Contents

1 Modern Steelmaking in Electric Arc Furnaces: History and Development 1
1.1 General Requirements to Steelmaking Units 1
1.1.1 Process Requirements 2
1.1.2 Economic Requirements 2
1.1.3 Environmental and Health and Safety Requirements 5
1.2 High-Power Furnaces: Issues of Power Engineering. 7
1.2.1 Increasing Power of EAF Transformers 7
1.2.2 Specifics of Furnace Electrical Circuit. 8
1.2.3 Optimum Electrical Mode of the Heat 11
1.2.4 Direct Current Furnaces. 12
1.2.5 Problems of Energy Supply 13
1.3 The Most Important Energy and Technology Innovations. 14
1.3.1 Intensive Use of Oxygen, Carbon and Chemical Heat . . . 14
1.3.2 Foamed Slag Method. 15
1.3.3 Furnace Operation with Hot Heel 18
1.3.4 Single Scrap Charging. 18
1.3.5 Use of Hot Metal and Reduced Iron 19
1.3.6 Post-Combustion of CO Above the Bath 20
1.3.7 Increase in Capacity of Furnaces 21
1.3.8 Continuous Charging and Melting of Scrap in the Liquid Bath. 22
References 24

2 Electric Arc Furnace as Thermoenergetical Unit. 25
2.1 Thermal Performance of Furnace: Terminology and Designations 25
2.2 External and Internal Sources of Thermal Energy: Useful Heat 27
2.3 Factors Limiting the Power of External Sources 28
2.4 Key Role of Heat Transfer Processes. 29
Reference 31

3 The Fundamental Laws and Calculating Formulae of Heat Transfer Processes 33
3.1 Three Ways of Heat Transfer: General Concepts 33
3.2 Conduction Heat Transfer 34
3.2.1 Fourier's Law. Flat Uniform Wall. Electrical–Thermal Analogy 34
3.2.2 Coefficient of Thermal Conductivity 37
3.2.3 Multi-Layer Flat Wall 39
3.2.4 Contact Thermal Resistance 41
3.2.5 Uniform Cylindrical Wall 42
3.2.6 Multi-Layer Cylindrical Wall 43
3.2.7 Simplifying of Formulae for Calculation of Cylindrical Walls 44
3.2.8 Bodies of Complex Shape: Concept of Numerical Methods of Calculating Stationary and Non-Stationary Conduction Heat Transfer 45
3.3 Convective Heat Exchange 49
3.3.1 Newton's Law: Coefficient of Heat Transfer α 49
3.3.2 Two Modes of Fluid Motion 50
3.3.3 Boundary Layer 50
3.3.4 Free (Natural) Convection 52
3.3.5 Convective Heat Transfer at Forced Motion 53
3.3.6 Heat Transfer Between Two Fluid Flows Through Dividing Wall; Heat Transfer Coefficient k 55
3.4 Heat Radiation and Radiant Heat Exchange 58
3.4.1 General Concepts 58
3.4.2 Stefan–Boltzmann Law; Radiation Density; Body Emissivity 59
3.4.3 Heat Radiation of Gases 62
3.4.4 Heat Exchange Between Parallel Surfaces in Transparent Medium: Effect of Screens 63
3.4.5 Heat Exchange Between the Body and Its Envelope: Transparent Medium 65
3.4.6 Heat Exchange Between the Emitting Gas and the Envelope 66

4 Energy (Heat) Balances of Furnace 67
4.1 General Concepts 67
4.2 Heat Balances of Different Zones of the Furnace 69
4.3 Example of Heat Balance in Modern Furnace 71
4.4 Analysis of Separate Items of Balance Equations 72
4.4.1 Output Items of Balance 72
4.4.2 Input Items of Balance 75

4.5 Chemical Energy Determination Methods . . . 76
4.5.1 Utilization of Material Balance Data . . . 76
4.5.2 About the So-Called "Energy Equivalent" of Oxygen . . . 76
4.5.3 Calculation of Thermal Effects of Chemical Reactions by Method of Total Enthalpies . . . 77
References . . . 82

