Table of Contents*

I. Introduction 1

1. Definition of Thermofluids 1
2. Energy Sources and Conversion 2
3. Energy in Perspective 4
4. Power Producing Systems 5
5. Power Producing Systems, Fossil Power Plants 6
6. Power Producing Systems, Nuclear Power Plants 11
7. Power Producing Systems, Greenpower Plants 17
8. Comparison of Various Energy Sources 23
9. Thermofluid Analysis of Systems 25

Questions 27
Problems 28

II. Thermodynamics 31

IIa. Fundamentals 32

1. Definition of Terms 33
2. Equation of State for Ideal Gases 41
3. Equation of State for Water 46
4. Heat, Work, and Thermodynamic Processes 55
5. Conservation Equation of Mass for a Control Volume 64
6. The First Law of Thermodynamics 66
7. Applications of the First Law, Steady State 70
8. Applications of the First Law, Transient 81
9. The Second Law of Thermodynamics 96
10. Entropy and the Second Law of Thermodynamics 105
11. Exergy or Availability 116

Questions 123
Problems 125

IIb. Power Cycles 144

1. Gas Power Systems 144
2. Vapor Power Systems 161
3. Actual Versus Ideal Cycles 174

* The related flow chart follows this section

Questions 177
Problems 178

IIc. Mixtures 187
1. Mixture of Non-reactive Ideal Gases 187
2. Gases in Contact with Ice, Water, and Steam 193
3. Processes Involving Moist Air 196
4. Charging and Discharging Rigid Volumes 203
Questions 217
Problems 218

III. Fluid Mechanics 223

IIIa. Single-Phase Flow Fundamentals 224
1. Definition of Fluid Mechanic Terms 224
2. Fluid Kinematics 233
3. Conservation Equations 239
Questions 274
Problems 275

IIIb. Incompressible Viscous Flow 286
1. Steady Incompressible Viscous Flow 286
2. Steady Internal Incompressible Viscous Flow 289
3. Pressure Drop in Steady Internal Incompressible Viscous Flow 295
4. Steady Incompressible Viscous Flow in Piping Systems 310
5. Steady Incompressible Viscous Flow Distribution in Piping Networks 337
6. Unsteady Internal Incompressible Flow 343
7. Fundamentals of Waterhammer Transients 371
Questions 383
Problems 383

IIIc. Compressible Flow 399
1. Steady Internal Compressible Viscous Flow 399
2. The Phenomenon of Choked or Critical Flow 414
Questions 426
Problems 427

IV. Heat Transfer 431

IVa. Conduction 431
1. Definition of Heat Conduction Terms 432
2. The Heat Conduction Equation 437
3. Analytical Solution of Heat Conduction Equation 444

4. Lumped-Thermal Capacity Method for Transient Heat Conduction ... 445
5. Analytical Solution of 1-D S-S Heat Conduction Equation, Slab ... 448
6. Analytical Solution of 1-D S-S Heat Conduction Equation, Cylinder ... 461
7. Analytical Solution of 1-D S-S Heat Conduction Equation, Sphere ... 474
8. Analytical Solution of Heat Conduction Equation, Extended Surfaces ... 477
9. Analytical Solution of Transient Heat Conduction ... 485
10. Numerical Solution of Heat Conduction Equation ... 499
Questions ... 501
Problems ... 502

IVb. Forced Convection ... 518
1. Definition of Forced Convection Terms ... 518
2. Analytical Solution ... 521
3. Empirical Relations ... 534
Questions ... 541
Problems ... 541

IVc. Free Convection ... 549
1. Definition of Free Convection Terms ... 549
2. Analytical Solution ... 550
3. Empirical Relations ... 553
Questions ... 557
Problems ... 558

IVd. Thermal Radiation ... 561
1. Definition of Thermal Radiation Terms ... 561
2. Ideal Surfaces ... 568
3. Real Surfaces ... 573
4. Gray Surfaces ... 578
5. Radiation Exchange Between Surfaces ... 579
Questions ... 592
Problems ... 592

V. Two-Phase Flow and Heat Transfer ... 601

Va. Two-Phase Flow Fundamentals ... 601
1. Definition of Two-Phase Flow Terms ... 601
2. Two-Phase Flow Relation ... 606
3. Two-Phase Critical Flow ... 622
Questions ... 632
Problems ... 632

Vb. Boiling 637
1. Definition of Boiling Heat Transfer Terms 637
2. Convective Boiling, Analytical Solutions 641
3. Convective Boiling, Experimental Observation 648
4. Pool Boiling Modes 650
5. Flow Boiling Modes 658
Questions 672
Problems 673

Vc. Condensation 677
1. Definition of Condensation Heat Transfer Terms 677
2. Analytical Solution 678
3. Empirical Solution 682
4. Condensation Degradation 684
Questions 685
Problems 686

VI. Applications 687

VIa. Heat Exchangers 687
1. Definition of Heat Exchanger Terms 687
2. Analytical Solution 690
3. Analysis of Shell and Tube Heat Exchanger 702
4. Analysis of Condensers 710
5. Analysis of Steam Generators 716
6. Transient Analysis of Concentric Heat Exchangers 719
Questions 723
Problems 723

VIb. Fundamentals of Flow Measurement 728
1. Definition of Flow Measurement Terms 728
2. Repeatability, Accuracy, and Uncertainty 729
3. Flowmeter Types 732
4. Flowmeter Installation 744
Questions 745
Problems 745

VIc. Fundamentals of Turbomachines 747
1. Definition of Turbomachine Terms 747
2. Centrifugal Pumps 749
3. Dimensionless Centrifugal Pumps Performance 755
4. System and Pump Characteristic Curves 762
5. Analysis of Hydraulic Turbines 769
6. Analysis of Turboject for Propulsion 777
Questions 779
Problems 780

VId. Simulation of Thermofluid Systems 784
1. Definition of Terms..... 784
2. Mathematical Model for a PWR Loop..... 786
3. Simplified PWR Model..... 791
4. Mathematical Model for PWR Components, Pump..... 802
5. Mathematical Model for PWR Components, Pressurizer 811
6. Mathematical Model for PWR Components, Containment 819
7. Mathematical Model for PWR Components, Steam Generator 827
Questions 829
Problems 829

VIe. Nuclear Heat Generation..... 841
1. Definition of Some Nuclear Engineering Terms..... 841
2. Neutron Transport Equation..... 853
3. Determination of Neutron Flux in an Infinite Cylindrical Core..... 859
4. Reactor Thermal Design 877
5. Shutdown Power Production..... 882
Questions 884
Problems 884

VII. Engineering Mathematics 901

VIIa. Fundamentals..... 901
1. Definition of Terms..... 901

VIIb. Differential Equations 911
1. Famous Differential Equations 911
2. Analytical Solutions to Differential Equations 919
3. Pertinent Functions and Polynomials..... 936

VIIc. Vector Algebra..... 943
1. Definition of Terms..... 943

VIId. Linear Algebra..... 963
1. Definition of Terms..... 963
2. The Inverse of a Matrix..... 968
3. Set of Linear Equations..... 971

VIIe. Numerical Analysis 976
1. Definition of Terms 976
2. Numerical Solution of Ordinary Differential Equations 979
3. Numerical Solutions of Partial Differential Equations..... 985
4. The Newton–Raphson Method 1004
5. Curve Fitting to Experimental Data 1006

VIII. Appendices 1011

I. Unit Systems, Constants and Numbers 1013
II. Thermodynamic Data 1023
III. Pipe and Tube Data 1049
IV. Thermophysical Data 1059
V. Nuclear Properties of Elements 1091

References 1097

Index 1111