

Contents

1	Definitions and Basic Principles	1
1.1	Typical Pressurized Water Reactor	1
1.2	Scope of Thermodynamics	3
1.3	Units	5
1.3.1	Fundamental Units	5
1.3.2	Thermal Energy Units	6
1.3.3	Unit Conversion	7
1.4	Classical Thermodynamics	7
1.5	Open and Closed Systems	8
1.6	System Properties	10
1.6.1	Density	11
1.6.2	Pressure	11
1.6.3	Temperature	13
1.7	Properties of the Atmosphere	15
1.8	The Laws of Thermodynamics	16
	References	16
2	Properties of Pure Substances	17
2.1	Introduction	17
2.2	Properties of Pure Substances—Phase Changes	19
2.2.1	Phases of Pure Substances	21
2.2.2	Equations of State	21
2.3	Ideal Gas	22
2.4	Real Gases and Vapors	24
2.4.1	Simple Real Gas Equations of State	24
2.4.2	Determining the Adjustable Parameters	25
2.4.3	Other Useful Two Parameter Equations of State	28
2.4.3.1	Redlich-Kwong Equation of State	28
2.4.3.2	Peng-Robinson Equation of State	29
2.4.4	Common Equations of State with Additional Parameters	30
2.4.4.1	Beattie-Bridgeman Equation of State	30
2.4.4.2	Benedict-Webb-Rubin Equation of State	31

2.4.4.3	Virial Equation of State	31
2.4.4.4	Equation of State Comparison	33
2.4.5	The Liquid-Vapor Region	37
2.5	$T-V$ Diagram for a Simple Compressible Substance	39
2.6	$P-V$ Diagram for a Simple Compressible Substance	40
2.7	$P-V-T$ Diagram for a Simple Compressible Substance	40
	References	44
3	Mixture	45
3.1	Ideal Gas Mixtures	45
3.1.1	Avogadro's Number	45
3.1.2	Mass Fractions	46
3.1.3	Mole Fractions	46
3.1.4	Dalton's Law and Partial Pressures	47
3.1.5	Amagat's Law and Partial Volumes	48
3.2	Real Gas Mixtures	49
3.2.1	Pseudo Critical States for Mixtures—Kay's Rule	49
3.2.2	Real Gas Equations of State	49
3.3	Liquid Mixtures	50
3.3.1	Conservation of Volumes	50
3.3.2	Non-Conservation of Volumes and Molecular Packing	50
	References	51
4	Work and Heat	53
4.1	Introduction of the Work and Heat	53
4.2	Definition of Work	53
4.3	Quasi-Static Processes	56
4.4	Quasi-Equilibrium Work Due to Moving Boundary	57
4.5	Definition of a Cycle in Thermodynamic	61
4.6	Path Functions and Point or State Functions	63
4.7	PdV Work for Quasi-Static Process	65
4.8	Non-equilibrium Work	67
4.9	Other Work Modes	68
4.10	Reversible and Irreversible Process	77
4.11	Definition of Energy (Thermal Energy or Internal Energy)	79
4.12	Definition of Heat	80
4.13	Comparison of Work and Heat	81
	References	84
5	First Law of Thermodynamics	85
5.1	Introduction	85
5.2	System and Surroundings	88
5.2.1	Internal Energy	88
5.2.2	Heat Engines	89
5.3	Signs for Heat and Work in Thermodynamics	90
5.4	Work Done During Volume Changes	90

