

Contents

Preface

v

1. Introduction and Basic Concepts

1.1–1.18

Introduction 1.1

- 1.1 Applications of Thermodynamics 1.1
- 1.2 Macroscopic and Microscopic Points of View 1.5
- 1.3 Thermodynamic Definitions 1.5
- 1.4 Thermodynamic Properties 1.7
- 1.5 Equilibrium 1.7
- 1.6 Processes and Cycles 1.8
- 1.7 Continuum 1.10
- 1.8 Units and Dimensions 1.10
- 1.9 Pressure and its Measurement 1.11
- 1.10 Temperature 1.13
- 1.11 Zeroth Law 1.14
- 1.12 Thermometer 1.15
- 1.13 Temperature Scale 1.16
- Points to Remember* 1.16
- Practice Problems* 1.17
- Multiple Choice Questions* 1.18

2. Work and Heat Transfer

2.1–2.10

Introduction 2.1

- 2.1 Work 2.1
- 2.2 Different Types of Work 2.4
- 2.3 Heat 2.6
- 2.4 Comparison between Work and Heat 2.6
- 2.5 Specific Heat and Latent Heat 2.7
 - 2.5.1 Specific Heat 2.7
 - 2.5.2 Latent Heat 2.7
- 2.6 Energy and its Various Forms 2.8
- Points to Remember* 2.8

Practice Problems 2.9
Multiple Choice Questions 2.10

3. First Law of Thermodynamics **3.1–3.8**

Introduction 3.1
3.1 First Law Statement 3.1
3.2 Application to a Process 3.2
3.3 Energy—A Property of the System 3.2
3.4 Perpetual Motion Machine of the First Kind (PMM I) 3.4
3.5 Specific Heat 3.5
 3.5.1 Specific Heat at Constant Volume 3.5
 3.5.2 Specific Heat at Constant Pressure 3.5
3.6 Limitations of First Law 3.6
Points to Remember 3.6
Practice Problems 3.6
Multiple Choice Questions 3.8

4. First Law Applied to Flow Processes **4.1–4.14**

Introduction 4.1
4.1 Assumptions of SFEE 4.1
4.2 Derivation of SFEE 4.2
4.3 Applications of SFEE 4.3
 4.3.1 Hydroturbine 4.3
 4.3.2 Steam Turbine 4.4
 4.3.3 Centrifugal Pump 4.4
 4.3.4 Centrifugal Compressor 4.4
 4.3.5 Steam Boiler 4.5
 4.3.6 Condenser 4.6
 4.3.7 Evaporator 4.6
 4.3.8 Nozzle 4.6
 4.3.9 Blunt Bodies 4.7
4.4 Throttling Process 4.9
4.5 Comparison of SFEE with Euler's and Bernoulli's Equations 4.10
4.6 Variable Processes 4.12
Points to Remember 4.13
Practice Problems 4.13
Multiple Choice Questions 4.14

5. Second Law of Thermodynamics **5.1–5.17**

Introduction 5.1
5.1 Heat Engine 5.1
5.2 Heat Pump 5.2
5.3 Refrigerator 5.2
5.4 Second Law of Thermodynamics 5.3

- 5.5 Equivalence of the two Statements 5.5
- 5.6 Irreversibility 5.7
 - 5.6.1 Causes of Irreversibility 5.7
- 5.7 Carnot's Theorem 5.10
 - 5.7.1 Proof 5.10
 - 5.7.2 Corollary 5.11
- 5.8 Thermodynamic Scale 5.13
- 5.9 Perpetual Motion Machine of the Second Kind (PMM II) 5.14
- Points to Remember* 5.15
- Practice Problems* 5.15
- Multiple Choice Questions* 5.16

6. Entropy

6.1–6.16

- Introduction* 6.1
- 6.1 Entropy as a Property of System 6.1
- 6.2 Clausius Theorem 6.2
 - 6.2.1 Clausius Inequality 6.2
- 6.3 Entropy Change in an Irreversible Process 6.5
 - 6.3.1 Entropy Change for an Ideal Gas Undergoing a State Change 6.5
 - 6.3.2 Entropy Change as a Function of Pressure and Volume Changes 6.6
- 6.4 Entropy Principle 6.8
 - 6.4.1 Application of Entropy Principle 6.11
- 6.6 Introduction to the Third Law of Thermodynamics 6.13
- 6.7 Entropy Generation in Closed and Open Systems 6.14
- Points to Remember* 6.15
- Practice Problems* 6.15
- Multiple Choice Questions* 6.16

