

BASIC MECHANICAL ENGINEERING

SECOND EDITION

 Pearson

Pravin Kumar

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Basic Mechanical Engineering

Second Edition

Pravin Kumar

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Dedicated to
My Wife and Sons

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Brief Contents

<i>Preface to the Second Edition</i>	xxvii
<i>Preface to the First Edition</i>	xxx
<i>About the Author</i>	xxxii
<i>Acknowledgements</i>	xxxiii
1. Concepts of Thermodynamics and Properties of Gases	1
2. Fuels and Combustion	55
3. Power Plant Engineering and Sources of Energy	73
4. Properties of Steam and Steam Generators	97
5. Steam and Gas Turbines	141
6. Internal Combustion Engines	182
7. Heat Transfer	225
8. Refrigeration and Air Conditioning	239
9. Fluid Mechanics and Hydraulic Machines	273
10. Air Compressors	330
11. Centroid and Moment of Inertia	352
12. Stress and Strain	377
13. Machine Elements	406
14. Flywheel and Governors	431
15. Power Transmission Devices	455
16. Couplings, Clutches, and Brakes	485
17. Engineering Materials	511
18. Mechanical Measurement	529
19. Machine Tools	556
20. Casting and Welding	597
21. Mechanical Working of Metals, Sheet Metal Work, Powder Metallurgy, and Smithy	655
22. Manufacturing Systems: NC, CNC, DNC, and Robotics	695
23. Heat Treatment	716
<i>Appendix 1: Mollier Diagram for Steam</i>	727
<i>Appendix 2: Steam Table</i>	728
<i>Index</i>	739

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Contents

<i>Preface to the Second Edition</i>	xxvii
<i>Preface to the First Edition</i>	xxx
<i>About the Author</i>	xxxix
<i>Acknowledgements</i>	xxxix

I CONCEPTS OF THERMODYNAMICS AND PROPERTIES OF GASES	1
1.1 Introduction	1
1.2 Important Terminologies Used in Thermodynamics	2
1.3 Specific Heat Capacity	8
1.3.1 Specific Heat at Constant Volume (C_v)	8
1.3.2 Specific Heat at Constant Pressure (C_p)	8
1.3.3 Relationship Between C_p and C_v	9
1.4 The First Law of Thermodynamics	10
1.4.1 Mechanical Equivalent of Heat	10
1.4.2 Internal Energy	11
1.4.3 Physical Interpretation of Internal Energy	12
1.4.4 Energy Transfer Across the System Boundary (Heat and Work)	13
1.4.5 Non-flow Processes	14
1.4.6 Application of First Law of Thermodynamics in Steady Flow Process and Variable Flow Process	24
1.4.7 Limitations of First Law of Thermodynamics	28
1.5 The Second Law of Thermodynamics	29
1.5.1 Kelvin–Planck Statement	29
1.5.2 Clausius Statement	29
1.5.3 Equivalence of Kelvin–Planck and Clausius Statement	30
1.6 Reversible and Irreversible Processes	32
1.7 The Carnot Cycle	32
1.8 The Clausius Inequality	34
1.9 Entropy and Entropy Generation	34
1.9.1 Entropy	34
1.9.2 Entropy Generation	35
1.9.3 Entropy Balance	35
1.9.4 Evaluation of Entropy Change	36
1.10 Third Law of Thermodynamics	41
1.11 Gas Laws	41
1.11.1 Boyle’s Law	42

1.11.2 Charles's Law 43
1.11.3 Gay–Lussac's Law 43
1.11.4 The Combined Gas Law 44
1.11.5 Gas Constant 45
Points to Remember 46
Important Formulae 48
Multiple-choice Questions 50
Fill in the Blanks 52
Review Questions 52
Exercise Problems 53

2 FUELS AND COMBUSTION

55

2.1 Introduction 55
2.2 Coal 56
 2.2.1 Analysis of Coal 57
 2.2.2 Advantages of Solid Fuels over the Liquid Fuels 58
2.3 Liquid Fuels 58
 2.3.1 Petroleum 58
 2.3.2 Kerosene 59
 2.3.3 Diesel 59
 2.3.4 Gasoline 60
 2.3.5 Calorific Value of Liquid Fuels 60
 2.3.6 Major Contents of Liquid Fuels 60
 2.3.7 Advantages and Disadvantages of Liquid Fuels over Solid Fuels 61
2.4 Gaseous Fuels 62
 2.4.1 Liquefied Petroleum Gas (LPG) 62
 2.4.2 Compressed Natural Gas (CNG) 62
 2.4.3 Advantages and Disadvantages of Gaseous Fuels over the Solid Fuels 63
2.5 Biofuels 63
 2.5.1 Bioalcohols 63
 2.5.2 Biodiesel 64
 2.5.3 Green Diesel 64
 2.5.4 Vegetable Oil 65
 2.5.5 Biogas 65
 2.5.6 Bioethers 65
 2.5.7 Syngas 65
 2.5.8 Solid Biofuels 65
 2.5.9 Scope of Second-generation Biofuels 66
2.6 Combustion 66
 2.6.1 Principle of Combustion 66
2.7 Determination of Calorific Value of Fuel Using Bomb Calorimeter 67
 Points to Remember 69
 Important Formulae 70
 Review Questions 72
 Exercise Problems 72

3 POWER PLANT ENGINEERING AND SOURCES OF ENERGY 73

- 3.1 Introduction 73
- 3.2 Prime Movers 73
 - 3.2.1 Historical Development of Prime Movers 74
- 3.3 Power Plant Engineering 74
 - 3.3.1 Thermal Power Plant 75
 - 3.3.2 Hydroelectric Power Plant 76
 - 3.3.3 Nuclear Power Plant 76
 - 3.3.4 Diesel Power Plant 80
 - 3.3.5 Tidal Power Plant 82
 - 3.3.6 The Geothermal Power Plant 85
 - 3.3.7 Windmill 87
- 3.4 Sources of Energy 89
 - 3.4.1 Renewable Energy 89
 - 3.4.2 Non-renewable Energy 91

Points to Remember 93

Multiple Choice Questions 94

Answers 95

Review Questions 95

4 PROPERTIES OF STEAM AND STEAM GENERATORS 97

- 4.1 Introduction 97
- 4.2 Formation of Steam at Constant Pressure 97
- 4.3 Throttling Calorimeter 108
- 4.4 Separating and Throttling Calorimeter 110
- 4.5 Steam Table 111
- 4.6 Mollier Diagram or h - S Chart 111
- 4.7 Steam Generators/Boilers 112
 - 4.7.1 Classification of Boilers 112
 - 4.7.2 Requirements of a Good Boiler 113
 - 4.7.3 Cochran Boiler 114
 - 4.7.4 Babcock and Wilcox Boiler 115
 - 4.7.5 Locomotive Boiler 116
 - 4.7.6 Lancashire Boiler 117
 - 4.7.7 Cornish Boiler 118
- 4.8 Boiler Mountings 118
 - 4.8.1 Safety Valves 118
 - 4.8.2 High Steam Low Water Safety Valve 120
 - 4.8.3 Water Level Indicator 121
 - 4.8.4 Pressure Gauge 122
 - 4.8.5 Feed Check Valve 122

- 4.8.6 Steam Stop Valve 123
- 4.8.7 Blow-off Cock 123
- 4.8.8 Fusible Plug 124
- 4.8.9 Manhole 125

4.9 Boiler Accessories 125

- 4.9.1 Economizer 125
- 4.9.2 Air Preheater 126
- 4.9.3 Superheater 127
- 4.9.4 Feed Pump 127
- 4.9.5 Injector 128
- 4.9.6 Steam Trap 128
- 4.9.7 Steam Separator 128
- 4.9.8 Pressure Reducing Valve 129