5.5	Paths Between Thermodynamic States	93
5.6	Path Independence	96
5.7	Heat and Work	98
5.8	Heat as Energy in Transition	99
5.9	The First Law of Thermodynamics Applied to a Cycle	100
5.10	Sign Convention	101
5.11	Heat is a Path Function	101
5.12	Energy is a Property of System	103
5.13	Energy of an Isolated System is Conserved	104
5.14	Internal Energy and the First Law of Thermodynamics	106
5.15	Internal Energy of an Ideal Gas	111
5.16	Introduction to Enthalpy	112
5.17	Latent Heat	114
5.18	Specific Heats	115
5.19	Heat Capacities of an Ideal Gas	122
5.20	Adiabatic Processes for an Ideal Gas	124
5.21	Summary	129
	References	130
6	The Kinetic Theory of Gases	131
6.1	Kinetic Theory Basis for the Ideal Gas Law	131
6.2	Collisions with a Moving Wall	135
6.3	Real Gas Effects and Equations of State	136
6.4	Principle of Corresponding States	137
6.5	Kinetic Theory of Specific Heats	138
6.6	Specific Heats for Solids	141
6.7	Mean Free Path of Molecules in a Gas	142
6.8	Distribution of Mean Free Paths	144
6.9	Coefficient of Viscosity	146
6.10	Thermal Conductivity	150
	Reference	151
7	Second Law of Thermodynamics	153
7.1	Introduction	153
7.2	Heat Engines, Heat Pumps, and Refrigerators	153
7.3	Statements of the Second Law of Thermodynamics	155
7.4	Reversibility	156
7.5	The Carnot Engine	156
7.6	The Concept of Entropy	159
7.7	The Concept of Entropy	161
7.8	Entropy for an Ideal Gas with Variable Specific Heats	163
7.9	Entropy for Steam, Liquids and Solids	165
7.10	The Inequality of Clausius	166
7.11	Entropy Change for an Irreversible Process	168
7.12	The Second Law Applied to a Control Volume	169

8 Reversible Work, Irreversibility, and Exergy (Availability)	173
8.1 Reversible Work, and Irreversibility	173
8.2 Exergy	176
9 Gas Kinetic Theory of Entropy	181
9.1 Some Elementary Microstate and Macrostate Models	182
9.2 Stirling's Approximation for Large Values of N	187
9.3 The Boltzmann Distribution Law	188
9.4 Estimating the Width of the Most Probable Macrostate Distribution	192
9.5 Estimating the Variation of W with the Total Energy	194
9.6 Analyzing an Approach to Thermal Equilibrium	196
9.7 The Physical Meaning of β	197
9.8 The Concept of Entropy	198
9.9 Partition Functions	199
9.10 Indistinguishable Objects	200
9.11 Evaluation of Partition Functions	207
9.12 Maxwell-Boltzmann Velocity Distribution	211
References	212
10 Thermodynamic Relations	213
10.1 Thermodynamic Potentials	213
10.2 Maxwell Relations	216
10.3 Clapeyron Equation	220
10.4 Specific Heat Relations Using the Maxwell Relations	221
10.5 The Difference Between the Specific Heats for a Real Gas	223
10.6 Joule-Thomson Coefficient	224
References	225
11 Combustion	227
11.1 Introduction	227
11.2 Chemical Combustion	229
11.3 Combustion Equations	230
11.4 Mass and Mole Fractions	233
11.5 Enthalpy of Formation	235
11.6 Enthalpy of Combustion	239
11.7 Adiabatic Flame Temperature	239
References	242
12 Heat Transfer	243
12.1 Fundamental Modes of Heat Transfer	243
12.2 Conduction	244
12.3 Convection	244
12.4 Radiation	245
12.5 Heat Conduction in a Slab	248

