

Contents

| | |
|--|-----------|
| Preface | ix |
| Structure | xiii |
| Symbols | xv |
| 1 State of Equilibrium | 1 |
| 1.1 Equilibrium of a thermodynamic system | 2 |
| 1.2 Helmholtz energy (Helmholtz function) | 5 |
| 1.3 Gibbs energy (Gibbs function) | 6 |
| 1.4 The use and significance of the Helmholtz and Gibbs energies | 6 |
| 1.5 Concluding remarks | 9 |
| Problems | 10 |
| 2 Availability and Exergy | 13 |
| 2.1 Displacement work | 13 |
| 2.2 Availability | 14 |
| 2.3 Examples | 15 |
| 2.4 Available and non-available energy | 21 |
| 2.5 Irreversibility | 21 |
| 2.6 Graphical representation of available energy and irreversibility | 25 |
| 2.7 Availability balance for a closed system | 27 |
| 2.8 Availability balance for an open system | 34 |
| 2.9 Exergy | 36 |
| 2.10 The variation of flow exergy for a perfect gas | 42 |
| 2.11 Concluding remarks | 43 |
| Problems | 43 |
| 3 Pinch Technology | 47 |
| 3.1 A heat transfer network without a pinch problem | 49 |
| 3.2 A heat transfer network with a pinch point | 56 |
| 3.3 Concluding remarks | 60 |
| Problems | 61 |

| | |
|---|------------|
| 4 Rational Efficiency of a Powerplant | 64 |
| 4.1 The influence of fuel properties on thermal efficiency | 64 |
| 4.2 Rational efficiency | 65 |
| 4.3 Rankine cycle | 69 |
| 4.4 Examples | 71 |
| 4.5 Concluding remarks | 82 |
| Problems | 82 |
| 5 Efficiency of Heat Engines at Maximum Power | 85 |
| 5.1 Efficiency of an internally reversible heat engine when producing maximum power output | 85 |
| 5.2 Efficiency of combined cycle internally reversible heat engines when producing maximum power output | 92 |
| 5.3 Concluding remarks | 96 |
| Problems | 96 |
| 6 General Thermodynamic Relationships (single component systems, or systems of constant composition) | 100 |
| 6.1 The Maxwell relationships | 100 |
| 6.2 Uses of the thermodynamic relationships | 104 |
| 6.3 Tds relationships | 108 |
| 6.4 Relationships between specific heat capacities | 111 |
| 6.5 The Clausius–Clapeyron equation | 115 |
| 6.6 Concluding remarks | 118 |
| Problems | 118 |
| 7 Equations of State | 121 |
| 7.1 Ideal gas law | 121 |
| 7.2 Van der Waals' equation of state | 123 |
| 7.3 Law of corresponding states | 125 |
| 7.4 Isotherms or isobars in the two-phase region | 129 |
| 7.5 Concluding remarks | 131 |
| Problems | 132 |
| 8 Liquefaction of Gases | 135 |
| 8.1 Liquefaction by cooling – method (i) | 135 |
| 8.2 Liquefaction by expansion – method (ii) | 140 |
| 8.3 The Joule–Thomson effect | 141 |
| 8.4 Linde liquefaction plant | 148 |
| 8.5 Inversion point on $p–v–T$ surface for water | 150 |
| 8.6 Concluding remarks | 155 |
| Problems | 155 |
| 9 Thermodynamic Properties of Ideal Gases and Ideal Gas Mixtures of Constant Composition | 158 |
| 9.1 Molecular weights | 158 |