4.10 Performance of Boilers 129

- Points to Remember* 133
- Important Formulae* 135
- Multiple-choice Questions* 135
- Fill in the Blanks* 137
- Review Questions* 138
- Exercise Problems* 138

5 STEAM AND GAS TURBINES

141

5.1 Introduction 141

5.2 Steam Engines and their Working Principles 141

- 5.2.1 Modified Rankine Cycle: Theoretical Indicator Diagram 143
- 5.2.2 Rankine Cycle 145

5.3 Steam Turbines 147

- 5.3.1 Classification of Steam Turbine 147
- 5.3.2 Compounding of Impulse Turbine 153
- 5.3.3 Impulses-reaction Turbine (Reaction Turbine) 157
- 5.3.4 Differences Between Impulse and Reaction Turbines 164
- 5.3.5 Losses in Steam Turbines 164
- 5.3.6 Governing of Steam Turbines 164

5.4 Gas Turbines 165

- 5.4.1 Classification of Gas Turbine 165
- 5.4.2 Applications of Gas Turbines 165
- 5.4.3 Gas Turbine Cycle with Regenerator 175
- 5.4.4 Gas Turbine Cycle with Reheating and Intercooling 175

- Points to Remember* 176
- Important Formulae* 177

<i>Objective Questions</i>	178
<i>Fill in the Blanks</i>	179
<i>Review Questions</i>	180
<i>Exercise Problems</i>	181

6 INTERNAL COMBUSTION ENGINES

182

6.1 Introduction	182
6.2 Classification of I.C. Engines	183
6.3 Basic Structure of I.C. Engines	185
6.3.1 Nomenclature	187
6.4 Working Principle of I.C. Engines	188
6.4.1 Four-stroke Spark Ignition Engine	188
6.4.2 Four-stroke Compression Ignition Engine	190
6.4.3 Two-stroke Spark Ignition Engine	192
6.4.4 Two-stroke C.I. Engine	194
6.4.5 Comparison Between Four-stroke and Two-stroke Engines	196
6.4.6 Comparison Between S.I. and C.I. Engines	197
6.4.7 Comparison Between Otto Cycle and Diesel Cycle	197
6.5 Valve Timing Diagrams	197
6.5.1 Valve Timing Diagram for Four-stroke S.I. Engines	197
6.5.2 Port Timing Diagram for Two-stroke S.I. Engines	198
6.5.3 Valve Timing Diagram for Four-stroke C.I. Engine	199
6.6 Otto Cycle	200
6.7 Diesel Cycle	203
6.8 Dual Cycle	206
6.9 Engine Performance Parameters	209
6.10 Emission Control	212
6.10.1 Types of Emissions	212
6.10.2 Emission Control Techniques	212
6.11 Some Recent Developments in Automotive Technology	214
6.11.1 Multi-point Fuel Injection	214
6.11.2 Common Rail Direct Injection (CRDI)	216
6.11.3 Hybrid Engine	217
<i>Points to Remember</i>	218
<i>Important Formulae</i>	219
<i>Multiple-choice Questions</i>	219
<i>Fill in the Blanks</i>	220
<i>Review Questions</i>	221
<i>Exercise Problems</i>	222

7 HEAT TRANSFER	225
7.1 Introduction	225
7.1.1 Conduction	225
7.1.2 Convection	227
7.1.3 Radiation	228
7.1.4 Combined Heat Transfer	229
<i>Points to Remember</i>	235
<i>Important Formulae</i>	236
<i>Multiple-choice Questions</i>	237
<i>Review Questions</i>	238
<i>Exercise Problems</i>	238
8 REFRIGERATION AND AIR CONDITIONING	239
8.1 Introduction	239
8.2 Refrigerator and Heat Pump	240
8.3 Components of Refrigeration System	241
8.3.1 Evaporator	241
8.3.2 Compressor	241
8.3.3 Condenser	242
8.3.4 Expansion Valve	242
8.4 Types of Refrigeration Systems	242
8.4.1 Air-refrigeration System	242
8.4.2 Vapour Compression Refrigeration System	247
8.4.3 Absorption Refrigeration Cycle	250
8.5 Type of Refrigerants	250
8.6 Domestic Refrigerator	251
8.7 Psychrometry	253
8.8 Psychrometric Processes	254
8.8.1 Psychrometric Chart	254
8.9 Air Washers	264
8.10 Human Comfort Conditions	264
8.11 Room Air Conditioner	265
8.11.1 Window Air Conditioner	265
8.11.2 Split Air Conditioner	266
8.11.3 Difference Between Split and Window ACs	267
<i>Points to Remember</i>	268
<i>Important Formulae</i>	268
<i>Multiple-choice Questions</i>	269
<i>Review Questions</i>	271
<i>Exercise Problems</i>	272

9 FLUID MECHANICS AND HYDRAULIC MACHINES **273****FLUID MECHANICS 273****9.1 Introduction 273****9.2 Properties of Fluids 273**

9.2.1 Density 274

9.2.2 Viscosity 274

9.2.3 Newtonian and Non-Newtonian Fluids 276

9.2.4 Surface Tension 277

9.2.5 Capillarity 278

9.2.6 Pressure Variation with Depth 280

9.3 Bernoulli's Equation 281**9.4 Types of Flow 284****HYDRAULIC MACHINES 284****9.5 Introduction 284****9.6 Hydraulic Turbines 285**

9.6.1 Classification of Hydraulic Turbines 285

9.7 Terminology Used in Turbine 286**9.8 Pelton Turbine 287**

9.8.1 Main Components of Pelton Turbine 287

9.8.2 Selection of Speed of Pelton Turbine 288

9.8.3 Velocity Triangle for Pelton Turbine 289

9.9 Francis Turbine 293

9.9.1 Main Components of Francis Turbine 293

9.9.2 Different Shapes of Draft Tubes 295

9.10 Kaplan Turbine 299

9.10.1 Velocity Triangle for Kaplan Turbine 300

9.11 Governing of Turbines 304**9.12 Pumps 304****9.13 Centrifugal Pump 304**

9.13.1 Main Components of Centrifugal Pump 304

9.13.2 Velocity Triangle for Centrifugal Pump 306

9.13.3 Various Heads and Efficiencies of
Centrifugal Pumps 3079.13.4 Some Important Points Related to
Centrifugal Pump 307**9.14 Reciprocating Pump 311**

9.14.1 Air Vessels 315

9.15 Gear Pump 317

- 9.16 Vane Pump 318
- 9.17 Lobe Pump 318
- 9.18 Screw Pump 319
 - 9.18.1 Two-screw, Low-pitch, Screw Pump 319
 - 9.18.2 Three-screw, High-pitch, Screw Pump 319
 - Points to Remember* 321
 - Important Formulae* 322
 - Multiple-choice Questions* 325
 - Review Questions* 327
 - Exercise Problems* 328

10 AIR COMPRESSORS

330

- 10.1 Introduction 330
- 10.2 Classification of Compressors 330
- 10.3 Reciprocating Compressors 331
 - 10.3.1 Polytropic Compression 333
 - 10.3.2 Isothermal Compression 334
 - 10.3.3 Effect of Clearance on Work Done 334
 - 10.3.4 Volumetric Efficiency 335
 - 10.3.5 Multistage Compression 337
 - 10.3.6 Work Done in Multistage Compression 337
- 10.4 Rotary compressors 342
 - 10.4.1 Fixed Vane Type Compressors 342
 - 10.4.2 Multiple Vane Type Rotary Compressors 343
- 10.5 Centrifugal Compressors 344
- 10.6 Axial Flow Compressors 345
 - Points to Remember* 346
 - Important Formulae* 347
 - Multiple-choice Questions* 348
 - Fill in the Blanks* 350
 - Review Questions* 350
 - Exercise Problems* 351

