

# Contents

## Part I : Thermodynamics 8

### 1 Thermodynamics 8

#### 1.1 Development 8

#### 1.2 Basic Concepts 8

##### 1.2.1 Approach to Thermodynamics 8

##### 1.2.2 Thermodynamic System 10

##### 1.2.3 Properties of a System 11

##### 1.2.4 Phase, Component, Pure Substance 13

##### 1.2.5 Equilibrium 12

##### 1.2.6 Diagram Form of Thermodynamic Relation 13

##### 1.2.7 Thermodynamic Process 16

##### 1.2.8 Basic Information on Gases 9

##### 1.2.9 Basic Quantities of Thermodynamic Systems 18

#### 1.3 Basic Laws of Thermodynamics 27

##### 1.3.1 Zero-th Law of Thermodynamics 27

##### 1.3.2 First Law of Thermodynamics 27

Closed System 27

Open System 29

##### 1.3.3 Second Law of Thermodynamics 30

Kelvin-Planck and Clausius Statement 30

Carnot Principles 32

Mathematical Formulation of the Second Law 34

Entropy Balance 35

Entropy and Probability 35

##### 1.3.4 Third Law of Thermodynamics 36

#### 1.4 Mathematical Relations of Thermodynamics 36

##### 1.4.1 General Relations for State Functions $U, I, S$ 36

##### 1.4.2 Properties Defined by Partial Derivatives. Thermodynamic Surface 38

##### 1.4.3 Thermodynamic Surface 39

##### 1.4.4 Generalised Mayer relation 39

##### 1.4.5 Properties Involving an Ideal Gas System 40

Internal energy 40

Enthalpy 41

Entropy 42

#### 1.5 Reversible Processes in Ideal Gas 43

##### 1.5.1 Isochoric (Isometric) Process 43

##### 1.5.2 Isobaric Process 44

##### 1.5.3 Isothermal Process 46

##### 1.5.4 Isentropic Process 47

##### 1.5.5 Polytropic process 49

##### 1.5.6 Application of Reversible Processes - Operation of Compressor 51

Ideal Compressor 51

Real Compressor 53

#### 1.6 Mixtures of Ideal Gases 54

1.6.1	Composition of a Gas Mixture	54
1.6.2	Dalton's Law and Amagat's Law	55
1.6.3	Thermodynamic Characteristics of Mixtures	55
1.7	Irreversible Processes in Ideal Gas	56
1.7.1	Heat Transfer	57
1.7.2	Unrestrained Expansion	57
1.7.3	Throttling	58
1.7.4	Isothermal Mixing, Diffusion	58
1.7.5	Adiabatic Mixing at Constant Volume	59
1.7.6	Adiabatic Continual Mixing at Constant Pressure	60
1.7.7	Irreversible Adiabatic Expansion and Compression	61
1.8	Real Gases	62
1.8.1	Semi-Ideal Gas	63
1.8.2	Principle of Corresponding States	64
1.8.3	Equations of State of Real Gas	64
	Van der Waals' Equation of State	65
	Other Semiempirical Equations of State	67
1.9	Phase-Change Process	68
1.9.1	Phase Change Liquid-Vapour	68
1.9.2	Clapeyron-Clausius Equation	68
1.9.3	Properties of Water Vapour	69
1.9.4	Tables and Diagrams	71
1.10	Reversible Processes in Vapour Region	73
1.10.1	Isochoric process, $dv = 0$	73
1.10.2	Isobaric process, $dp = 0$	74
1.10.3	Isothermal process, $dT = 0$	75
1.10.4	Isoentropic process, $ds = 0$	75
1.11	Irreversible Processes in Vapour Region	76
1.11.1	Typical Irreversible Processes in Vapour	76
1.11.2	Throttling and Joule-Thomson's Effect	76
1.11.3	Mixing Processes	79
	Mixing at Constant Volume	79
	Mixing at Constant Pressure	79
1.12	Psychrometrics - Moist Air	81
1.12.1	Moist Air	81
1.12.2	Composition Characteristics of Moist Air	82
1.12.3	Moisture Characteristics	83
	Dew Point	84
	Adiabatic Saturation Temperature	85
1.12.4	Properties of Moist Air	85
1.12.5	Psychrometric Chart $i-x$	86
1.12.6	Isobaric Moist Air Processes	88
1.13	Processes with Chemical Reactions	91
1.13.1	Chemical Reactions	91
1.13.2	First Law Involving Chemical Reactions	92
1.13.3	Second Law Involving Chemical Reactions	95
1.13.4	Combustion	97



