

Contents

Chapter 1 Introduction	1
1.1. Applications Involving Cryogenic Engineering	1
Chapter 2 Properties of Cryogenic Fluids	13
2.1. Oxygen	13
2.2. Nitrogen	15
2.3. Air	15
2.4. Argon	16
2.5. Neon	17
2.6. Fluorine	17
2.7. Hydrogen	18
2.8. Helium	25
References	37
Chapter 3 Properties of Solids	39
3.1. Mechanical Properties	39
3.2. Thermal Properties	58
3.3. Electrical Properties	83
3.4. Superconductivity	87
References	101
Chapter 4 Refrigeration and Liquefaction	103
4.1. Refrigeration and Liquefaction Principles	103
4.2. Joule–Thomson Expansion	110
4.3. Isentropic Expansion	125
4.4. Cascade Processes	143
4.5. Ortho–Parahydrogen Conversion	147
4.6. Cold-Gas Refrigerators	148
4.7. Miniature Refrigerators	162
4.8. Ultra-Low-Temperature Refrigerators	166
4.9. Thermodynamic Analyses of Systems	175
References	187

Chapter 5	Equipment Associated with Low-Temperature Systems . . .	189
	5.1. Heat Exchangers	189
	5.2. Compressors	247
	5.3. Expanders	257
	5.4. Effect of Component Inefficiencies	268
	5.5. System Optimization	276
	<i>References</i>	284
Chapter 6	Separation and Purification Systems	287
	6.1. Ideal Separation of Gases	287
	6.2. Characteristics of Mixtures	291
	6.3. Principles of Gas Separation	302
	6.4. Air Separation Systems	333
	6.5. Hydrogen Separation Systems.	356
	6.6. Helium Separation Systems.	360
	6.7. Gas Purification	362
	<i>References</i>	375
Chapter 7	Storage and Transfer Systems	377
	7.1. Insulation Concepts	377
	7.2. Storage Systems for Cryogenic Liquids	407
	7.3. Transfer Systems	433
	7.4. Industrial Storage and Transfer	449
	7.5. Cooldown of Storage and Transfer Systems	457
	<i>References</i>	475
Chapter 8	Cryogenic Instrumentation	477
	8.1. Properties Characterizing Cryogenic Instrumentation.	477
	8.2. Strain	479
	8.3. Displacement and Position	483
	8.4. Pressure	484
	8.5. Flow	492
	8.6. Liquid Level	509
	8.7. Density	515
	8.8. Temperature	520
	<i>References</i>	550
Appendix A	Conversion Factors and Temperature Scales	555
Appendix B	Properties of Cryogenic Fluids	563
Appendix C	Thermodynamic Diagrams of Cryogenic Fluids	585
Index	605