11 CENTROID AND MOMENT OF INERTIA

352

- 11.1 Introduction 352
- 11.2 Determination of Position of Centroid of Plane Geometric Figures 352
 - 11.2.1 Center of Gravity, Center of Mass, and Centroid of an Irregular Shape 352
 - 11.2.2 Centroid of I-section 354

11.2.3	Centroid of U-section	354
11.2.4	Centroid of H-section	355
11.2.5	Centroid of L-section	355
11.2.6	Centroid of T-section	356
11.2.7	Centroid of C-section	356
11.2.8	Centroid of Circular Arc	357
11.2.9	Centroid of Semicircular-section of a Disc	357
11.2.10	Centroid of a Sector of a Circular Disc	358
11.2.11	Centroid of a Parabola	358
11.2.12	Centroid of a Triangle	359
11.3	Second Moment of Area	360
11.3.1	Radius of Gyration	360
11.3.2	Theorem of Perpendicular Axis	361
11.3.3	Theorem of Parallel Axis	361
11.3.4	Moment of Inertia from First Principle	361
11.3.5	Moment of Inertia of Some Composite Sections	363
11.4	Center of Gravity of Solids	363
11.5	Mass Moment of Inertia	363
11.5.1	Mass Moment of Inertia of a Circular Ring	363
11.5.2	Mass Moment of Inertia of a Circular Disc	364
11.5.3	Mass Moment of Inertia of a Hollow Cylinder	365
11.5.4	Mass Moment of Inertia of Sphere	365
11.5.5	Mass Moment of Inertia of a Circular Cone	366
	<i>Points to Remember</i>	368
	<i>List of Mass Moment of Inertia</i>	368
	<i>List of Area Moment of Inertia</i>	371
	<i>Important Formulae</i>	373
	<i>Multiple-choice Questions</i>	374
	<i>Review Questions</i>	375
	<i>Exercise Problems</i>	376

12 STRESS AND STRAIN

377

12.1	Introduction	377
12.2	Hooke's Law	379
12.3	Stress–Strain Diagram	379
12.4	Extension in Varying Cross-section or Taper Rod	383
12.5	Stress and Strain in Varying Cross-section Bar of Uniform Strength	385
12.6	Stress and Strain in Compound Bar	386
12.7	Stress and Strain in an Assembly of Tube and Bolt	387
12.8	Stress and Strain in Composite Bar	392
12.9	Temperature Stress	393

12.10 Stress and Strain Due to Suddenly Applied Load 394
12.11 Stress and Strain for Impact Load 395
12.12 Relation Between Stress and Volumetric Strain 396
12.13 Relation Between Modulus of Elasticity and Bulk Modulus 397
12.14 Relation Between Modulus of Elasticity and Modulus of Rigidity 397
 Points to Remember 401
 Important Formulae 402
 Multiple-choice Questions 403
 Review Questions 404
 Exercise Problems 405

13 MACHINE ELEMENTS

406

SPRINGS 406

13.1 Introduction 406
13.2 Types of Springs 407
13.3 Materials used for Springs 409
13.4 Shear Stress in Helical Springs 410
13.5 Deflection in Helical Spring 412
13.6 Series and Parallel Connection of Helical Springs 414

CAM AND FOLLOWER 416

13.7 Introduction 416
13.8 Types of Cams 417
13.9 Types of Followers 418

BUSHING AND ROLLER BEARING 420

13.10 Introduction 420
13.11 Bushing Materials 420
13.12 Bearings 421
 13.12.1 Sliding Contact or Bush Bearings 421
 13.12.2 Rolling Contact Bearings 422
13.13 Properties of Bearing Materials 426
13.14 Bearing Materials 427
 Points to Remember 427
 Important Formulae 427
 Multiple-choice Questions 428
 Review Questions 430
 Exercise Problems 430

14 FLYWHEEL AND GOVERNORS 431

FLYWHEEL 431

14.1 Introduction 431

14.2 Mass Moment of Inertia of Flywheel 432

GOVERNORS 434

14.3 Introduction 434

14.4 Terminology Used in Governors 435

14.5 Classification of Governors 436

14.6 Gravity Controlled Centrifugal Governors 436

14.6.1 Watt Governor 436

14.6.2 Porter Governor 437

14.6.3 Proell Governor 440

14.7 Spring Controlled Centrifugal Governor 442

14.7.1 Hartnell Governor 442

14.7.2 Willson–Hartnell Governor 445

14.7.3 Hartung Governor 447

14.8 Sensitiveness of Governors 448

14.9 Governing of I.C. Engines 449

14.9.1 Qualitative Governing 449

14.9.2 Quantitative Governing 449

14.9.3 Hit and Miss Governing 449

14.10 Differences Between Flywheel and Governors 450

Points to Remember 450

Important Formulae 451

Multiple-choice Questions 452

Review Questions 453

Exercise Problems 454

15 POWER TRANSMISSION DEVICES 455

15.1 Introduction 455

15.2 Belt Drive 455

15.2.1 Type of Belt Cross-sections 456

15.2.2 Velocity Ratio 457

15.2.3 Creep 458

15.2.4 Flat Belt Drives 458

15.2.5 Ratio of Tensions 463

15.2.6 Effect of Centrifugal Force on Belt Drive 465

15.3 Rope Drive 468

- 15.4 Chain Drive 469
 - 15.4.1 Chain Length 469
 - 15.4.2 Types of Chain 471
- 15.5 Gear Drive 472
 - 15.5.1 Gear Terminology 472
 - 15.5.2 Law of Gearing 474
 - 15.5.3 Forms of Teeth 475
- 15.6 Classification of Gears 476
 - 15.6.1 Parallel Shafts 476
 - 15.6.2 Intersecting Shaft 477
 - Points to Remember* 479
 - Important Formulae* 480
 - Multiple-choice Questions* 481
 - Fill in the Blanks* 482
 - Review Questions* 483
 - Exercise Problems* 483

16 COUPLINGS, CLUTCHES, AND BRAKES

485

COUPLINGS 485

- 16.1 Introduction 485
- 16.2 Rigid Coupling 485
- 16.3 Flexible Bushed Coupling 486
- 16.4 Universal Joint 487

CLUTCHES 488

- 16.5 Introduction 488
- 16.6 Single Plate Clutch 488
- 16.7 Multi-plate Disc Clutch 493
- 16.8 Cone Clutch 494
- 16.9 Centrifugal Clutch 496

BRAKES 497

16.10 Introduction 497

- 16.10.1 Block or Shoe Brake 497
- 16.10.2 Band Brake 500
- 16.10.3 Band and Block Brake 503
- 16.10.4 Internal Expanding Shoe Brake 504
- Points to Remember* 507
- Important Formulae* 507
- Multiple-choice Questions* 508
- Review Questions* 509
- Exercise Problems* 510

