## Contents

## Acknowledgments ix Preface xi 3.3.2.1 Crude Oil 114 1. Fundamentals of Thermodynamics 3.3.2.2 Natural Gas 118 1.1 Introduction 1 3.3.2.3 Shale Oil 119 1.2 Thermodynamic Properties and Basic 3.3.2.4 Oil Sands 120 Concepts 2 3.3.3 Gas Hydrates 121 1.3 Equations of State and Ideal Gas Behavior 15 3.3.4 Petrochemical Fuels 122 1.4 Laws of Thermodynamics 18 3.4 Alternative Fuels 126 1.5 Exergy 27 3.4.1 Biomass 126 1.6 Balance Equations for Thermodynamic 3.4.2 Biofuels, Biogas, and Fuel Blends 129 Analysis 32 3.4.3 Hydrogen 134 1.6.1 Mass Balance Equation 32 3.5 Concluding Remarks 138 1.6.2 Energy Balance Equation 33 References 141 1.6.3 Entropy Balance Equation 34 1.6.4 Exergy Balance Equation 36 4. Hydrogen and Fuel Cell Systems 1.7 Efficiency Definitions 39 1.8 Concluding Remarks 49 4.1 Introduction 143 References 53 4.2 Hydrogen 144 2. Energy, Environment, and Sustainable 4.3 Hydrogen Production Methods 4.3.1 Water Electrolysis 152 Development 4.3.2 Thermochemical Cycles 4.3.3 Gasification and Hydrocarbon 2.1 Introduction 55 Reformation 164 2.2 Energy Resources Available on Earth 56 4.3.4 Photochemical and Photo-Biochemical 2.3 Environmental Impact of Power Generation Methods 166 Systems 72 4.4 Fuel Cells 169 2.4 Sustainability Assessment of Power Generation 4.4.1 Proton-Exchange-Membrane Fuel Technologies 81 Cells 171 2.5 Concluding Remarks 91 4.4.2 Phosphoric Acid Fuel Cells 172 References 93 4.4.3 Solid Oxide Fuel Cells with Proton Fossil Fuels and Alternatives Conduction (SOFC+) 173 4.4.4 Alkaline Fuel Cells 174 3.1 Introduction 95 4.4.5 Solid Oxide Fuel Cells with Oxygen Ion 3.2 Fuels Classification and Main Properties 97 Conduction 174 3.3 Fossil Fuels 104 4.4.6 Molten Carbonate Fuel Cells 175 3.3.1 Coal 104 4.4.7 Direct Methanol Fuel Cells 176