| | | |
|-----------|---|------------|
| 9.2 | State equation for ideal gases | 159 |
| 9.3 | Tables of $u(T)$ and $h(T)$ against T | 164 |
| 9.4 | Mixtures of ideal gases | 172 |
| 9.5 | Entropy of mixtures | 175 |
| 9.6 | Concluding remarks | 178 |
| | Problems | 178 |
| 10 | Thermodynamics of Combustion | 182 |
| 10.1 | Simple chemistry | 184 |
| 10.2 | Combustion of simple hydrocarbon fuels | 185 |
| 10.3 | Heats of formation and heats of reaction | 187 |
| 10.4 | Application of the energy equation to the combustion process – a macroscopic approach | 188 |
| 10.5 | Combustion processes | 192 |
| 10.6 | Examples | 195 |
| 10.7 | Concluding remarks | 205 |
| | Problems | 205 |
| 11 | Chemistry of Combustion | 208 |
| 11.1 | Bond energies and heats of formation | 208 |
| 11.2 | Energy of formation | 210 |
| 11.3 | Enthalpy of reaction | 216 |
| 11.4 | Concluding remarks | 216 |
| 12 | Chemical Equilibrium and Dissociation | 218 |
| 12.1 | Gibbs energy | 218 |
| 12.2 | Chemical potential, μ | 220 |
| 12.3 | Stoichiometry | 221 |
| 12.4 | Dissociation | 222 |
| 12.5 | Calculation of chemical equilibrium and the law of mass action | 225 |
| 12.6 | Variation of Gibbs energy with composition | 229 |
| 12.7 | Examples of the significance of K_p | 231 |
| 12.8 | The Van't Hoff relationship between equilibrium constant and heat of reaction | 238 |
| 12.9 | The effect of pressure and temperature on degree of dissociation | 239 |
| 12.10 | Dissociation calculations for the evaluation of nitric oxide | 242 |
| 12.11 | Dissociation problems with two, or more, degrees of dissociation | 245 |
| 12.12 | Concluding remarks | 259 |
| | Problems | 259 |
| 13 | The Effect of Dissociation on Combustion Parameters | 265 |
| 13.1 | Calculation of combustion both with and without dissociation | 267 |
| 13.2 | The basic reactions | 267 |
| 13.3 | The effect of dissociation on peak pressure | 268 |
| 13.4 | The effect of dissociation on peak temperature | 268 |
| 13.5 | The effect of dissociation on the composition of the products | 269 |
| 13.6 | The effect of fuel on composition of the products | 272 |
| 13.7 | The formation of oxides of nitrogen | 273 |

| | |
|---|------------|
| 14 Chemical Kinetics | 276 |
| 14.1 Introduction | 276 |
| 14.2 Reaction rates | 276 |
| 14.3 Rate constant for reaction, k | 279 |
| 14.4 Chemical kinetics of NO | 280 |
| 14.5 The effect of pollutants formed through chemical kinetics | 286 |
| 14.6 Other methods of producing power from hydrocarbon fuels | 288 |
| 14.7 Concluding remarks | 289 |
| Problems | 289 |
| 15 Combustion and Flames | 291 |
| 15.1 Introduction | 291 |
| 15.2 Thermodynamics of combustion | 292 |
| 15.3 Explosion limits | 294 |
| 15.4 Flames | 296 |
| 15.5 Flammability limits | 303 |
| 15.6 Ignition | 304 |
| 15.7 Diffusion flames | 305 |
| 15.8 Engine combustion systems | 307 |
| 15.9 Concluding remarks | 314 |
| Problems | 314 |
| 16 Irreversible Thermodynamics | 316 |
| 16.1 Introduction | 316 |
| 16.2 Definition of irreversible or steady state thermodynamics | 317 |
| 16.3 Entropy flow and entropy production | 317 |
| 16.4 Thermodynamic forces and thermodynamic velocities | 318 |
| 16.5 Onsager's reciprocal relation | 319 |
| 16.6 The calculation of entropy production or entropy flow | 321 |
| 16.7 Thermoelectricity – the application of irreversible thermodynamics to a thermocouple | 322 |
| 16.8 Diffusion and heat transfer | 332 |
| 16.9 Concluding remarks | 342 |
| Problems | 342 |
| 17 Fuel Cells | 345 |
| 17.1 Electric cells | 346 |
| 17.2 Fuel cells | 351 |
| 17.3 Efficiency of a fuel cell | 358 |
| 17.4 Thermodynamics of cells working in steady state | 359 |
| 17.5 Concluding remarks | 361 |
| Problems | 361 |
| Bibliography | 363 |
| Index (including Index of tables of properties) | 369 |