17 ENGINEERING MATERIALS	511
17.1 Introduction	511
17.2 Mechanical Properties of Engineering Materials	512
17.3 Mechanical Testing of Engineering Materials	513
17.3.1 Tensile Test	513
17.3.2 Hardness	515
17.4 Impact Test	518
17.5 Classification of Engineering Materials	519
17.5.1 Ferrous Metals	519
17.5.2 Non-ferrous Metals	522
17.5.3 Plastics	523
17.5.4 Abrasive Materials	524
17.5.5 Ceramics	524
17.5.6 Silica	525
17.5.7 Glasses	525
<i>Points to Remember</i>	525
<i>Multiple-choice Questions</i>	526
<i>Review Questions</i>	528
18 MECHANICAL MEASUREMENT	529
18.1 Introduction	529
18.2 Temperature Measurement	530
18.2.1 Thermocouple	530
18.2.2 Resistance Temperature Devices (RTD)	530
18.2.3 Infrared Temperature Measurement Devices	530
18.2.4 Bimetallic Temperature Measurement Devices	530
18.2.5 Fluid-expansion Temperature Measurement Devices	531
18.2.6 Change-of-state Temperature Measurement Devices	531
18.3 Pressure Measurement	531
18.3.1 Manometers	532
18.3.2 Bourdon Tube Pressure Gauge	533
18.3.3 Low Pressure Measurement	534
18.4 Velocity Measurement	535
18.4.1 Velocity Measurement of Fluid with Pitot Tube	535
18.4.2 Hot Wire Anemometer	536
18.5 Flow Measurement	536
18.5.1 Flow Measurement Through Velocity of Fluid Over Known Area	536
18.5.2 Orificemeter	538
18.5.3 Rotameter	538

18.6 Strain Measurement	539
18.6.1 Strain Gauge	540
18.7 Force Measurement	541
18.7.1 Cantilever Beam	542
18.8 Torque Measurement	543
18.8.1 Prony Brake Dynamometer	543
18.8.2 Rope Brake Dynamometer	543
18.8.3 Torque Measurement by Pointer and Scale	544
18.9 Measurement Errors	545
18.10 Uncertainties of Measurement	546
18.11 Vernier calipers	546
18.12 Micrometer or Screw Gauge	547
18.12.1 Measurement Procedure	549
18.13 Dial Gauge or Dial Indicator	549
18.14 Slip Gauges	549
18.14.1 Classification of Slip Gauges	550
18.14.2 Applications of Slip Gauge	551
18.15 Sine Bar	551
18.16 Combination Set	552
<i>Points to Remember</i>	553
<i>Multiple-choice Questions</i>	554
<i>Review Questions</i>	555

19 METAL CUTTING AND MACHINE TOOLS

556

19.1 Introduction	556
19.2 Mechanism of Metal Cutting	557
19.2.1 Types of Chip Formation	557
19.3 Orthogonal and Oblique Metal Cutting	558
19.4 Lathe	559
19.4.1 Classification of Lathes	559
19.4.2 Specifications of Lathe	560
19.4.3 Constructional Detail of Lathe	560
19.4.4 Power Transmission System in Lathe Machine	562
19.4.5 Cutting Tools Used in Lathe	564
19.4.6 Types of Operations on Lathe Machine	564
19.5 Shaper, Slotter, and Planer	569
19.5.1 Shaping and Planing	569
19.5.2 Constructional Detail of Shaper	570
19.5.3 Slotter Machine	571

19.5.4	Crank and Slotted Arm Quick Return Mechanism	571
19.5.5	Specification of Shaper	572
19.5.6	Constructional Detail of Planer	573
19.5.7	Fast and Loose Pulleys Driving Mechanism of Planer	573
19.5.8	Specifications of Planer	575
19.5.9	Difference Between Shaper and Planer	575
19.6	Drilling Machine	575
19.6.1	Driving Mechanism in Drilling Machine	575
19.6.2	Drill Bit	576
19.6.3	Specifications of a Drilling Machine	577
19.6.4	Operations Performed on Drilling Machine	577
19.6.5	Advanced Types of Drilling Machine	579
19.7	Boring	580
19.7.1	Specification of Boring Machines	580
19.8	Milling Machines	581
19.8.1	Constructional Detail of Milling Machine	581
19.8.2	Basic Milling Operations	582
19.8.3	Nomenclature of Milling Cutter	585
19.9	Grinding Machines	586
19.9.1	Grinding Wheel Specification	586
19.9.2	Methods of Grindings	588
19.9.3	Cylindrical Grinders	589
19.9.4	Plain Cylindrical Grinders	590
19.9.5	Plain Surface Grinders	590
19.9.6	Universal Cylindrical Grinders	591
19.9.7	Centerless Grinders	591
	<i>Points to Remember</i>	593
	<i>Multiple-choice Questions</i>	594
	<i>Fill in the Blanks</i>	595
	<i>Review Questions</i>	596

20 CASTING AND WELDING

597

CASTING 597

20.1	Introduction	597
20.2	Classification of Casting Process	598
20.3	Sand Casting	598
20.3.1	Steps in Sand Casting	599
20.3.2	Pattern Making	600
20.3.3	Types of Pattern	601
20.3.4	Mould Making	605
20.3.5	Properties of Mouldings Sands	607
20.3.6	Hand Tools Used in Moulding	608

20.3.7	Moulding Procedure	609
20.3.8	Gating System	610
20.3.9	Chills	611
20.3.10	Chaplets	612
20.3.11	Cores	612
20.3.12	Sand Testing	614
20.4	Special Casting Methods	615
20.4.1	Gravity/Permanent Mould Casting	615
20.4.2	Die Casting	615
20.4.3	Centrifugal Casting	617
20.5	Casting Defects	619
20.6	Surface Cleaning of the Casting	621
	WELDING	622
20.7	Introduction	622
20.7.1	Definition of Welding	622
20.8	Classification of Welding Process	624
20.9	Gas Welding	625
20.9.1	Oxyacetylene Welding	625
20.9.2	Gas Welding Methods	628
20.10	Electric Arc Welding	629
20.10.1	Functions of Electrode Coatings	631
20.10.2	Ingredients of Electrode Coating	632
20.10.3	Selection of Electrodes	632
20.10.4	Specifications for Electrodes	632
20.11	Types of Electric Arc Welding	633
20.11.1	Carbon Arc Welding	633
20.11.2	Shielded Metal Arc Welding (SMAW)	633
20.11.3	Metal Inert Gas Arc Welding (MIG)/Gas Metal Arc Welding (GMAW)	634
20.11.4	Tungsten Inert Gas Arc Welding (TIG)/Gas Tungsten Arc Welding (GTAW)	635
20.11.5	Submerged Arc Welding (SAW)	636
20.11.6	Electroslag Welding	637
20.11.7	Atomic Hydrogen Welding	638
20.11.8	Plasma Arc Welding	639
20.12	Resistance Welding	640
20.12.1	Resistance Spot Welding	641
20.12.2	Resistance Seam Welding	642
20.12.3	Resistance Projection Welding	642
20.12.4	Flash Welding	643

- 20.12.5 Percussion Welding 644
- 20.12.6 Resistance Butt Welding 645
- 20.13 Thermit Welding 645**
- 20.14 Welding Allied Processes 645**
 - 20.14.1 Soldering 645
 - 20.14.2 Brazing 646
 - 20.14.3 Braze Welding 647
- 20.15 Welding Defects 648**
 - Points to Remember* 649
 - Multiple-choice Questions* 650
 - Fill in the Blanks* 653
 - Review Questions* 654

