Contents

T	Modern Steelmaking in Electric Arc Furnaces: History				
	and l	Prospects	for Development	i	
	1.1	General	Requirements for Steelmaking Units	1	
		1.1.1	Process Requirements	1	
		1.1.2	Economic Requirements	2	
		1.1.3	Environmental and Health and Safety Requirements	5	
	1.2	High-Pe	ower Furnaces: Issues of Power Engineering	6	
		1.2.1	Maximum Productivity as the Key Economic		
			Requirement to EAF	6	
		1.2.2	Increasing Power of EAF Transformers	7	
		1.2.3	Specifics of Furnace Electrical Circuit	8	
		1.2.4	Optimum Electrical Mode of the Heat	11	
		1.2.5	DC Furnaces	13	
		1.2.6	Problems of Energy Supply	13	
	1.3	The Mo	ost 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	16	
		1.3.4	Use of Hot Metal and Reduced Iron	17	
		1.3.5	Single Scrap Charging	17	
		1.3.6	Post-combustion of CO Above the Bath	18	
	1.4	Outlook	·	20	
		1.4.1	World Steelmaking and Mini-mills	20	
		1.4.2	The Furnaces of a New Generation	20	
		1.4.3	Consteel Process	22	
	Refe	rences		23	
2	Elect		Furnace as Thermoenergetical Unit	25	
	2.1	Thermal Performance of Furnace: Terminology and Designations 2			
	2.2	External and Internal Sources of Thermal Energy: Useful Heat . 2			
	23	Factors Limiting the Power of External Sources			



	2.4 Refer	Key Ro	ole of Heat Transfer Processes	29 30
_				
3			ental Laws and Calculating Formulae of Heat	31
			cesses	31
	3.1		Ways of Heat Transfer: General Concepts	32
	3.2		ction Heat Transfer	34
		3.2.1		32
		222	Electrical—Thermal Analogy	35
		3.2.2 3.2.3	Multi-layer Flat Wall	38
		3.2.3	Contact Thermal Resistance	39
		3.2.5	Uniform Cylindrical Wall	40
		3.2.5	Multi-layer Cylindrical Wall	41
		3.2.7	Simplifying of Formulae for Calculation of	71
		3.2.1	Cylindrical Walls	42
		3.2.8	Bodies of Complex Shape: Concept of	
		5.2.0	Numerical Methods of Calculating Stationary	
			and Non-stationary Conduction Heat Transfer	43
	3.3	Conve	ctive Heat Exchange	47
		3.3.1	Newton's Law: Coefficient of Heat Transfer α	47
		3.3.2	Two Modes of Fluid Motion	47
		3.3.3	Boundary Layer	48
		3.3.4	Free (Natural) Convection	49
		3.3.5	Convective Heat Transfer at Forced Motion	50
		3.3.6	Heat Transfer Between Two Fluid Flows	
			Through Dividing Wall; Heat Transfer	
			Coefficient k	52
	3.4	Heat R	Radiation and Radiant Heat Exchange	56
		3.4.1	General Concepts	56
		3.4.2	Stefan-Boltzmann Law; Radiation Density;	
			Body Emissivity	57
		3.4.3	Heat Radiation of Gases	60
		3.4.4	Heat Exchange Between Parallel Surfaces in	
			Transparent Medium: Effect of Screens	61
		3.4.5	Heat Exchange Between the Body and Its	
			Envelope: Transparent Medium	62
		3.4.6	Heat Exchange Between the Emitting Gas and	
			the Envelope	63
4	Ener	gy (Hea	t) Balances of Furnace	65
	4.1	Genera	al Concepts	65
	4.2		Balances of Different Zones of the Furnace	66
	4.3		ple of Heat Balance in Modern Furnace	69
	4.4		sis of Separate Items of Balance Equations	70
		4.4.1	Output Items of Balance	70
			•	