7. Available Energy, Availability and Irreversibility

7.1–7.16

- Introduction* 7.1
- 7.1 Available and Unavailable Energy 7.1
 - 7.1.1 Available Energy and Unavailable Energy 7.2
 - 7.1.2 Available Energy for a Finite Process 7.2
 - 7.1.3 Loss of Available Energy due to Heat Transfer through a Finite Temperature Difference 7.3
- 7.2 Availability, Irreversibility and Gouy-Stodola Theorem 7.4
 - 7.2.1 Availability 7.4
 - 7.2.2 Irreversibility 7.5
 - 7.2.3 Gouy-Stodola Theorem 7.7
- 7.3 Useful Work 7.9
- 7.4 Second Law Efficiency 7.13
- 7.5 Exergy 7.14

Points to Remember 7.15
Practice Problems 7.15
Multiple Choice Questions 7.16

8. Properties of Pure Substances, Gases and Gas Mixtures

8.1–8.26

Introduction 8.1

- 8.1 Pure Substance 8.1
 - 8.1.1 p - V Diagram for a Pure Substance 8.1
 - 8.1.2 p - T Diagram for a Pure Substance 8.4
 - 8.1.3 T- S Diagram for a Pure Substance 8.7
 - 8.1.4 H- S Diagram for a Pure Substance 8.11
- 8.2 Quality or Dryness Fraction 8.13
- 8.3 Use of Steam Tables and Mollier Chart 8.14
- 8.4 Avogadro's Law 8.18
- 8.5 Dalton's Law of Partial Pressure 8.19
- 8.6 Ideal Gas and Real Gas 8.20
 - 8.6.1 Enthalpy of an Ideal Gas 8.20
 - 8.6.2 Van der Waal's Equation 8.21
 - 8.6.3 Gibbs Function of a Mixture of Inert Ideal Gases 8.21

Points to Remember 8.23
Practice Problems 8.23
Multiple Choice Questions 8.24

9. Thermodynamics Relations, Equilibrium and Stability

9.1–9.24

Introduction 9.1

- 9.1 Maxwell's Equations 9.1
 - 9.1.1 Important Mathematical Relations 9.1
- 9.2 Gibbs-Helmholtz Functions 9.4
 - 9.2.1 Internal Energy 9.4
 - 9.2.2 Enthalpy 9.4
 - 9.2.3 Helmholtz Free Energy 9.5
 - 9.2.4 Gibbs Function 9.5
- 9.3 Maxwell's Equations 9.6
- 9.4 TdS Relations 9.9
 - 9.4.1 TdS Equations 9.9
 - 9.4.2 Volume Change Coefficients 9.10
- 9.5 Joule-Kelvin Effect 9.13
- 9.6 Clausius-Clapeyron Equation 9.16
 - 9.6.1 Equation 9.17
- 9.7 Gibbs Phase Rule 9.20
- 9.8 General Relations 9.20
 - 9.8.1 Internal Energy 9.21
 - 9.8.2 Enthalpy 9.21
 - 9.8.3 Entropy 9.22

Points to Remember 9.22
Practice Problems 9.23
Multiple Choice Questions 9.23

10. Vapour Power Cycle

10.1–10.35

Introduction 10.1

- 10.1 Vapour Power Cycles 10.1
- 10.2 Rankine Cycle 10.2
- 10.3 Actual Vapour Cycle Processes 10.5
- 10.4 Piping Losses 10.5
- 10.5 Turbine Losses 10.6
- 10.6 Pump Losses 10.6
- 10.7 Condenser Losses 10.6
- 10.8 Reheat Cycle 10.11
- 10.9 Ideal Regenerative Cycle 10.16
- 10.10 Regenerative Cycle 10.17
- 10.11 Reheat-Regenerative Cycle 10.20
- 10.12 Binary Vapour Cycle 10.28
 - 10.12.1 Characteristics of an Ideal Working Fluid in Vapour Power Cycles 10.28

Points to Remember 10.33

Practice Problems 10.33

Multiple Choice Questions 10.34

11. Gas Power Cycles

11.1–11.27

Introduction 11.1

- 11.1 Engine 11.1
 - 11.1.1 Air Standard Assumption 11.2
- 11.2 Carnot Cycle (1824) 11.2
 - 11.2.1 Processes in Carnot Cycle 11.2
 - 11.2.2 Efficiency of a Carnot Cycle 11.3
- 11.3 Stirling Cycle (1827) 11.4
 - 11.3.1 Processes in Stirling Cycle 11.5
 - 11.3.2 Efficiency of Stirling Cycle 11.5
- 11.4 Ericsson Cycle (1850) 11.6
 - 11.4.1 Processes in Ericsson Cycle 11.6
- 11.5 Otto Cycle (1876) 11.8
 - 11.5.1 Analysis of Otto Cycle 11.8
- 11.6 Diesel Cycle 11.11
- 11.7 Lenoir Cycle 11.14
- 11.8 Atkinson Cycle 11.17
- 11.9 Brayton Cycle 11.19
- 11.10 Differences between Otto, Diesel and Dual Cycle 11.22