4.4.8 Direct Ammonia Fuel Cells 178

3.3.2 Petroleum 114

•	
V1	CONTENTS

6.2 Nuclear Reactions 312

6.3 Nuclear Fuel 319

<ul> <li>4.5 Fuel Cell Modeling 178</li> <li>4.6 Optimization of Fuel Cell Systems 186</li> <li>4.7 Integrated Fuel Cell Systems for Power Generation 188</li> <li>4.8 Concluding Remarks 195</li> <li>References 197</li> </ul>	<ul> <li>6.4 Nuclear Reactors 324</li> <li>6.4.1 Reactivity Control 324</li> <li>6.4.2 Exergy Destructions in a Nuclear Reactor 328</li> <li>6.4.3 Conventional Reactors 331</li> <li>6.4.4 Advanced Nuclear Reactors 337</li> </ul>
5 Communication Description Communication Communication	6.4.5 Generation IV Nuclear Reactors 339
5. Conventional Power Generating Systems	6.5 Nuclear-Based Cogeneration Systems 354 6.6 Concluding Remarks 366
5.1 Introduction 199	References 368
5.2 Vapor Power Cycles 200	
5.2.1 The Simple Rankine Cycle 201	
5.2.2 Exergy Destructions in Rankine Power	7. Renewable-Energy-Based Power
Plants 209	Generating Systems
5.2.3 Ideal Reheat Rankine Cycle 222	
5.2.4 Ideal Regenerative Rankine	7.1 Introduction 369
Cycle 224	7.2 Solar Power Generation Systems 370
5.2.5 Steam Rankine Power Stations 234	7.2.1 Solar Radiation 371
5.2.5.1 Reheating-Regenerative Steam	7.2.2 Classification of Solar Power
Rankine Cycle 234	Generators 377
5.2.5.2 Coal-Fired Power Stations 241	7.2.3 Photovoltaic Systems 380
5.2.6 Organic Rankine Cycles 254	7.2.3.1 Photovoltaic Cells 380
5.3 Gas Power Cycles 263	7.2.3.2 Concentrated Photovoltaic
5.3.1 Totally Reversible Gas Power	Systems 389
Cycles 263	7.2.3.3 Photovoltaic-Thermal
5.3.2 Otto and Diesel Power Cycles 266	Systems 395
5.3.3 Gas Turbine (Brayton) Power	7.2.4 Concentrated Photothermal
Cycles 270	Systems 402
5.3.3.1 Air-Standard Brayton	7.2.4.1 Central Receiver Power
Cycle 271	Stations 402
5.3.3.2 Regenerative Brayton	7.2.4.2 Through-Type Concentrated
Cycle 277	Solar Power Systems 415
5.3.3.3 Reheat-Regenerative Brayton	7.2.4.3 Parabolic Dish Units 421
Cycle 279	7.3 Wind Energy Systems 425
5.3.3.4 Brayton Cycle with	7.4 Geothermal Power Generation
Intercooler 282	Systems 434
5.3.3.5 Exergy Destructions in Brayton	7.5 Biomass Energy Systems 441
Cycle Power Plants 282	7.6 Ocean Energy Systems 446
5.4 Combined Cycle Power Plants 301	7.7 Concluding Remarks 450
5.5 Hydropower Plants 303	References 452
5.6 Concluding Remarks 306	
References 310	8. Integrated Power Generating Systems
6Nuclear Power Generation	8.1 Introduction 455
	8.2 Multistaged Systems 457
6.1 Introduction 311	8.3 Cascaded Systems 468

8.4 Combined Systems 473

8.5 Hybrid Systems 488

CONTENTS vii

	CONTENTO
8.6 Case Studies 495	9.4.3 Integrated Biomass-Fueled
8.6.1 Integration Options of a Coal-	
Plant 495	9.4.4 Solar-Based Coal Gasification System with
8.6.1.1 Reference System: Co	
Coal-Fired Power Plan	
8.6.1.2 System Integration O	
Integration of an Adv	
Gasifier with a Ranki	ne Heating, and Desalination 554
Plant 499	9.4.7 Multigeneration System for Power, Hot
8.6.1.3 System Integration O	Option 2: Water, and Fuel from Biomass and
Coal/Biomass Gasifica	ation with Coal 559
Rankine Plant 500	9.4.8 SOFC-ORC-Absorption Trigeneration
8.6.1.4 System Integration O	
Gasifier + SOFC + GT	
Plant 502	9.4.9 Hybrid Solar/Syngas Trigeneration with
8.6.1.5 System Integration O	=
G+SOFC+GT+Two	8
Cycles + Cogeneration	
8.6.1.6 Comparison of the In	
Systems 505	Absorption Cooling, Heating, and
8.6.2 Exergoeconomic and environ	
optimization of a CCPP 506	
8.6.3 Optimization of a Closed Multi	
ORC with Two-Phase Flow Exp	anders 508
8.7 Concluding Remarks 511	
References 515	10. Novel Power Generating Systems
9. Multigeneration Syster	ns 10.1 Introduction 575
5. Waitigeneration System	10.2 Novel Ammonia–Water Power Cycles 576
9.1 Introduction 517	10.3 Solar Thermoelectrical Power Generation 587
9.2 Key Processes and Subsystems for	10.4 Chemical Looping Combustion for Power
Multigeneration 519	Generation 590
9.3 Assessment and Optimization of Mul	tigeneration 10.5 Linear Engine Power Generators 592
Systems 524	10.6 Concluding Remarks 594
9.4 Case Studies 528	References 596
9.4.1 Thermally Driven Multigener	ation
System 528	Appendix A: Conversion Factors 597
9.4.2 Micro-Gas-Turbine-Based	Appendix B: Thermophysical
Multigeneration System 535	D
9.4.2.1 System Modeling 53	
9.4.2.2 System Optimization	538 Index 617