		4.4.2 Input Items of Balance	72
	4.5	Chemical Energy Determination Methods	73
		4.5.1 Utilization of Material Balance Data	73
		4.5.2 About the So-Called "Energy Equivalent" of Oxygen .	74
		4.5.3 Calculation of Thermal Effects of Chemical	
		Reactions by Method of Total Enthalpies	75
	Refer	rences	80
5	Ener	gy Efficiency Criteria of EAFs	81
	5.1	Preliminary Considerations	81
	5.2	Common Energy Efficiency Coefficient of EAF	0.
		and Its Deficiencies	83
	5.3	Specific Coefficients η for Estimation of Energy	
		Efficiency of Separate Energy Sources and EAF as a Whole	84
	5.4	Determining Specific Coefficients η	88
		5.4.1 Electrical Energy Efficiency Coefficient η_{EL}	88
		5.4.2 Fuel Energy Efficiency Coefficient of Oxy-gas	
		Burners η_{NG}	89
		5.4.3 Energy Efficiency Coefficient of Coke Charged	
		Along with Scrap	90
		5.4.4 Determining the Specific Coefficients η by the	
		Method of Inverse Heat Balances	91
	5.5	Tasks of Practical Uses of Specific Coefficients η	91
	Refer	rences	92
6	Preh	eating of Scrap by Burners and Off-Gases	93
	6.1	Expediency of Heating	93
	6.2	Consumptions of Useful Heat for Scrap Heating, Scrap	
		Melting, and Heating of the Melt	94
	6.3	High-Temperature Heating of Scrap	95
		6.3.1 Calculation of Potential of Electrical Energy Savings .	95
		6.3.2 Sample of Realization: Process BBC-Brusa	96
	6.4	Specifics of Furnace Scrap Hampering Its Heating	97
	6.5	Processes of Heating, Limiting Factors, Heat Transfer	98
		6.5.1 Two Basic Methods of Heating	98
		6.5.2 Heating a Scrap Pile in a Large-Capacity Container	99
		6.5.3 Heating on Conveyor	102
	6.6	Devices for Heating of Scrap: Examples	105
		6.6.1 Heating in Charging Baskets	105
		6.6.2 DC Arc Furnace Danarc Plus	108
		6.6.3 Shaft Furnaces	110
		6.6.4 Twin-Shell Steelmelting Units	111
	Refer	rences	113
7	Repla	acement of Electric Arcs with Burners	115
-	-		115
	7.1	Attempts for Complete Replacement	113

	7.2	Potentialities of Existing Burners: Heat Transfer,	
		Limiting Factors	117
	7.3	High-Power Rotary Burners (HPR-Burners)	120
		7.3.1 Fundamental Features	120
		7.3.2 Two-Stage Heat with HPR-Burners	120
	7.4	Industrial Trials of HPR-Burners	122
		7.4.1 Slag Door Burners: Effectiveness of Flame	
		Direction Changes	122
		7.4.2 Two-Stage Process with a Door Burner in 6-ton Furnaces	124
		7.4.3 Two-Stage Process with Roof Burners in	
		100-ton and 200-ton EAFs	127
	7.5	Oriel and Sidewall HPR-Burners	131
	7.6	Fuel Arc Furnace (FAF)	135
	7.7	Economy of Replacement of Electrical Energy with Fuel	137
	Refer	rences	139
	т	District Charles I.D. Const. I.P. and J. D. and D. Charles D. Char	
8		Physical-Chemical Processes in Liquid Bath: Process	141
		nanisms	141
	8.1	Interaction of Oxygen Jets with the Bath: General Concepts	141
	8.2	Oxidation of Carbon	144
	8.3	Melting of Scrap	144
	8.4	Heating of the Bath	140
9	Bath	Stirring and Splashing During Oxygen Blowing	149
	9.1	Stirring Intensity: Methods and Results of Measurement	149
	9.2	Mechanisms of Bath Stirring	150
		9.2.1 Stirring Through Circulation and Pulsation	150
		9.2.2 Stirring by Oxygen Jets and CO Bubbles	151
	9.3	Factors Limiting Intensity of Bath Oxygen Blowing	
		in Electric Arc Furnaces	152
		9.3.1 Iron Oxidation: Effect of Stirring	152
		9.3.2 Bath Splashing	154
	9.4	Oxygen Jets as a Key to Controlling Processes in the Bath	157
	Refer	rences	157
10	let S	treams: Fundamental Laws and Calculation Formulae	159
10	10.1	Jet Momentum	159
	10.2	Flooded Free Turbulent Jet: Formation Mechanism	,
		and Basic Principles	160
	10.3	Subsonic Jets: Cylindrical and Tapered Nozzles	162
	10.3	Supersonic Jets and Nozzles: Operation Modes	165
	10.5	Simplified Formulae for Calculations of High-Velocity	103
	10.0	Oxygen Jets and Supersonic Nozzles	167
		10.5.1 A Limiting Value of Jets' Velocity	169
	10.6	Long Range of Jets	170
		rence	170
	110101		170

