iron and types of hot metal.....	228
17.2	Slag formation	230
18.	Desulphurisation of hot metal	236
18.1	Sulphur behavior in the blast furnace.....	236
18.2	Factors affecting sulphur content in hot metal	239
18.3	External desulphurisation.....	243
19.	Heat exchange	247
19.1	Fundamentals of Kitaev's theory	247
19.2	Heat exchange in the hearth of the modern blast furnace	249
19.2.1	<i>Effect of flame temperature on blast furnace operation efficiency</i>	250
19.2.2	<i>Effect of pulverised coal on heat exchange in the raceway</i>	252
20.	Injection technologies	255
20.1	Effect of auxiliary reducing agent injection on the blast furnace process (general remarks).....	257
20.2	Injection of natural gas.....	260
20.2.1	<i>Fundamentals of natural gas combustion</i>	261
20.2.2	<i>Natural gas mixing and combustion in the tuyere and raceway</i>	263
20.3	Injection of coke oven gas.....	264
20.4	Oil injection	265
20.5	Pulverised coal injection	266
20.5.1	<i>Fundamentals of pulverised coal combustion</i>	267
20.5.2	<i>Measures for improving coal use efficiency</i>	269
20.6	Injection of other solid substances and mixtures	275
20.6.1	<i>Injection of organic wastes and their mixtures with pulverised coal</i> ...	275
20.6.2	<i>Injection of iron containing materials and their mixtures with pulverised coal</i>	279

20.6.3	<i>Injection of further solid materials and mixtures</i>	282
20.7	Co-injection	283
20.8	Hot reducing gas injection.....	283
20.9	Controlling thermal state of the blast furnace hearth using injection	287
20.10	Equipment for solid material injection.....	289
21.	Measurements, modelling and automatic control.....	300
21.1	Measurements.....	300
21.2	Mathematical models	309
21.2.1	<i>Characteristic features of the blast furnace process and classification of mathematical models</i>	310
21.2.2	<i>Analysis of mathematical models</i>	311
21.3	Automatic control of the blast furnace process	317
21.3.1	<i>Tasks of the process control</i>	318
21.3.2	<i>Automatic control systems</i>	318
22.	State-of-the-art and challenges of the blast furnace ironmaking ..	325
22.1	Achievements and trends.....	325
22.2	Factors governing blast furnace productivity.....	329
22.3	Factors governing coke rate	330
22.4	Topical issues of the blast furnace ironmaking.....	332
23.	Energy saving and environment	334
23.1	Ways for energy saving and CO ₂ minimising in ironmaking	335
23.1.1	<i>High blast temperature</i>	336
23.1.2	<i>Use of pre-reduced ore</i>	336
23.1.3	<i>Charge of coal on the top</i>	337
23.1.4	<i>Top gas recycling</i>	338
23.1.5	<i>Use of renewable energy sources</i>	341
23.2	Waste recycling	344
Annex II-1	.....	349
Annex II-2	.....	350
Annex II-3	.....	352
Annex II-4	.....	354
Annex II-5	.....	358
Annex II-6	.....	361
Recommended literature and links	.....	367

Part III Direct and Smelting Reduction Processes 371

24	Introduction.....	371
24.1	Steel production routes.....	372
24.2	Direct reduced iron production	373
24.3	Historical data.....	375

25	Direct Reduction	375
25.1	Definition and classification.....	375
25.2	Iron bearing raw materials.....	378
25.3	Reductants for direct reduction processes.....	379
25.4	Products and options for utilisation.....	381
25.5	Direct reduction processes.....	382
26	Smelting reduction	390
26.1	Definition and principle.....	390
26.2	Classification of smelting reduction.....	391
26.3	Smelting reduction processes.....	392
27	Hybrid processes	397
28	Characteristics and terminology of DR processes.....	398
	Literature	400