21 MECHANICAL WORKING OF METALS, SHEET METAL WORK, POWDER METALLURGY, AND SMITHY 655

MECHANICAL WORKING PROCESS 655

- 21.1 Introduction 655**
 - 21.1.1 Advantages of Mechanical Working Process Over Other Manufacturing Processes 656
- 21.2 Rolling 657**
 - 21.2.1 Terminology 657
 - 21.2.2 Types of Rolling Mills 658
 - 21.2.3 Rolling Defects 659
- 21.3 Forging 660**
 - 21.3.1 Different Types of Forging 660
- 21.4 Extrusion 663**
 - 21.4.1 Hot Extrusion 664
 - 21.4.2 Cold Extrusion 664
 - 21.4.3 Impact Extrusion 664
- 21.5 Wire Drawing 665**
- 21.6 Bar Drawing 666**
- 21.7 Tube Drawing 666**
- 21.8 High Energy Rate Forming 667**
 - 21.8.1 Explosive Forming 667
 - 21.8.2 Electrohydraulic Forming 668
 - 21.8.3 Electromagnetic Forming 668
- 21.9 Thread Rolling 668**
- 21.10 Piercing or Seamless Tubing 669**
- 21.11 Some Other Forming Processes 670**

SHEET METAL PROCESS 671

21.12 Introduction 671

21.13 Sheet Metal Joints 671

21.14 Materials Used for Sheet Metal 672

21.15 Hand Tools Used in Sheet Metal Work 673

21.16 Sheet Metal Operations 677

21.16.1 Shearing 677

21.16.2 Bending 678

21.16.3 Stretch Forming 678

21.16.4 Deep Drawing 678

21.16.5 Hot Spinning 680

POWDER METALLURGY 681

21.17 Introduction 681

21.18 Manufacturing of Metal Powders 681

21.18.1 Characteristics of Metal Powder 681

21.18.2 Methods of Production 681

21.19 Blending/Mixing of the Metal Powders 682

21.20 Compacting 683

21.21 Sintering 684

21.22 Finishing Operations 684

21.23 Advantages of Powder Metallurgy 684

21.24 Limitations of Powder Metallurgy 685

21.25 Applications of Powder Metallurgy 685

SMITHY 685

21.26 Introduction 685

21.27 Major Tools Used in Smithy Shop 686

21.27.1 Smith's Forge or Hearth 686

21.27.2 Anvil 686

21.27.3 Hammer 687

21.27.4 Swage Block 688

21.27.5 Tongs 689

21.27.6 Chisels 689

21.27.7 Punches 690

21.27.8 Flatters 690

21.27.9 Set Hammer 690

21.27.10 Fullers 690

21.27.11 Swages 691

<i>Points to Remember</i>	691
<i>Multiple-choice Questions</i>	693
<i>Fill in the Blanks</i>	693
<i>Review Questions</i>	694

22 MANUFACTURING SYSTEMS: NC, CNC, DNC, AND ROBOTICS 695

22.1 Introduction 695

22.1.1 Production Machines, Tools, Fixtures, and Other Related Hardware	695
22.1.2 Material Handling System	696
22.1.3 Computer Systems	696
22.1.4 Human Workers	696

22.2 Automation 696

22.3 Computer Integrated Manufacturing (CIM) 698

22.4 CAD/CAM 698

22.4.1 Computer Aided Design (CAD)	698
22.4.2 Computer Aided Manufacturing (CAM)	699

22.5 Numerical Control (NC) 700

22.5.1 Limitations/Drawback of Conventional NC System	700
--	-----

22.6 Computer Numerical Control (CNC) 701

22.7 Programming Methods 701

22.8 Comparison of NC and CNC Machines 703

22.9 Direct Numerical Control (DNC) 703

ROBOTICS 704

22.10 Introduction 704

22.11 Robot Anatomy 705

22.12 Three Degree of Freedom for Robot's Wrist 706

22.13 Robot Configurations 706

22.14 Robot Control 708

22.14.1 Type of Robot Control	708
-------------------------------	-----

22.15 Control Systems 709

22.15.1 Basic Form of Control Systems	709
22.15.2 Sequential Control	711
22.15.3 Microprocessor Based Controllers	711
22.15.4 Sensors Used in Robotics	711
22.15.5 Transducers used in Robotics	712

22.16 Applications of Robots 712

- Points to Remember* 713
- Multiple-choice Questions* 714
- Review Questions* 715

23 HEAT TREATMENT **716**

- 23.1 Introduction 716
- 23.2 Iron–Carbon Phase Diagram 716
- 23.3 TTT (Time–Temperature–Transformation) Diagram 718
- 23.4 Normalizing 719
- 23.5 Annealing 720
- 23.6 Spheroidizing 720
- 23.7 Hardening 720
- 23.8 Tempering 721
 - 23.8.1 Austempering 721
 - 23.8.2 Martempering 721
- 23.9 Carburizing 722
- 23.10 Cyaniding 723
- 23.11 Nitriding 723
- 23.12 Induction Hardening 723
 - Points to Remember* 724
 - Multiple-choice Questions* 725
 - Fill in the Blanks* 725
 - Review Questions* 726

<i>Appendix 1: Mollier Diagram for Steam</i>	727
<i>Appendix 2: Steam Table</i>	728
<i>Index</i>	739

Preface to the Second Edition

It is my great pleasure to present the second edition of the Basic Mechanical Engineering textbook after the much praised first edition of the book. Due to continuous change in the curriculum of the engineering education, it becomes necessary to modify the contents of the book as per the requirements of the universities. After the first edition, it has been observed that few topics of the book are not much relevant for the first year engineering students, for example, Chapter 13—Lifting Machines and Chapter 23—Unconventional Machining Processes and therefore, these two chapters are removed from the second edition of the book.

Also, in the second edition, several topics have been added. Global warming and bio-fuels are now discussed in detail in Chapter 2. Due to fast change in the technology, some advanced technologies such as Multi-point Fuel Injection Engine (MPFI), Common Rail Direct Injection (CRDI), Hybrid Engines have been introduced in Chapter 6. Chapter 13 has been upgraded by removing the Lifting Machines and adding spring, CAM and followers, and bushing and bearing. In Chapter 19, grinding and surface finishing processes have been included. Smithy works have been added in Chapter 21. Introduction to Automation and Robotics have been included in Chapter 22.

In addition to the above changes, some minor improvements have been done in the entire book and the questions asked in various university examinations have also been included. These questions are indicated by an asterisk (*) symbol.

Chapter Structure and Coverage

This book provides a basic knowledge of the various aspects of mechanical engineering. The chapter structure and coverage are discussed below:

Chapter 1 covers the laws of thermodynamics and properties of gases. Under the laws of thermodynamics, we first discuss, second and third laws of thermodynamics, concepts of specific heat, enthalpy, entropy, etc., followed by the discussion on properties of gases such as Boyle's Law, Charles's Law, Gay Lussac's Law, combined gas law and gas constant, etc.

Chapter 2 deals with fuels and their combustion. The various types of fuels such as solid, liquid, and gaseous fuels are introduced and their applications for power generation have been discussed. Again to measure the calorific value of fuel, a basic idea about calorimeters and their working procedure has been given.

Chapter 3 describes power plant engineering. In this chapter, the methods of conversion of various forms of energy into mechanical energy and electrical energy along with an introduction to the basic concepts of thermal power plant, hydroelectric power plant, and nuclear power plant with some of the non-conventional energy sources has been discussed.

Chapter 4 covers steam properties and its generation. Various properties of steam such as internal energy, enthalpy, and entropy at different ambient conditions are discussed. The steam table and the Mollier diagram that are helpful in showing the methods to find the properties of steam at the given condition are also introduced. In addition to this, the working of steam generators (boilers) and the functions of various mountings and accessories used in boilers are also discussed.

Chapter 5 deals with the conversion of heat energy into mechanical energy or shaft power followed by discussion on the working of steam engines, steam turbines, and gas turbines in detail. These are the devices used to convert heat energy carried by steam or gases into shaft power. The shaft power is further converted into electrical energy using an electricity generator.