12.6	Heat Conduction in Curve-Linear Geometries	249
12.7	Convection	253
12.8	Boundary Layer Concept	254
12.9	Dimensionless Numbers or Groups	259
12.10	Correlations for Common Geometries	261
12.11	Enhanced Heat Transfer	269
12.12	Pool Boiling and Forced Convection Boiling	272
12.13	Nucleate Boiling Regime	276
12.14	Peak Heat Flux	279
12.15	Film Boiling Regime	281
	References	283
13	Heat Exchangers	285
13.1	Heat Exchangers Types	285
13.2	Classification of Heat Exchanger by Construction Type	288
13.2.1	Tubular Heat Exchangers	288
13.2.2	Plate Heat Exchangers	289
13.2.3	Plate Fin Heat Exchangers	290
13.2.4	Tube Fin Heat Exchangers	290
13.2.5	Regenerative Heat Exchangers	291
13.3	Condensers	291
13.4	Boilers	292
13.5	Classification According to Compactness	292
13.6	Types of Applications	293
13.7	Cooling Towers	293
13.8	Regenerators and Recuperators	294
13.9	Heat Exchanger Analysis: Use of the LMTD	299
13.10	Effectiveness-NTU Method for Heat Exchanger Design	307
13.11	Special Operating Conditions	313
13.12	Compact Heat Exchangers	314
	References	318
14	Gas Power Cycles	319
14.1	Introduction	319
14.1.1	Open Cycle	323
14.1.2	Closed Cycle	324
14.2	Gas Compressors and Brayton Cycle	324
14.3	The Non-Ideal Brayton Cycle	331
14.4	The Air Standard Cycle	335
14.5	Equivalent Air Cycle	339
14.6	Carnot Cycle	340
14.7	Otto Cycle	344
14.7.1	Mean Effective Pressure (Otto Cycle)	347
14.8	Diesel Cycle	350
14.8.1	Mean Effective Pressure (Diesel Cycle)	354

14.9	Comparison of Otto and Diesel Cycles	355
14.10	Dual Cycle	357
14.10.1	Mean Effective Pressure for Dual Cycle	360
14.11	Stirling Cycle	361
14.12	Ericsson Cycle	364
14.13	Atkinson Cycle	366
14.14	Lenoir Cycle	368
14.15	Deviation of Actual Cycles from Air Standard Cycles	370
14.16	Recuperated Cycle	370
	References	373
15	Vapor Power Cycles	375
15.1	The Basic Rankine Cycle	375
15.2	Process Efficiency	380
15.3	The Rankine Cycle with a Superheater	385
15.4	External Reversibilities	387
15.5	Superheated Rankine Cycle with Reheaters	389
15.6	Feed Water Heaters	392
15.6.1	Open or Direct Contact Feedwater Heaters	392
15.6.2	Closed Feed Water Heaters with Drain Pumped Forward Second Type	394
15.6.3	Closed Feed Water Heaters with Drain Pumped Forward Third Type	396
15.7	The Supercritical Rankine Cycle	400
	Reference	400
16	Circulating Water Systems	401
16.1	Introduction	401
16.2	Cooling Power Plants	404
16.2.1	Steam Cycle Heat Transfer	405
16.2.2	Cooling to Condense the Steam and Discharge Surplus Heat	407
16.3	Circulating Water Systems	408
16.4	Service or Cooling Water Systems	410
17	Electrical System	413
17.1	Introduction	413
17.2	Balancing the Circuit to Maximize the Energy Delivered to the Load	413
17.3	Optimizing the Transmission of Energy to the Load	416
17.4	Overview of an Electrical Grid System	417
17.5	How Power Grids System Work	418
17.5.1	Electrical Alternating (AC)	420
17.5.2	Three-Phase Power	420
17.5.3	Transmission System	421