Points to Remember 11.24
Practice Problems 11.24
Multiple Choice Questions 11.26

12. Refrigeration Cycle

12.1–12.13

Introduction 12.1

- 12.1 Vapour Compression Refrigeration Cycle 12.1
 - 12.1.1 Features of Different Processes 12.2
 - 12.1.2 Deviations of Carnot Cycle 12.2
 - 12.1.3 Analysis of Vapour Compression Refrigeration Cycle 12.3
 - 12.1.4 Rating of a Refrigerator 12.3
- 12.2 Vapour Absorption Cycle 12.6
- 12.3 Gas Cycle of Refrigeration 12.7
 - 12.3.1 Description of Gas Refrigeration Cycle 12.8
 - 12.3.2 Expression for COP of an Ideal Gas Refrigeration Cycle with a Regenerative Heat Exchanger 12.9

Points to Remember 12.11
Practice Problems 12.12
Multiple Choice Questions 12.12

13. Psychrometrics

13.1–13.12

Introduction 13.1

- 13.1 Properties of Atmospheric Air 13.1
- 13.2 Psychrometric Chart 13.4
- 13.3 Psychrometric Process 13.5

Points to Remember 13.10
Practice Problems 13.11
Multiple Choice Questions 13.12

14. Reactive Systems

14.1–14.24

Introduction 14.1

- 14.1 Law of Mass Action 14.1
 - 14.1.1 Standard Derivation using Chemical Potential 14.2
- 14.2 Enthalpy of Formation and Enthalpy of Combustion 14.3
 - 14.2.1 Heat Generated by Combustion 14.3
 - 14.2.2 Enthalpy of Formation (ΔH_f^0) 14.3
 - 14.2.3 Enthalpy of Combustion 14.4
- 14.3 Combustion and Fuel 14.5
 - 14.3.1 Air-Fuel Ratio 14.6
 - 14.3.2 Factors Affecting the Process of Combustion 14.6
- 14.4 First Law for Reactive System 14.10
 - 14.4.1 For Steady Flow Systems 14.10

- 14.4.2 For Closed Systems 14.10
- 14.5 Adiabatic Flame Temperature 14.14
 - 14.5.1 Adiabatic Flame Temperature at Constant Volume 14.15
 - 14.5.2 Adiabatic Flame Temperature at Constant Pressure 14.15
- 14.6 Second Law Analysis of Reactive Systems 14.18
 - 14.6.1 Determination of Reversible Work 14.19

Points to Remember 14.21

Practice Problems 14.22

Multiple Choice Questions 14.22

Annexure 1: Enthalpy of Formation (at 298 K) for Commonly Used Fuels or Products 14.24

15. Gas Compressors

15.1–15.19

Introduction 15.1

- 15.1 Mechanical Energy 15.1
 - 15.1.1 Compressor 15.2
- 15.2 Reciprocating Air Compressor 15.3
 - 15.2.1 Theory 15.3
 - 15.2.2 Construction 15.3
 - 15.2.3 Working 15.3
 - 15.2.4 Important Terminology of Reciprocating Compressor 15.4
- 15.3 Work of Compression in Single Stage Compressor 15.5
 - 15.3.1 Indicated Work for a Single Acting Compressor Without Clearance 15.5
 - 15.3.2 Minimising Compression Work 15.6
 - 15.3.3 Methods for Improving Isothermal Efficiency 15.6
 - 15.3.4 Advantages of Compressor with Clearance Volume 15.6
 - 15.3.5 Disadvantages of Compressor with Clearance Volume 15.6
 - 15.3.6 Indicated Compression Work with Clearance 15.7
 - 15.3.7 Limitations of Single Stage Compression 15.9
- 15.4 Volumetric Efficiency 15.9
 - 15.4.1 Definition 15.9
 - 15.4.2 Free Air Delivery (FAD) 15.9
- 15.5 Multistage Compression 15.10
 - 15.5.1 Advantages 15.10
 - 15.5.2 Disadvantages 15.10
 - 15.5.3 Work Done in Multistage Compression 15.10
 - 15.5.4 Heat Rejected Per Stage of Compression 15.11
 - 15.5.5 Condition for Minimum Work 15.11
 - 15.5.6 Minimum Compressor Work 15.11
- 15.6 Rotary Compressor 15.13
 - 15.6.1 Introduction 15.13
 - 15.6.2 Advantages 15.13
 - 15.6.3 Disadvantages 15.13

15.6.4	Root Blower Type Rotary Compressor	15.14
15.7	Centrifugal Compressor	15.14
15.7.1	Introduction	15.14
15.7.2	Velocity Diagram	15.14
	<i>Points to Remember</i>	15.17
	<i>Practice Problems</i>	15.17
	<i>Multiple Choice Questions</i>	15.18

Appendix

A.1–A.36