Chapter 6 describes internal combustion engines and their working. There is a wide scope to discuss various mechanisms and developments in I.C. engines, we have however focused our discussion only to the basic concepts of working on I.C. engines such as petrol (Gasoline) engines, diesel engines, two-stroke engines, four-stroke engines, thermodynamic cycles, and performance measurement of an I.C. engine.

Chapter 7 deals with the various modes of heat transfer. It gives a basic idea about the thermal conductivity and the overall heat transfer coefficient.

Chapter 8 covers refrigeration and air conditioning. Refrigeration deals with the various types of processes such as vapor compression refrigeration, air refrigeration, absorption type refrigeration, and the properties of some of the refrigerants. Air conditioning deals with psychrometric properties of air and the processes to control these properties.

Chapter 9 covers fluid mechanics and hydraulic machines. Fluid mechanics provides an introduction to fluid statics and fluid dynamics. Hydraulic machines deal with the working of water turbines, water pumps, hydraulic coupling, and torque converters.

Chapter 10 describes air compression systems. Single-stage and multistage compressors, as well as rotary compressors, are discussed in detail and vane type compressors, centrifugal compressors, and axial flow compressors are discussed at an introductory level.

Chapter 11 describes centroid, the center of gravity and moment of inertia for various sections. Parallel and perpendicular axis theorems are used to find the moment of inertia for the different cross sections. This chapter is very useful to analyze the dynamics of a machine element.

Chapter 12 describes stress and strain, that is, the properties of materials under various types of loading. It also demonstrates relationships among different types of elastic constants.

Chapter 13 deals with springs, different types of CAMs and followers, bushing and bearing.

Chapter 14 describes the working of flywheel and governor. Flywheel works just like an energy reservoir while governor controls the speed by controlling the fuel supply.

Chapter 15 deals with power transmission devices such as belt drive, chain drive, and gear drive. In belt drive, we discuss open and cross belt drives and their applications; in the chain drive, we provide a basic idea about the power transmission mechanisms; and in gear drive, we discuss different types of gears and working on gear trains.

Chapter 16 covers other types of power transmission devices such as coupling and clutch. It also discusses the mechanisms of various types of braking systems. Clutch provides a flexibility to engage or disengage the engine from the load.

Chapter 17 covers some of the important engineering materials and their mechanical properties such as tensile strength, hardness, toughness, ductility, malleability, etc. Some practical methods to measure the tensile strength, hardness, and toughness are also discussed.

Chapter 18 demonstrates various types of measurements such as the measurement of pressure, velocity, flow, force, torque, etc. Also, some of the devices used in metrology have been introduced such as vernier caliper, screw gauge, sine bar, dial gauge and slip gauge.

Chapter 19 deals with the mechanism of machining and working of various machine tools such as lathe, shaper and planer, drilling and boring, and milling operations.

Chapter 20 describes the primary shaping (casting) and joining (welding) processes such as welding. In this chapter, sand casting and other casting processes with casting defects are discussed. Different conventional and non-conventional welding and allied processes with welding defects are also explained.

Chapter 21 covers various forging operations, sheet metal processes, and powder metallurgy. These are the basic processes frequently used in mechanical workshops.

Chapter 22 provides a basic idea of the numerical control machine, computer numerical control machine, and direct numerical control machines. Also, the basic concepts of automation and robotics have been discussed. These are the machines used in metal cutting with improved productivity and accuracy.

Chapter 23 deals with heat treatment processes. In this chapter, the mechanism of controlling the mechanical properties by heating and cooling with different rates is discussed.

Preface to the First Edition

In many institutions and universities, Basic Mechanical Engineering is a compulsory paper for the first year engineering students. This book covers a basic overview of several areas of mechanical engineering. The main purpose to teach Basic Mechanical Engineering to the non-mechanical students is to provide the knowledge of the basic mechanical operations and familiarize the students with the commonly used mechanical machines/instruments. It is broadly divided into three parts—thermal engineering, mechanical design, and manufacturing engineering.

In thermal engineering, we discuss various forms of energy transfer, laws of thermodynamics, steam properties and steam generators, fluid mechanics, turbines, internal combustion engines, heat transfer, refrigeration and air conditioning, compressors, etc. In mechanical design, we discuss the mechanism of working of machine elements such as belt drive, chain drive, gear drive, springs, CAM and follower, bushing and bearing, couplings, etc. Also, some basic concepts of centroid and moment of inertia, stress and strain, power transmission, etc have been discussed. In manufacturing engineering, we discuss basic manufacturing processes such as casting, welding, machining, machine tools (Lathe, Drilling, Boring, Slotting, Shaper, Planer, Milling, and Grinding Machines), powder metallurgy, sheet metal working, smithy and metrology and provide a basic idea of automation (NC, CNC, DNC) and robotics. Thus, the basic concepts of mechanical engineering are covered completely and hence this book will be useful to both mechanical as well as other engineering students. In this book, the author has tried to cover the maximum syllabi of all the major institutions/universities in India.

Pravin Kumar

About the Author



Pravin Kumar obtained his Ph.D. from IIT Delhi and M.Tech. from Institute of Technology (BHU), Varanasi. Presently, he is working as a faculty in the Department of Mechanical Engineering, Delhi Technological University (Formerly Delhi College of Engineering). He has more than 16 years of teaching and research experience. He has been teaching Basic Mechanical Engineering for several years. He has also authored two more books—Industrial Engineering and Management, published by Pearson Education, and Fundamentals of Engineering Economics, published by Wiley India Pvt. Ltd. He has published more than 50 research papers in the National and International Journals and Conferences.

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I am grateful to my elder brothers Arun Kumar Singh and Pramod Kumar for their moral support and motivation to pursue my research and publish this work. I would like to thank my wife Dr Prerna Sinha and my sons Harshit and Arpit for their support, patience, and wholehearted participation in accomplishing this work. I am also grateful to all the well-wishers, whose names could not be mentioned here, for their direct and indirect support. I would also like to express my gratitude to my parents, father-in-law and mother-in-law, who remain a continuous source of inspiration.

Last but not least, I am immensely grateful to the Pearson Education, especially Harsha Singh and G. Sharmilee, for their continuous support during writing and editing process of the book. This book could not have attained its present form both in content and presentation without their active interest and direction.

Pravin Kumar

Concepts of Thermodynamics and Properties of Gases

Learning Objectives

By the end of this chapter, the student will be able:

- To describe the basic concepts of thermodynamics
- To state the laws of thermodynamics
- To apply the laws of thermodynamics for different engineering applications
- To state the gas laws and solve the related problems

1.1 ► INTRODUCTION

There are different forms of energy; all the energy cannot be used as a work. The convertibility of energy into work depends on its availability, i.e., how much energy can be converted into useful work. Thermodynamics is a branch of science and engineering that deals with interaction of energy mainly in the forms of heat and work. Thermodynamics is concerned with the thermal behavior of a matter and its interaction with other physical and chemical behavior of the matter. Broadly, thermodynamics is studied into two forms—Classical and Statistical. Classical thermodynamics is concerned with the macrostructure of matter. It addresses the gross characteristics of large aggregations of molecules and not the behavior of individual molecules. The microstructure of matter is studied in kinetic theory and statistical mechanics. Statistical thermodynamics is concerned with the microstructure of the matter and addresses behavior of individual molecules of the matter. In this chapter, only classical approach to thermodynamics has been discussed. Gases are very important part of engineering thermodynamics; therefore, to know the behavior of an ideal gas at standard temperature and pressure is very important. In this chapter, we have also discussed about the different gas laws and universal gas constants.