11	Devic	es for l	Blowing of Oxygen and Carbon		
		he Bath		171	
	11.1	Blowin	g by Consumable Pipes Submerged into Melt		
		and by	Mobile Water-Cooled Tuyeres	171	
		11.1.1	Manually Operated Blowing Through		
			Consumable Pipes	172	
		11.1.2	BSE Manipulator	172	
		11.1.3		174	
	11.2	Jet Mo	dules: Design, Operating Modes, Reliability	177	
		11.2.1	Increase in Oxygen Jets Long Range: Coherent Jets	178	
		11.2.2	Effectiveness of Use of Oxygen, Carbon, and		
			Natural Gas in the Modules	181	
	11.3	Blowin	g by Tuyeres Installed in the Bottom Lining	183	
		11.3.1	Converter-Type Non-water-Cooled Tuyeres	183	
		11.3.2	Tuyeres Cooled by Evaporation of Atomized Water	184	
		11.3.3	Explosion-Proof Highly Durable Water-Cooled		
			Tuyeres for Deep Blowing	187	
	Refer	ences .		191	
12	Water-Cooled Furnace Elements				
	12.1		Inary Considerations	193 193	
	12.2		al Performance of Elements: Basic Laws	193	
	12.3		les of Calculation and Design of Water-Cooled Elements	197	
	12.5	12.3.1		197	
		12.3.2	Minimum Necessary Water Flow Rate	199	
		12.3.3	Critical Zone of the Element	200	
		12.3.4	Temperature of Water-Cooled Surfaces	200	
		12.3.5	Temperature of External Surfaces	202	
		12.3.6	General Diagram of Element Calculation	204	
		12.3.7	Hydraulic Resistance of Elements	204	
	12.4		les of Calculation Analysis of Thermal	20.	
			nance of Elements	207	
		12.4.1	Mobile Oxygen Tuyere	207	
		12.4.2	Elements with Pipes Cast into Copper Body		
			and with Channels	209	
		12.4.3		212	
		12.4.4		213	
	Refer			215	
13	Principles of Automation of Heat Control				
13					
	13.1 Preliminary Considerations				
	13.2	13.2.1	Use of Accumulated Information: Static Control	217 217	
		13.2.1	Mathematical Simulation as Method of Control	218	
		13.2.2	Dynamic Control: Use of On-line Data	221	
	13.3		al Degree of Automation	227	
			ii Degree of Automation	228	
	References 228				

14	Off-gas Evacuation and Environmental Protection			
	14.1	Preliminary Considerations	29	
	14.2	Formation and Characteristics of Dust-Gas Emissions 22	29	
*		14.2.1 Sources of Emissions	29	
		14.2.2 Primary and Secondary Emissions	30	
		14.2.3 Composition, Temperature, and Heat Content		
		of Off-gases	31	
	14.3	Capturing Emissions: Preparing Emissions		
		for Cleaning in Bag Filters	33	
		14.3.1 General Description of the System	33	
		14.3.2 Problems of Toxic Emissions	34	
		14.3.3 A Simplified Method of Gas Parameters'		
		Calculation in the Direct Evacuation System 23	36	
		14.3.4 Energy Problems	16	
	14.4	Use of Air Curtains	18	
	References			
Ind	lex		53	