## **Part II : Heat Transfer 100**

### **2 Heat Transfer 100**

#### **2.1 Basic Concepts 100**

#### **2.2 Heat Transfer by Conduction 102**

##### **2.2.1 General Equation of Conduction Heat Transfer 102**

##### **2.2.2 Boundless Plane Wall 104**

##### **2.2.3 Boundless Cylindrical Wall 105**

##### **2.2.4 Spherical Wall 107**

#### **2.3 Heat Transfer by Convection 108**

##### **2.3.1 Concepts Related to Convection 108**

##### **2.3.2 Newton's Law of Cooling 109**

##### **2.3.3 Similarity and Dimensional Approach 109**

##### **2.3.4 Convection Without Phase Change 114**

###### **Forced Convection 112**

###### **Free Convection 113**

##### **2.3.5 Convection Involving Phase Change 112**

#### **2.4 Heat Transfer by Radiation 116**

##### **2.4.1 Basic Concepts 116**

##### **2.4.2 Plank's Law and Stefan- Boltzmann Law 117**

##### **2.4.3 Kirchhoff's Law 119**

##### **2.4.4 Lambert's Laws 119**

##### **2.4.5 Radiative Heat Transfer Between Two Parallel Surfaces 120**

##### **2.4.6 Radiative Heat Transfer Between a Closed Surface and an Enclosed Body 122**

##### **2.4.7 General Configuration of Irradiating Surfaces 123**

#### **2.5 Overall Heat Transfer 124**

##### **2.5.1 Plane Wall 123**

##### **2.5.2 Cylindrical Wall 125**

##### **2.5.3 Spherical Wall 125**

#### **2.6 Heat Exchanger 126**

##### **2.6.1 Parallel Flow Heat Exchanger 127**

##### **2.6.2 Counterflow Heat Exchanger 130**

##### **2.6.3 Comparison of Parallel Flow and Counterflow Exchanger 132**

##### **2.6.4 Condenser 132**

##### **2.6.5 Evaporator 133**

## **Part III : Compressible Flow 135**

### **3 Compressible Flow 135**

#### **3.1 Basic Laws of Compressible Flow 135**

##### **3.1.1 Mass Conservation Principle 135**

##### **3.1.2 Momentum Equation 135**

##### **3.1.3 Energy Conservation Principle 137**

##### **3.1.4 Increase of Entropy Principle 138**

#### **3.2 Characteristics of the Compressible Flow 138**

##### **3.2.1 Speed of Sound 138**

##### **3.2.2 Static and Stagnation Properties 140**

#### **3.3 Isentropic Flow 141**

- 3.3.1 Flow Discharge from Stagnation State 141
- 3.3.2 Critical State 143
- 3.3.3 Incompressible Flow Behaviour at Small Velocities 143
- 3.3.4 Shape of a Duct 144
- 3.3.5 Mass Flow Rate Flux 145
- 3.3.6 Dynamic Functions 146
- 3.4 Normal Shock Wave 146
  - 3.4.1 The Prandtl Equation 147
  - 3.4.2 Determination of State after the Shock Wave 149
  - 3.4.3 The Rankine - Hugoniot Equation 151
  - 3.4.3 Entropy Change Across the Shock Wave 151
- 3.5 Nozzles and Diffusers 152
  - 3.5.1 Design of a Nozzle 152
  - 3.5.2 Flow through the Nozzle 153
    - Converging Nozzle 153
    - Converging-Diverging Nozzle 154
  - 3.5.3 Design of a Subsonic Diffuser 156
  - 3.5.4 Actual Flow through Nozzles and Diffusers 156

## **Part IV : Cycles in Engineering Applications 159**

- 4 Cycles 159
  - 4.1 Basic Concepts 159
    - 4.1.1 Classification of Cycles 159
    - 4.1.2 Concepts Involving Reciprocating Engines 160
  - 4.2 Cycles of Internal Combustion Engines 160
    - 4.2.1 Dual Cycle 161
    - 4.2.2 Otto Cycle 163
    - 4.2.3 Diesel Cycle 164
    - 4.2.4 Cycles for Gas-Turbines 165
  - 4.3 Vapour Power Cycles 168
    - 4.3.1 Clausius-Rankine Cycle 168
    - 4.3.2 Regenerative Rankine Cycle 169
    - 4.3.3 Reheat Rankine Cycle 170
    - 4.3.4 Combined Gas-Vapour Power Cycles 171
  - 4.4 Refrigeration and Heat Pump Cycles 172
    - 4.4.1 Vapour Compression Refrigerator Cycle 172
    - 4.4.2 Gas Refrigeration Cycle 174

**Other Recommended Study Sources 176**