Macroscopic Vs Microscopic Viewpoint of Thermodynamics

Macroscopic and Microscopic views are used to study the behavior of the matter. If the matter is studied about its behavior on the basis of certain amount or volume without consideration of its properties at the molecular level, it is known as macroscopic thermodynamics. If the matter is studied at its molecular level for its properties, it is known as microscopic thermodynamics. Both, macroscopic and microscopic thermodynamics are discussed in the following sections in detail.

Macroscopic (Classical Thermodynamics)

- ▶ In this approach, a certain quantity or volume of the matter is considered, without taking into account the events occurring at the molecular level.
- ▶ This approach to the study of thermodynamic properties does not require knowledge of the behavior of individual particles.
- ▶ It is only concerned with the effects of the action of many combined molecules, and these effects can be perceived by human senses.
- ▶ The macroscopic observations are completely independent of the assumptions regarding the nature of matter.

Microscopic (Statistical Thermodynamics)

- ▶ From the microscopic viewpoint, it is assumed that matter is composed of a large number of small molecules and atoms.
- ▶ This approach to the study of thermodynamics requires knowledge of the behavior of individual particles.
- ▶ It is concerned with the effects of the action of many molecules, and these effects cannot be perceived by human senses.
- ▶ The microscopic observations are completely dependent on the assumptions regarding the nature of matter.

1.2 ► IMPORTANT TERMINOLOGIES USED IN THERMODYNAMICS

Thermodynamics: It is the field of thermal engineering that studies the properties of systems that have a temperature and involve the laws that govern the conversion of energy from one form to another, the direction in which heat will flow, and the availability of energy to do the work.

Mass and Force: Mass is one of the fundamental dimensions, like time, it cannot be defined in terms of other dimensions. Much of our intuition of what mass is followed from its role in Newton's second law of motion

$$F = M \cdot f$$

In this relationship, the force F required to produce a certain acceleration f of a particular body is proportional to its mass M .

Volume: The familiar property, volume, is formally defined as the amount of space occupied in three-dimensional space. The *SI* unit of volume is cubic meters (m^3).

Pressure: For a fluid system, the pressure is defined as the normal force exerted by the fluid on a solid surface or a neighboring fluid element, per unit area. From a molecular point of view, the pressure exerted by a gas on the walls of its container is a measure of the rate at which the momentum of the molecules colliding with the wall is changed.

The *SI* unit for pressure is a Pascal,

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

Also commonly used unit is bar, which is defined as

$$1 \text{ bar} = 10^5 \text{ Pa} = 10^5 \text{ N/m}^2$$

As a result of some practical devices measuring pressures relative to the local atmospheric pressure, we distinguish between gauge pressure and absolute pressure. Gage pressure is defined as

$$P_{\text{gauge}} = P_{\text{abs}} + P_{\text{atm}}$$

System: System is the fixed quantity of matter and/or the region that can be separated from everything else by a well-defined boundary/surface. Thermodynamic system is the system on which thermodynamic investigation is done. The surface separating the system and surroundings is known as the *control surface* or *system boundary*. The control surface may be movable or fixed. Everything beyond the system is the *surroundings*. A system of fixed mass is referred to as a closed system. When there is flow of mass through the control surface, the system is called an *open system*. An *isolated system* is a closed system that does not interact in any way with its surroundings.

Properties of a System

Any characteristic of a system by which its physical condition is defined called as property. Pressure, temperature, volume, mass, viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electrical resistivity, velocity, elevation, etc.

4 Chapter 1

are the examples of the properties of a system. Properties may be either *intensive* or *extensive*.

- ▶ Intensive properties are those that are independent of the mass of a system, such as temperature, pressure, and density.
- ▶ Extensive properties are those whose values depend on the size or extent of the system. Total mass, total volume, and total momentum are some examples of extensive properties.
- ▶ Extensive properties per unit mass are called specific properties.

State: At any instant of time, the condition of a system is called a *state*. The state at a given instant of time is defined by the properties of the system such as pressure, volume, temperature, etc. A *property* is any quantity whose numerical value depends on the state but not on the history of the system. There are two types of properties—extensive and intensive. Extensive properties depend on the size or extent of the system. Volume, mass, energy, and entropy are examples of extensive properties. An extensive property is additive in the sense that its value for the whole system equals the sum of the values for its molecules. Intensive properties are independent of the size or extent of the system. Pressure and temperature are examples of intensive properties.

State and Equilibrium

When no change occurs in the system properties, at this point, all the properties can be measured or calculated throughout the entire system. The properties at this static condition describe the state of the system. At a given state, all the properties of a system have fixed values. If the value of even one property changes, the state will change to a different one. The word equilibrium implies a state of balance. In an equilibrium state, there are no unbalanced potentials/forces within the system. When a system is isolated from its surroundings, the system experiences no change in it. There are mainly three types of equilibrium, and a system is not in thermodynamic equilibrium unless the conditions of all the three relevant types of equilibrium are satisfied:

- (a) Thermal equilibrium: Temperature should be same throughout the system.
- (b) Mechanical equilibrium: Unbalanced forces should be absent, e.g., change in pressure.
- (c) Chemical equilibrium: No chemical reaction and mass transfer occur.

Change in State: Thermodynamic system undergoes changes due to flow of mass and energy. The mode in which the changes in the state of a system take place is known as process such as isobaric (constant pressure) process, isochoric (constant volume) process,

isothermal (constant temperature) process, adiabatic (constant entropy) process, etc. The path is the loci of series of state changes from initial state to final state during a process. The changes in state and path of a process are shown in Figure 1.1. The thermodynamic cycle refers to the sequence of processes in which initial and final states of the system are same. For example, Otto cycle, Diesel cycle, Dual cycle, Joule cycle, Rankine cycle, Carnot cycle, etc. have identical initial and final states.

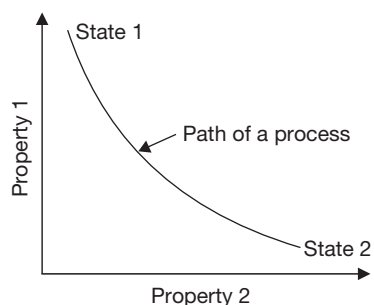


FIGURE 1.1

Change in State with a Process

Process: Two states are identical if, and only if, the properties of the two states are same. When any property of a system changes its value, there is a change in the state, and the system is said to undergo a *process*. When a system from a given initial state goes into a sequence of processes and finally returns to its initial state, it is said to have undergone a *cycle*.

Phase: Phase refers to a quantity of matter that is homogeneous throughout in its chemical composition and physical structure. A system can contain one or more phases. A mixture of water and water vapor has two phases. A pure substance is one that is uniform and invariable in chemical composition. A pure substance can exist in more than one phase, but its chemical composition must be the same in each phase. For example, if liquid water and water vapor form a system with two phases, the system can be regarded as a pure substance because each phase has the same composition.

Equilibrium: In thermodynamics the concept of equilibrium includes not only a balance of forces, but also a balance of other influencing factors, such as thermal equilibrium, pressure equilibrium, phase equilibrium, etc. To observe a thermodynamic equilibrium in a system, one may test it by isolation of the system from its surroundings and watch for changes in its observable properties. If no change takes place, it may be said that the system is in equilibrium. The system can be in an equilibrium state. When a system is isolated, it cannot interact with its surroundings; however, its state can change as a consequence of spontaneous changes occurring internally as its intensive properties, such as temperature and pressure, tend toward uniform values. When all such changes cease, the system is in equilibrium. At equilibrium, temperature and pressure are uniform throughout. If gravity is significant, a pressure variation with height can exist, as in a vertical column of liquid.