5 Energy Efficiency Criteria of EAFs . . . 85
5.1 Preliminary Considerations . . . 85
5.2 Common Energy Efficiency Coefficient of EAF and Its Deficiencies . . . 87
5.3 Specific Coefficients η for Estimation of Energy Efficiency of Separate Energy Sources and EAF as a Whole . . . 89
5.4 Determining Specific Coefficients η . . . 92
5.4.1 Electrical Energy Efficiency Coefficient $\boldsymbol{\eta}_{EL}$ . . . 92
5.4.2 Fuel Energy Efficiency Coefficient of Oxy-Gas Burners $\boldsymbol{\eta}_{NG}$ . . . 93
5.4.3 Energy Efficiency Coefficient of Coke Charged Along with Scrap . . . 94
5.4.4 Determining the Specific Coefficients η by the Method of Inverse Heat Balances . . . 95
5.5 Tasks of Practical Uses of Specific Coefficients η . . . 95
References . . . 97

6 Preheating of Scrap by Offgases in Combination with Burners . . . 99
6.1 Potentials and Limiting Factors . . . 99
6.1.1 Expediency of Heating . . . 99
6.1.2 Comparison of Consumptions of Useful Heat for Scrap Heating, Scrap Meltdown, and for Heating of Metal up to Tapping Temperature . . . 100
6.1.3 Reduction in Electrical Energy Consumption with High-Temperature Heating of Scrap: Calculation of Potentials . . . 101
6.1.4 Sample of Realization of High-Temperature Heating: Process BBC-Brusa . . . 102
6.1.5 Specifics of Furnace Scrap Hampering Its Heating . . . 103
6.2 Heating on Conveyor . . . 105
6.2.1 Consteel Furnaces with Continuous Scrap Charging into the Bath . . . 105
6.2.2 Comparison of Melting Rates, Productivities, and Electrical Energy Consumptions Between the Consteel Furnaces and EAFs . . . 106
6.2.3 Scrap Preheating Temperature . . . 109

6.3 Heating Scrap in a Large-Thickness Layer 111
6.3.1 Heat Transfer Processes 111
6.3.2 Heating Scrap in Baskets and Special Buckets 114
6.3.3 Twin-Shell Furnaces with Removal of Off-Gas Through the Second Bath 118
6.4 Heating Scrap in Shaft Furnaces 120
6.4.1 Shaft Furnaces with Fingers Retaining Scrap 120
6.4.2 Shaft Furnaces with Continuous Scrap Charging into the Liquid Bath by Pushers 122
6.5 From Utilizing Off-Gases to Scrap Preheating by Burners Only 126
References 127

7 Replacement of Electric Arcs with High Power Oxy-Gas Burners 129
7.1 Attempts for Complete Replacement 129
7.2 Potentialities of Existing Burners: Heat Transfer, Limiting Factors 131
7.3 High-Power Rotary Burners (HPR-Burners) 134
7.3.1 Fundamental Features 134
7.3.2 Slag Door Burners: Effectiveness of Flame-Direction Changes 134
7.3.3 Roof Burners 136
7.3.4 Oriel Burners 138
7.3.5 Sidewall Burners 140
7.4 Two-Stage Process of the Heat with Use of HPR Burners: Industrial Trials 143
7.4.1 General Energy Ratios 143
7.4.2 Process with a Door Burner in 6-ton Furnaces 145
7.4.3 Process with Roof Burners in 100-ton and 200-ton Furnaces 148
7.5 Fuel Arc Furnaces (FAFs) 151
7.5.1 FAF with Scrap Heating in a Furnace Freeboard 151
7.5.2 Conveyor FAFs with Continuous Scrap Charging into the Liquid Bath 153
7.5.3 Shaft FAFs with Continuous Scrap Charging by a Pusher 155
7.6 Economy of Replacement of Electrical Energy with Fuel 157
References 160

8 Basic Physical–Chemical Processes in Liquid Bath Blown with Oxygen: Process Mechanisms 161
8.1 Interaction of Oxygen Jets with the Bath: General Concepts 161
8.2 Oxidation of Carbon 163

8.3 Melting of Scrap 164
8.4 Heating of the Bath 166

9 Bath Stirring and Splashing During Oxygen Blowing 169
9.1 Stirring Intensity: Methods and Results of Measurement 169
9.2 Mechanisms of Bath Stirring. 170
9.2.1 Stirring Through Circulation and Pulsation. 170
9.2.2 Stirring by Oxygen Jets and CO Bubbles. 171
9.3 Factors Limiting Intensity of Bath Oxygen Blowing in Electric Arc Furnaces. 172
9.3.1 Iron Oxidation: Effect of Stirring 172
9.3.2 Bath Splashing 174
9.4 Oxygen Jets as a Key to Controlling Processes in the Bath 177
References 178

