

CONTENTS

	Page
1. Synopsis	1
1.1 Introduction	1
1.2 Extraction of Copper from sulphide Ores	1
1.3 Extraction of copper from Oxide Ores	16
1.4 Melting and Casting of Copper	17
1.5 Miscellaneous Copper Processes	18
1.6 Summary of Chapter	19
Suggested Reading and References	20
2. Production Statistics, Ores, Beneficiation	21
2.1 Copper Statistics	21
2.2 Beneficiation of Copper Ores	30
2.3 Comminution	32
2.4 Froth Flotation	44
2.5 Specific Flotation Procedures for Copper Ores	50
2.6 The Flotation Products	53
2.7 Improvements in Flotation Practice	54
2.8 Summary of Chapter	58
Suggested Reading and References	59
3. Roasting of Copper Concentrates	61
3.1 Roasting Prior to Reverberatory Smelting	62
3.2 Roasting Prior to leaching	64
3.3 Chemistry of Roasting	65
3.4 Choice of roasting Temperature	68
3.5 Kinetics of Roasting	70
3.6 Roasting Furnaces and Methods	70
3.7 Summary of Chapter	78
Suggested Reading and References	78
4. Matte Smelting	80
4.1 Physical Chemistry of Matte Smelting	81
4.2 Formation, Constitution and Characteristics of Matte	83
4.3 Formation, Constitution and Characteristics of Slags	87
4.4 The Smelting Criterion: Separating matte from Slag	89
4.5 Magnetite in Matte Smelting	95
4.6 Behaviour of Other Metals During Smelting	96
4.7 Summary of Chapter	97
Suggested Reading and References	98
5. Blast-Furnace Matte Smelting	100
5.1 Process Description	101
5.2 Reactions in the Blast Furnace	104
5.3 Recent Developments in Blast Furnace Smelting	105
5.4 Summary of Chapter	108
Suggested Reading and References	109
Appendix 5A The TORCO (Segregation) Process	110
6. Reverberatory-Furnace Matte Smelting	113
6.1 Description of Process	114
6.2 Construction Details	119

6.3	Combustion, Temperatures, Heat Balances	121
6.4	Production Rates	125
6.5	Charging Methods	128
6.6	Reverberatory Slags	130
6.7	Magnetite Formation and Hearth Control	131
6.8	Recent Developments in Reverberatory Smelting	133
6.9	Summary of Chapter	136
	Suggested Reading and References	137
7.	Electric-Furnace Matte Smelting	138
7.1	Advantages and Disadvantages	139
7.2	Description of Process	140
7.3	Construction Details	143
7.4	Electrical System	143
7.5	Matte and Slag Conductivities, Automatic Power Control	149
7.6	Power Input, Productivity, Temperature Control	150
7.7	Energy Requirements and Costs	152
7.8	Slag and Hearth Control	153
7.9	Summary of Chapter	154
	Suggested Reading and References	155
8.	Flash-Furnace Matte Smelting	156
8.1	Advantages and Disadvantages	159
8.2	INCO Oxygen Flash Smelting Process	160
8.3	Outokumpu Flash Smelting Process	161
8.4	Heat Balances for Flash Smelting	164
8.5	Comparison of INCO and Outokumpu Processes	168
8.6	Computer Control of Flash Smelting	170
8.7	Future of Flash Smelting	174
8.8	Use of Oxygen in Flash Smelting	174
8.9	Summary of Chapter	175
	Suggested Reading and References	176
9.	Converting of Copper Matte	177
9.1	Stages of the Converting Process	180
9.2	Magnetite Formation in the Converter	185
9.3	Industrial Converting Operations	186
9.4	Recent Developments in Copper Converting	194
9.5	Summary of Chapter	201
	Suggested Reading and References	202
10.	Copper Losses in Slags	204
10.1	Magnitude of the Copper-Loss Problem	205
10.2	Copper losses in Smelting Furnace Slags	207
10.3	Treatment of Flash-furnace Slags	210
10.4	Treatment of Converter Slags	210
10.5	Summary of Chapter	214
	Suggested Reading and References	215
11.	Continuous Production of Blister Copper: Single-Step and Multi-Step Processes	217
11.1	Single –Step Processes	219
11.2	Noranda Process	224
11.3	Worcra Process	229
11.4	Mitsubishi Process	231
11.5	Comparison of Continuous Copper-making Processes	237
11.6	Summary of Chapter	239
	Suggested Reading and References	240
12.	Preparation of Anodes: Sulphur and Oxygen Removal	242
12.1	Industrial Methods of Anode Preparation	243