Systems and Control Volumes

A system is defined as a *quantity of matter or a region in space considered for study*. The mass or region outside the system is called the *surroundings*. The real or imaginary surface that

separates the system from its surroundings is called the boundary. The boundary of a system can be *fixed or movable*. *The boundary is the* contact surface shared by both the systems and the surroundings. The boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space.

Open and Closed Systems

Systems may be considered as closed, open, and isolated depending on the flow of mass and energy. A closed system consists of a fixed amount of mass, and no mass can cross its boundary. But energy, in the form of heat or work, can cross the boundary; and the volume of a closed system is not to be fixed necessarily. When the energy is also not allowed to cross the boundary, that system is called an isolated system. In an open system or a control volume, both mass and energy can cross the boundary of a control volume. In general, any arbitrary region in space can be selected as a control volume. The boundaries of a control volume are called a control surface, and they can be real or imaginary.

Zeroth Law of Thermodynamics

It is law of thermal equilibrium, which states that if a system A is in thermal equilibrium with systems B and C, then systems B and C will be in thermal equilibrium.

Zeroth law of thermodynamics is the basis of temperature measurement. To measure the temperature, a reference body is used, and a certain physical characteristic of this body, which changes with temperature is selected. The change in the selected characteristic may be taken as an indication of change in temperature. The selected characteristic is called the thermometric property, and the reference body, which is used in the determination of temperature is called the thermometer. A commonly used thermometer consists of a small amount of mercury in an evacuated capillary tube. In this case, the extension of the mercury in the tube is used as the thermometric property.

Quasi-static Process: When a process proceeds in such a way that the system remains infinitesimally close to an equilibrium state at all times, it is called a quasi static process. A quasi-static process can be understood as a sufficiently slow process that allows the system to adjust internally so that properties in one part of the system do not change any faster than those at other parts.

Temperature: Temperature is a property of a substance by which it can be differentiated from other substance in terms of degree of hot or cold. A scale of temperature independent of the thermometric substance is called a thermodynamic temperature scale. The Celsius temperature scale (centigrade scale) uses the degree Celsius ($^{\circ}\text{C}$), which has the same magnitude as the Kelvin. Thus, temperature differences are identical on both scales. However, the

zero point on the Celsius scale is shifted to 273.15 K, as shown by the following relationship between the Celsius temperature and the Kelvin temperature:

$$^{\circ}\text{C} = \text{K} - 273.15$$

Two other temperature scales are commonly used are the Rankine and Fahrenheit scale, the various relationships between temperature scales are as shown below:

$$\text{R} = 1.8 \text{K}$$

$$\text{F} = \text{R} - 459.67$$

$$\text{F} = 1.8^{\circ}\text{C} + 32$$

Internal Energy: The Internal Energy (U) of a system is the total energy content of the system. It is the sum of the kinetic, potential, chemical, electrical, and all other forms of energy possessed by the atoms and molecules of the system. U is path independent and depends only on temperature for an ideal gas. Internal energy may be stored in the system in the following forms:

- ▶ Kinetic energy of molecules.
- ▶ Molecular vibrations and rotations.
- ▶ Chemical bonds that can be released during a chemical reaction.
- ▶ Potential energy of the constituents of the system.

Work: Work in thermodynamics may be defined as any quantity of energy that flows across the boundary between the system and surroundings which can be used to change the height of a mass in the surroundings.

Heat: Heat is defined as the quantity of energy that flows across the boundary between the system and surroundings because of a temperature difference between system and surroundings. There are following characteristics of heat:

- ▶ Heat is transitory and appears during a change in state of the system and surroundings. It is not a point function.
- ▶ The net effect of heat is to change the internal energy of the system and surroundings in accordance to first law.
- ▶ If heat is transferred to the system, it is positive and if it is transferred from the system it is negative.

Enthalpy: Enthalpy, h , of a substance is defined as $h = u + PV$. It is intensive properties of a substance and measured in terms of kJ/kg.

1.3 ► SPECIFIC HEAT CAPACITY

1.3.1 Specific Heat at Constant Volume (C_v)

The rate of change of internal energy with respect to absolute temperature at constant volume is known as specific heat at constant volume (C_v).

$C_v = \left(\frac{\partial u}{\partial T} \right)_v$; Where u is internal energy and T is absolute temperature.

$$Q = \Delta u + W = \Delta u + PdV = \Delta u = \int_{T_1}^{T_2} C_v dT$$

Enthalpy is sum of internal energy and product of pressure and volume, i.e., $h = u + PV$. But,

$$Q = \partial u + PdV = \partial u + \partial(PV) = \partial(u + PV) = \partial h$$

since $dP = 0$ at constant pressure

1.3.2 Specific Heat at Constant Pressure (C_p)

The rate of change of enthalpy with respect to absolute temperature when pressure is constant is known specific heat at constant pressure (C_p).

$C_p = \left(\frac{\partial h}{\partial T} \right)_p$; for a constant pressure process.

$$\partial h = \partial Q = \int_{T_1}^{T_2} C_p dT$$

EXAMPLE 1.1

The property of a substance is given as

$$u = 186 + 0.718t$$

$$pv = 0.287(t + 273)$$

where u is the specific internal energy (kJ/kg), t is the temperature in °C, p is pressure in kN/m², and v is specific volume (m³/k). Find the C_v and C_p of the substance.

SOLUTION

$$C_v = \frac{\partial u}{\partial t} = 0.718 \text{ kJ/kg}$$

$$C_p = \frac{\partial h}{\partial t} = \frac{\partial(u + pv)}{\partial t} = \frac{\partial u}{\partial t} + \frac{\partial(pv)}{\partial t} = 0.718 \text{ kJ/kgK} + 0.287 \text{ kJ/kgK} = 1.005 \text{ kJ/kgK}$$

1.3.3 Relationship Between C_p and C_v

The specific heat capacity of a gas is the amount of heat required to raise the temperature by one degree Celsius of unit mass of the gas. We will use here specific values of the state variables (of the variable divided by the mass of the substance). The value of the constant is different for different materials and depends on the process. It is not a state variable.

If we are considering a gas, it is most convenient to use forms of the thermodynamic equations based on the enthalpy of the gas. From the definition of enthalpy:

$$h = u + pv$$

where h is the specific enthalpy, p is the pressure, v is the specific volume, and u is the specific internal energy. During a process, the values of these variables change. Let's denote the change by Δ . For a constant pressure process the enthalpy equation becomes:

$$\Delta h = \Delta u + p\Delta v$$

The enthalpy, internal energy, and volume are all changed, but the pressure remains the same. From our derivation of the enthalpy equation, the change of specific enthalpy is equal to the heat transfer for a constant pressure process:

$$\Delta h = c_p \Delta T$$

where ΔT is the change of temperature of the gas during the process, and c is the specific heat capacity. We have added a subscript p to the specific heat capacity at a constant pressure process.

The equation of state of a gas relates the temperature, pressure, and volume through a gas constant R . The gas constant is derived from the universal gas constant, but has a unique value for every gas.

$$pv = RT$$

For a constant pressure process:

$$p\Delta v = R\Delta T$$

Now let us consider a constant volume process with a gas that produces exactly the same temperature change as the constant pressure process that we have been discussing. Then the first law of thermodynamics tells us:

$$\Delta u = \Delta q - \Delta w$$

where q is the specific heat transfer and w is the work done by the gas. For a constant volume process, the work is equal to zero. And we can express the heat transfer as a constant times the change in temperature. This gives:

$$\Delta u = c_v \Delta T$$