10 Jet Streams: Fundamental Laws and Calculation Formulae 179
10.1 Jet Momentum 179
10.2 Flooded Free Turbulent Jet: Formation Mechanism and Basic Principles. 180
10.3 Subsonic Jets: Cylindrical and Tapered Nozzles 182
10.4 Supersonic Jets and Nozzles: Operation Modes. 186
10.5 Simplified Formulae for Calculations of High-Velocity Oxygen Jets and Supersonic Nozzles 188
10.5.1 A Limiting Value of Jets' Velocity 190
10.6 Long Range of Jets 191
Reference 191

11 Devices for Blowing of Oxygen and Carbon into the Bath 193
11.1 Blowing by Consumable Pipes Submerged into Melt and by Mobile Water-Cooled Tuyeres 193
11.1.1 Manually Operated Blowing Through Consumable Pipes. 194
11.1.2 BSE Manipulator 194
11.1.3 Mobile Water-Cooled Tuyeres 196
11.2 Jet Modules: Design, Operating Modes, Reliability 199
11.2.1 Increase in Oxygen Jets Long Range: Coherent Jets 201
11.2.2 Effectiveness of Use of Oxygen, Carbon, and Natural Gas in the Modules. 203
11.3 Blowing by Tuyeres Installed in the Bottom Lining. 205
11.3.1 Converter-Type Non-Water-Cooled Tuyeres. 205
11.3.2 Tuyeres Cooled by Evaporation of Atomized Water 207
11.3.3 Explosion-Proof Highly Durable Water-Cooled Tuyeres for Deep Blowing. 209
References 214

12 Water-Cooled Furnace Elements 215
12.1 Preliminary Considerations 215
12.2 Thermal Performance of Elements: Basic Laws. 215
12.3 Principles of Calculation and Design of Water-Cooled Elements 219
12.3.1 Determining of Heat Flux Rates 219
12.3.2 Minimum Necessary Water Flow Rate 221
12.3.3 Critical Zone of the Element 222
12.3.4 Temperature of Water-Cooled Surfaces 222
12.3.5 Temperature of External Surfaces 225
12.3.6 General Diagram of Element Calculation 226
12.3.7 Hydraulic Resistance of Elements 226
12.4 Examples of Calculation Analysis of Thermal Performance of Elements 229
12.4.1 Mobile Oxygen Tuyere 229
12.4.2 Elements with Pipes Cast into Copper Body and with Channels. 231
12.4.3 Jet Cooling of the Elements 234
12.4.4 Oxygen Tuyere for Deep Blowing of the Bath 235
References 237

13 Principles of Automation of Heat Control 239
13.1 Preliminary Considerations 239
13.2 Automated Management Systems 239
13.2.1 Use of Accumulated Information: Static Control. 239
13.2.2 Mathematical Simulation as Method of Control 240
13.2.3 Dynamic Control: Use of On-line Data 243
13.3 Rational Degree of Automation. 249
References 250

14 Off-Gas Evacuation and Environmental Protection 251
14.1 Preliminary Considerations 251
14.2 Formation and Characteristics of Dust–Gas Emissions 251
14.2.1 Sources of Emissions. 251
14.2.2 Primary and Secondary Emissions. 252
14.2.3 Composition, Temperature, and Heat Content of Off-Gases. 253
14.3 Capturing Emissions: Preparing Emissions for Cleaning in Bag Filters 255
14.3.1 General Description of the System 255
14.3.2 Problems of Toxic Emissions 256
14.3.3 A Simplified Method of Gas Parameters' Calculation in the Direct Evacuation System 259
14.3.4 Energy Problems. 268

14.4 Use of Air Curtains 270
References 275

Index 277

http://www.springer.com/978-3-642-36272-9

Innovation in Electric Arc Furnaces
Scientific Basis for Selection
Toulouevski, Y.N.; Zinurov, I.Y.
2013, XXI, 282 p., Hardcover
ISBN: 978-3-642-36272-9