Contents

Prei	FACE TO THE REPRINT EDITION	xiii
Prei	FACE	xvii
Аск	NOWLEDGEMENTS	xxii
Not	TATION	xxiii
1.	Elementary Thermodynamics of Power Plants	1
1.1	Introduction	1
1.2	Criteria for Performance of Power Plants 1.2.1 Efficiency of a Closed Circuit Plant 1.2.2 Efficiency of an Open Circuit Plant 1.2.3 Heat Rate	5 5 7 7
1.3	Ideal (Carnot) Power Plant Performance	8
1.4	Limitations of Other Cycles	9
1.5	Modifications of Other Cycles to Achieve Higher Thermal Efficiency 1.5.1 Gas Turbine Power Plants 1.5.1.1 The Basic Cycle (CBT) 1.5.1.2 The Regenerative Cycle (CBTX) 1.5.1.3 Reheating and Intercooling 1.5.2 Steam Turbine Power Plants 1.5.2.1 The Practical Cycle 1.5.2.2 Reheating 1.5.2.3 Regenerative Feed Heating 1.5.2.4 Discussion	11 12 12 15 17 18 18 22 23 25
1.6	Reversibility, Availability and Exergy 1.6.1 Flow in the Presence of an Environment at T_0 (not including chemical reaction) 1.6.2 Flow with Heat Transfer at Temperature T 1.6.3 Exergy Flux 1.6.4 Maximum Work Output in a Chemical Reaction at T_0	26 26 28 31 32

viii	Contents
------	----------

	1.6.5 The Adiabatic Combustion Process1.6.6 Work Output from a Power Plant1.6.7 Tracing Exergy Fluxes through a Power Plant	32 35 36
1.7	The Incentive for Using Combined Plant to Increase Efficiency	37
<i>2</i> .	Classification of Combined Power Plants	40
2.1	Introduction	40
2.2	Doubly Cyclic Plants (Single Fluid) 2.2.1 The Super-regenerative Cycle ("Joule"/"Rankine") 2.2.2 The Field Cycle ("Joule"/"Rankine") 2.2.3 The Sonnenfeld Cycle ("Joule"/"Rankine") 2.2.4 The Split "Rankine" Cycle and the Dual Pressure Cycle ("Rankine"/"Rankine")	42 42 43 45
	2.2.5 The Sulzer Half-Closed Plant ("Joule"/"Joule")	48
2.3	Binary and Ternary Closed Cycle Plants (Two or Three Condensing Fluids) 2.3.1 "Rankine"/"Rankine" Cycles 2.3.2 "Joule"/"Rankine" Cycles 2.3.3 "Rankine"/"Rankine" Cycles	52 52 53 54
2.4	Open Circuit/Closed Cycle Plant—The Combined Cycle Gas Turbine [CCGT] 2.4.1 Exhaust Heating Systems 2.4.1.1 Unfired HRSG 2.4.1.2 Supplementary Fired HRSG 2.4.1.3 Full Firing of the Exhaust Gases 2.4.1.4 A Note on Heat Recovery Steam Generators 2.4.2 Pressurised Combustion Plants 2.4.2.1 Clean Combustion Plant 2.4.2.2 Pressurised Fluidised Bed (Coal Combustion) Combined Plant 2.4.3 Some Other Developments 2.4.3.1 The Kalina Cycle 2.4.3.2 Topping Gasification/Fluidised Bed Combustion Plant	55 56 56 58 59 59 60 60 62 63 63 65
2.5	Doubly Open Circuit Plants (Two Working Fluids)	66
<i>3</i> .	Combined Power Plants—Some Thermodynamic Concepts	69
3.1	Introduction	69
3.2	Series Plants (Two Closed Cycles in Series) 3.2.1 The Ideal "Series" Plant 3.2.2 A Carnot Combined Plant	70 70 70

Contents	ix
----------	----

	3.2.3 Combined Carnot Plant with Intermediate Temperature Drop 3.2.4 The General Effect of Temperature Drop between Higher and	72
	Lower Level Plants	74
	3.2.4.1 Graphical Representation of the Lost Work3.2.4.2 Seippel and Bereuter's Interpretation of the	77
	Irreversibility I_{HI}^{Q}	78
	3.2.4.3 Summary	81
	3.2.5 Heat "Loss" Between Plants in Series	82
3.3	Parallel Plants (Joint Heating of Two Closed Cycles)	84
3.4	` ,	86
	3.4.1 Intermediate Heat Transfer and Supplementary Heat Supply Between Plants	86
	3.4.2 Intermediate Heat Transfer, Supplementary Heat Supply and	00
	Heat Loss Between Plants	87
3.5	Combined Plants Consisting of an Open Circuit (Higher) Plant and	
	a Closed Cycle (Lower) Plant	89
	3.5.1 Open Circuit/Closed Cycle Combined Plant (No Supplementary Firing)	90
	3.5.2 Open Circuit/Closed Cycle Combined Plant (With	90
	Supplementary Firing)	93
	3.5.2.1 Haywood's Analysis	94
	3.5.2.2 The Analysis of Mangan and Pettit	97
	3.5.2.3 Timmerman's Analysis	99
	3.5.3 Open Circuit/Closed Cycle Combined Plant (Pressurised	
	Combustion or Pressure Charged Boiler)	100
3.6	,,	
	Turbine Plants	101
3.7	Summary of Efficiency Relationships	110
4.	Parametric Studies of Combined Power Plants	114
4.1	Introduction	114
4.2	Parametric Studies of Combined Plants Based on Component	
	Efficiencies	115
	4.2.1 The Doubly Cyclic Series Plant	115
	4.2.2 Joint Heating of Two Closed Cycles	115
	4.2.3 Heat Unused Between Plants in Series	117
	4.2.4 Supplementary Heat Supply Between Plants in Series4.2.5 Heat Loss and Supplementary Heating Between Plants in	118
	Series	120
	4.2.6 Discussion	121

