

# Contents

<b>Part A – General Context</b> .....	<b>1</b>
<i>Chapter 1 – Industry Perspective and Introduction</i> .....	3
Introduction, Properties and Uses .....	3
World Supply and Demand .....	6
The Lead Smelting Industry .....	7
Primary Smelting .....	9
Secondary Lead Production .....	13
References and Further Reading .....	15
<i>Chapter 2 – Historical Background</i> .....	17
Lead Production in Early Times .....	17
The Lead Blast Furnace .....	21
Preparation of Blast Furnace Feed .....	23
Blast Furnace Products .....	25
Lead Refining .....	26
Silver Recovery .....	26
Direct Smelting .....	27
Secondary Lead .....	28
Historical Summary .....	29
References and Further Reading .....	29
<i>Chapter 3 – Raw Materials</i> .....	31
Lead Mineralogy .....	31
Separation and Concentration Methods .....	32
Commercial Lead Concentrates .....	36
Commercial Terms for the Purchase of Standard Lead Concentrates .....	38
Commercial Terms for the Purchase of Bulk Concentrates .....	40
Commercial Terms for the Sale of Lead Bullion .....	40
Secondary Materials .....	41
References and Further Reading .....	42
<b>Part B – Primary Smelting</b> .....	<b>43</b>
<i>Chapter 4 – Sintering</i> .....	45
Process Chemistry and Thermodynamics .....	45
The Sintering Process .....	46

The Structure of Sinter . . . . .	49
Process Operating Parameters . . . . .	50
Updraught Sintering . . . . .	55
Sinter Machine Capacity and Performance . . . . .	56
Gas Handling and Cleaning . . . . .	60
Sulfuric Acid Production . . . . .	62
References and Further Reading . . . . .	64
<i>Chapter 5 – The Blast Furnace . . . . .</i>	65
Introduction . . . . .	65
Chemical Principles and Thermodynamics . . . . .	65
Furnace Performance . . . . .	67
Slag Characteristics and Composition . . . . .	72
Furnace Construction . . . . .	75
Furnace Operation . . . . .	80
Environmental Issues . . . . .	85
References . . . . .	86
<i>Chapter 6 – The Imperial Smelting Furnace ( ISF) . . . . .</i>	89
General Introduction . . . . .	89
Process Description . . . . .	89
Slag Composition . . . . .	92
Evolution of Furnace Design and Operation. . . . .	92
Coke Use and Furnace Capacity . . . . .	96
References and Further Reading . . . . .	97
<i>Chapter 7 – Direct Smelting Processes. . . . .</i>	99
Principles . . . . .	99
The Boliden Lead Process . . . . .	105
The Kaldor Process (Top Blown Rotary Converter – TBRC) . . . . .	106
The Kivcet Process . . . . .	109
The Queneau-Schuhmann-Lurgi (QSL) Process . . . . .	116
Top Submerged Lance (TSL) – Slag Bath Processes . . . . .	119
The Isasmelt Process . . . . .	120
The Ausmelt Lead Process. . . . .	123
The Outokumpu Lead Process. . . . .	125
References . . . . .	126
<i>Chapter 8 – Smelter By-Products and Treatment Processes. . . . .</i>	129
Introduction . . . . .	129

Slag Cleaning . . . . .	129
Zinc Recovery from Slags. . . . .	130
The Conventional Slag Fuming Furnace . . . . .	135
Top Submerged Lance Slag Fuming . . . . .	140
High Intensity Fuming Processes . . . . .	144
Fume Treatment . . . . .	144
Electric Arc Fuming Furnace . . . . .	146
Treatment of Lead Smelter Mattes . . . . .	147
Sinter Plant and Smelter Dusts. . . . .	147
References . . . . .	148
<i>Chapter 9 – Electrochemical Reduction Processes. . . . .</i>	<i>151</i>
Background. . . . .	151
Processes Based on Molten Salt Electrolysis . . . . .	153
Processes Based on Aqueous Electrolysis . . . . .	158
References . . . . .	163
<b>Part C – Secondary Smelting. . . . .</b>	<b>165</b>
<i>Chapter 10 – Secondary Materials and Pretreatment . . . . .</i>	<i>167</i>
Introduction . . . . .	167
Lead-Acid Battery Composition . . . . .	168
Battery Breaking and Separation . . . . .	170
Paste Desulfurisation . . . . .	172
Processing of Secondary Residues . . . . .	174
References . . . . .	174
<i>Chapter 11 – Secondary Smelting Methods . . . . .</i>	<i>175</i>
General . . . . .	175
Reverberatory Furnace. . . . .	175
The Blast Furnace . . . . .	178
The Electric Arc Furnace . . . . .	180
Rotary Furnace Smelting . . . . .	181
Top Blown Rotary Converter (TBRC). . . . .	188
Top Lance Slag Bath Reactors. . . . .	188
Electrowinning Processes. . . . .	188
Refining of Secondary Lead . . . . .	193
References . . . . .	194