12.2	Chemistry of Fire Refining	246
12.3	Choice of Hydrocarbons for Deoxidation	248
12.4	Casting of Anodes	249
12.5	Summary of Chapter	252
	Suggested Reading and References	252
13.	Hydrometallurgical Copper Extraction: Introduction and Leaching	254
13.1	Leaching: Ores and Reagents	255
13.2	Chemistry of Leaching Processes	258
13.3	Bacterial Leaching of Sulphides	258
13.4	Leaching Methods	261
13.5	Discussion of Leaching Methods	268
13.6	Summary of Chapter	269
	Suggested Reading and References	270
14.	Recovery of Copper from Dilute Leach Solutions: Cementation and Solvent Extraction	271
14.1	Cementation	272
14.2	Solvent Extraction	279
14.3	Use of Solvent Extraction for Strong Leach Liquors	291
14.4	Summary of Chapter	292
	Suggested Reading and References	292
15.	Electrolytic Refining of Copper	295
15.1	Principles of Electrolytic Copper Refining	296
15.2	Behaviour of Anode Impurities	298
15.3	Industrial Tankhouse Equipment	300
15.4	Tankhouse Procedures	306
15.5	Control of the Refining Process	308
15.6	The Electrolyte	309
15.7	Purification of Electrolyte	310
15.8	Organic Additions to Electrolyte	312
15.9	Current Density and Production Rate	313
15.10	Current Efficiencies, Voltages, Energy Requirements	315
15.11	Recent Developments in Electrorefining	317
15.12	Summary of Chapter	321
	Suggested Reading and References	322
16.	Electrowinning of Copper	324
16.1	Electrowinning Reaction	324
16.2	Cell Voltage and Energy Consumption	325
16.3	Cathode Current Efficiency: Interfering Iron Reactions	328
16.4	Purity of Cathode : Behaviour of Electrolyte Impurities	330
16.5	Electrowinning Tankhouse Practice	331
16.6	Special Problems of Solvent Extraction Electrolytes	332
16.7	Recent Improvements in Electrowinning Practice	333
16.8	Summary of Chapter	334
	Suggested Reading and References	335
17.	Melting and Casting : Quality Control; Recovery of Copper from Scrap	336
17.1	Melting and Casting of Cathode Copper	336
17.2	Melting Techniques	339
17.3	Casting into Fabrication Shapes	345
17.4	Continuous Casting	345
17.5	Southwire Continuous Rod and Hazelett Contirod Systems	354
17.6	Quality Control of Final Copper Product	356
17.7	Recovery of Copper from Scrap	361
17.8	Smelting and Refining of Low-grade Scrap	363
17.9	Summary of Chapter	365
	Suggested Reading and References	366

18.	The Sulphur Problem and Possible Solutions	369
18.1	The Fixing of SO ₂	371
18.2	SO ₂ Concentration in Smelter Gases	376
18.3	Hydrometallurgical Answers to the Sulphur Problem	379
18.4	Discussion and Summary of Chapter	384
	Suggested Reading and References	385
19.	Costs of Extracting Copper	387
19.1	Overall Capital Costs: Mine to Refinery	389
19.2	Overall Direct Operating Costs: Mine to Refinery	392
19.3	Total Production Costs: Selling Prices; Profitability	393
19.4	Beneficiation Costs	394
19.5	Smelting Costs	396
19.6	Electrorefining Costs	400
19.7	Costs of Hydrometallurgical Processes	402
19.8	Discussion and Summary of Chapter	403
	Suggested Reading and References	404
Appendixes	A.I Units and Conversion Factors	405
	A.II Stoichiometric Data	406
	A.III Thermodynamic Data	408
	A.IV Properties of Electrolytic Tough Pitch Copper	417