X Contents

4.3	Parametric Studies of Combined Power Plants Based on Variations	
	of Main Thermodynamic Parameters	122
	4.3.1 Binary Plants (Doubly Cyclic)	123
	4.3.1.1 "Rankine"/"Rankine" Binary Plant	123
	4.3.1.2 "Joule"/"Rankine" (Gas/Vapor) Series Plant	127
	4.3.1.3 "Joule"/"Rankine" Series/Parallel Plant	132
	4.3.2 Open Circuit/Closed Cycle (CCGT) Plants	140
	4.3.2.1 Estimates of CCGT Plant Performance	141
	4.3.2.1.1 Cerri's Calculations	141
	4.3.2.1.2 Rufli's Calculations	148
	4.3.2.1.3 Kehlhofer's Calculations (including those	
	of Wunsch)	151
	4.3.2.2 Discussion of Some Important Aspects of CCGT Plant	155
	4.3.2.2.1 The Importance of Gas Turbine Specific Work	
	4.3.2.2.2 The Effect of Regenerative Feed Heating	158
	4.3.2.2.3 The Choice Between Supplementary Heating	1.63
	or Reheating in the Gas Turbine Plant	162
	4.3.2.2.4 Off-Design Behavior of CCGT Plants	167
	4.3.3 Doubly Open Plants	170
	4.3.3.1 The Steam Injection Combined Plant (STIG)	172
	4.3.3.2 Other STIG Type Combined Plants	175
4.4	General Discussion	175
5.	Exergy Analysis	184
5.1	Introduction	184
5.2	Lost Work Due to Irreversibility in Components	190
	5.2.1 Compressor	190
	5.2.2 Turbine	191
	5.2.3 Combustion Chamber	191
	5.2.4 Heat Transfer in a Boiler or HRSG	194
	5.2.5 Steam Turbine with Bleed for Regenerative Feed Heating	195
	5.2.6 Feed Heating Train	195
	5.2.7 Condenser	197
5.3	Exergy Analysis of a Binary Vapour Plant	197
	5.3.1 Cycle Calculations (for Unit Flow Rate of Mercury) and Plant	
	Overall Efficiency	200
	5.3.2 Power Output	202
	5.3.3 Coal Supply	203
	5.3.4 Exergy Fluxes and "Lost Work" Terms	203
	5.3.5 Summary	206
5.4		
	Steam Cycle)	206

	5.4.1 Calculations for the Gas Turbine Plant (for Unit Flow Rate	
	of Gas Products)	207
	5.4.2 Power Output	209
	5.4.3 Plant Overall Efficiency	209
	5.4.4 Exergy Fluxes and "Lost Work" Terms	210
	5.4.5 Summary	213
5.5	Exergy Analysis of a CCGT Plant (with No Feed Heating in the	
	Steam Cycle)	213
	5.5.1 Power Output	215
	5.5.2 Plant Overall Efficiency	215
	5.5.3 Exergy Fluxes and "Lost Work" Terms	216
	5.5.4 Summary	217
5.6	Parametric Exergy Studies of CCGT Plants	219
6.	Economics of Combined Plants	222
6.1	Introduction	222
6.2	Electricity Pricing	222
6.3	The Capital Charge Factor	224
6.4	Discounted Cash Flow	226
	6.4.1 Levelised Sums	227
	6.4.2 Rates of Return and the Effects of Tax Systems	228
	6.4.2.1 Rate of Return Under the U.S. Tax System	228
	6.4.2.2 Rate of Return Under the U.K. Tax System	230
6.5	Discussion	231
6.6	Comparative Pricing—Some Examples	232
	6.6.1 Pricing of a Combined Plant Compared with a Basic Gas	
	Turbine Plant	232
	6.6.2 Pricing of a Range of Combined Plants	234
	6.6.3 Pricing of IGCC Plants	235
	6.6.4 A Graphical Presentation	236
6.7	Exergoeconomic Analysis of a Combined Power Plant	238
<i>7</i> .	Some Practical Combined Power Plants	243
7.1	Introduction	243
7.2	The Mercury/Steam Binary Vapour Plant at Schiller, New Hampshire	244
7.3	The CCGT Plant (B) at Korneuburg, Austria (Unfired HRSG)	247
7.4	The CCGT Plant (A) at Korneuburg, Austria (Supplementary Fired HRSG)	251

Xii	Contents

7.5	The CCGT Plant at Hemweg, Netherlands (Maximally Fired)	254
7.6	The IGCC Plant at Cool Water, California	258
7.7	The STIG Plant at Ripon, California	262
7.8	The ABB KT24 Combined Cycle Plant for Jersey Central Power and Light, New Jersey, U.S.A.	266
7.9	The GE MS9001H Combined Cycle Plant	268
8.	Summary—Historical and Current Perspectives of Combined Power Plants	272
8.1	Introduction	272
8.2	History up to the Early Seventies	272
8.3	Subsequent Development of the Combined Gas/Steam Turbine (CCGT) Plant—1970-1990 8.3.1 The Unfired Recuperative Plant 8.3.2 The Supplementary Fired Plant 8.3.3 The Maximally Fired Plant 8.3.4 The Present Position on After Firing of the Exhaust 8.3.5 Advances in CCGT Plant	275 275 278 278 279 283
8.4	The IGCC Plant and Other Combined Plants	283
8.5	A Note on Cogeneration (Combined Heat and Power) Plants	284
8.6	Conclusions	285
ADD	DENDUM TO CHAPTER 5	287
Add	OTTIONAL RECENT REFERENCES	289
Indi	EX	293