17.5.4	Substation (Terminal Station) System	421
17.5.5	Zone Substation System	422
17.5.6	Regulator Bank System	423
17.5.7	Taps System	424
17.5.8	At the House Level	425
17.5.9	Safety Devices: Fuses, Circuit Breakers, Plugs and Outlets	428
17.5.10	Control Centers	431
17.5.11	Interstate Power Grids	431
17.6	United States Power Grid	431
17.7	Smart Power Grid (SG)	435
	Reference	436
18	Nuclear Power Plants	437
18.1	Fission Energy Generation	437
18.2	The First Chain Reaction	438
18.3	Concepts in Nuclear Criticality	441
18.4	Fundamental of Fission Nuclear Reactors	441
18.5	Reactor Fundamentals	443
18.6	Thermal Reactors	444
18.7	Nuclear Power Plants and Their Classifications	445
18.8	Classified by Moderator Material	445
18.8.1	Light Water Reactors (LWR)	445
18.8.2	Graphite Moderated Reactors (GMR)	446
18.8.3	Heavy Water Reactors (HWR)	447
18.9	Classified by Coolant Material	449
18.9.1	Pressurized Water Reactors (PWR)	449
18.9.1.1	The Arrangement of PWR	449
18.9.1.2	Advantages of PWR	450
18.9.1.3	Drawbacks of PWR	451
18.9.1.4	Pressuriser	451
18.9.2	Boiling Water Reactor (BWR)	451
18.9.3	Gas Cooled Reactors (GCR)	452
18.10	Classified by Reaction Type	455
18.10.1	Fast Neutron Reactor (FNR)	455
18.10.2	Thermal Neutron Reactor	457
18.10.3	Liquid Metal Fast Breeder Reactors (LMFBR)	458
18.11	Nuclear Fission Power Generation	461
18.12	Generation IV Nuclear Energy Systems	462
18.13	Technological State of the Art and Anticipated Developments	464
18.14	Next Generation Nuclear Plant (NGNP)	467
18.15	Generation IV Systems	468
18.15.1	Very High Temperature Reactor (VHTR)	470
18.15.2	Molten Salt Reactor (MSR)	471
18.15.3	Sodium Cooled Fast Reactor (SFR)	473

18.15.4	Super Critical Water Cooled Reactor (SCWR)	474
18.15.5	Gas Cooled Fast Reactor (GFR)	477
18.15.6	Lead Cooled Fast Reactor (LFR)	480
18.16	Next Generation of Nuclear Power Reactors for Power Production	480
18.17	Goals for Generation IV Nuclear Energy Systems	482
18.18	Why We Need to Consider the Future Role of Nuclear Power Now	484
18.19	The Generation IV Roadmap Project	487
18.20	Licensing Strategy Components	488
18.21	Market and Industry Status and Potentials	489
18.22	Barriers	490
18.23	Needs	491
18.24	Synergies with Other Sectors	492
	References	493
19	Nuclear Fuel Cycle	497
19.1	The Nuclear Fuel Cycle	497
19.2	Fuel Cycle Choices	501
19.3	In Core Fuel Management	504
19.4	Nuclear Fuel and Waste Management	505
19.4.1	Managing HLW from Used Fuel	506
19.4.2	Recycling Used Fuel	509
19.4.3	Storage and Disposal of Used Fuel and Other HLW	510
19.4.4	Regulation of Disposal	514
19.5	Processing of Used Nuclear Fuel	515
19.5.1	Reprocessing Policies	515
19.6	Back End of Fuel Cycle	516
20	The Economic Future of Nuclear Power	519
20.1	Introduction	519
20.2	Overall Costs: Fuel, Operation and Waste Disposal	520
20.2.1	Fuel Costs	521
20.2.2	Future Cost Competitiveness	525
20.2.3	Major Studies on Future Cost Competitiveness	526
20.2.4	Operations and Maintenance (O&M) Costs	532
20.3	Production Costs	532
20.3.1	Costs Related to Waste Management	535
20.3.2	Life-Cycle Costs (U.S. Figures)	538
20.3.3	Construction Costs	538
20.4	Comparing the Economics of Different Forms of Electricity Generation	539
20.5	System Cost	540
20.6	External costs	540
	Reference	544

Contents	xix
21 Safety, Waste Disposal, Containment, and Accidents	545
21.1 Safety	545
21.2 Nuclear Waste Disposal	546
21.3 Contamination	548
21.4 Accidents	550
References	552
Appendix A: Table and Graphs Compilations	553
Index	679

Thermodynamics In Nuclear Power Plant Systems

Zohuri, B.; McDaniel, P.

2015, XXIII, 724 p. 321 illus., 146 illus. in color.,

Hardcover

ISBN: 978-3-319-13418-5