**Part D – Refining of Lead Bullion . . . . . 195**

*Chapter 12 – Thermal Refining of Primary Lead Bullion. . . . . 197*

- Methods and Equipment . . . . . 199
- Copper Removal or Copper Drossing . . . . . 199
- Softening for Arsenic, Antimony and Tin Removal . . . . . 205
- Removal of Silver and Other Precious Metals . . . . . 210
- Separation of Thallium . . . . . 217
- Separation of Zinc from Lead . . . . . 217
- Separation of Bismuth . . . . . 219
- Final Caustic Refining . . . . . 220
- Refining of Secondary Lead . . . . . 221
- Summary of Common Impurities, Their Control and Recovery . . . . . 221
- References . . . . . 224

*Chapter 13 – Electrolytic Refining of Lead. . . . . 227*

- Process Principles . . . . . 227
- Practical Operations . . . . . 230
- Current Modulation . . . . . 236
- Periodic Current Reversal . . . . . 237
- Bipolar Electrode Cells . . . . . 238
- Final Refining of Cathode Lead . . . . . 238
- Anode Slimes Treatment . . . . . 238
- Other Electrolytic Refining Systems . . . . . 239
- References . . . . . 241

*Chapter 14 – Alloying and Casting . . . . . 243*

- Handling Molten Lead and Alloying . . . . . 243
- Specifications . . . . . 243
- Casting . . . . . 243

**Part E – Environmental and Economic Issues . . . . . 247**

*Chapter 15 – Health and Environment Issues . . . . . 249*

- Introduction . . . . . 249
- Lead in the Environment . . . . . 249
- The Toxicology of Lead . . . . . 249
- Exposure Pathways . . . . . 251
- Occupational Standards and Controls . . . . . 251
- External Environmental Controls . . . . . 254

Product Controls and Life Cycle Management . . . . .	256
References . . . . .	257
<i>Chapter 16 – Energy Consumption . . . . .</i>	<i>259</i>
Purpose and Scope . . . . .	259
Energy Consumption for the Sinter Plant–Blast Furnace. . . . .	259
Thermal Refining of Lead Bullion . . . . .	261
Electrolytic Lead Refining . . . . .	261
Direct Smelting Processes . . . . .	262
Electrochemical Lead Extraction Processes . . . . .	264
Comparison of Extraction Processes . . . . .	266
Energy Consumption in Supply of Lead Concentrates. . . . .	266
Energy Consumption for Secondary Lead Production . . . . .	267
<i>Chapter 17 – Costs and Economics of Lead Production . . . . .</i>	<i>269</i>
Purpose and Basis . . . . .	269
Smelting by the Sinter Plant–Blast Furnace. . . . .	269
Smelting by the Kivcet Process . . . . .	274
Smelting by the Isasmelt Process . . . . .	277
Comparison of Smelting Technologies. . . . .	279
Lead Refining . . . . .	280
Metal Pricing . . . . .	284
By-Products . . . . .	285
Overall Economics for Refined Lead Production . . . . .	286
Economics of Secondary Lead Production. . . . .	289
<i>Appendix 1 – Properties of Lead and Associated Compounds. . . . .</i>	<i>293</i>
Lead Metal Properties. . . . .	293
Binary Lead Rich Eutectics. . . . .	294
Properties of Lead Oxides . . . . .	294
Vapour Pressures . . . . .	295
Silver Metal Properties . . . . .	295
Thermodynamic Properties of Compounds Involved in Lead Extraction . . . . .	296
Heat Capacities at Constant Pressure . . . . .	297
<i>Index . . . . .</i>	<i>299</i>