Contents

Foreword xi
Michel FEIDT

Introduction xiii
Michel FEIDT and Antonio VALERO-CAPILLA

Chapter 1. From Equilibrium Thermodynamics to Irreversible Thermodynamics 1
Michel FEIDT

1.1. Recent emergence of thermodynamics: from heat to engines 1
1.1.1. Heat and temperature 1
1.1.2. Matter and chemical reactions 2
1.1.3. Mechanical energy 3
1.1.4. Heat–work equivalence 4
1.2. From engines to concepts (work by Carnot) 5
1.2.1. The steam engine and other engines 5
1.2.2. The Carnot cycle 5
1.2.3. Carnot efficiency 8
1.2.4. Engine power 8
1.3. From thermostatics to thermodynamics 9
1.3.1. The basics of thermodynamics 10
1.3.2. Thermodynamic transformation 14

1.3.3. Energy transfers and conversion 18
1.3.4. Generalization of cycle and efficiency concepts 22
1.4. Case study: the Carnot engine 25
1.4.1. Energy and entropy balances 25
1.4.2. Entropy production and energy efficiency 27
1.5. First conclusions and perspectives 34
1.6. References 35

Chapter 2. Two-Heat-Source Thermodynamic Cycles: Representation as a Ternary Diagram 37
Julien RAMOUSSE

2.1. Introduction to two-heat-source systems. 37
2.2. Definitions and convention 38
2.2.1. Work and heat 38
2.2.2. Sign convention 39
2.2.3. Heat source/sink. 40
2.2.4. First-law balance 40
2.2.5. Second-law balance. 41
2.3. Graphic representations – state of the art 44
2.3.1. Q-T diagram 45
2.3.2. Borel and Favrat diagram 46
2.3.3. Raveau diagram 49
2.4. Ternary diagram 50
2.4.1. Ternary diagram representation. 51
2.4.2. Interpretation using polar coordinates 56
2.5. Application examples 62
2.5.1. Endo-reversible (exo-irreversible) two-heat-source systems 63
2.5.2. Exo-reversible (endo-irreversible) two-heat-source systems 66
2.5.3. General case – endo- and exo-irreversible systems 71
2.6. Conclusion and prospects 74
2.7. References 77

Chapter 3. Thermodynamics with Finite Speed 79
Stoian PETRESCU and Monica COSTEA

3.1. Introduction. 79
3.2. First developments of TFS (1964–1974). 80
3.2.1. The origin of TFS 80

3.2.2. Fundamental concepts 82
3.2.3. The first law of thermodynamics for finite-speed processes in simple systems. 85
3.2.4. First approach to Beau de Rochas and Otto's finite speed irreversible cycle 92
3.3. Developments of TFS during the period 1990–2007 94
3.3.1. First law of thermodynamics for finite speed processes in complex closed systems 94
3.3.2. The direct method of TFS 98
3.4. Main achievements of TFS and the direct method 99
3.4.1. Modeling and optimization of the Stirling engine cycle 99
3.4.2. Optimization of the Carnot engine irreversible cycle 108
3.4.3. Effect of irreversibilities on the efficiency of the Beau de Rochas–Otto cycle at finite speed 112
3.4.4. Optimization of diesel cycle efficiency at finite speed 113
3.5. New developments and extension of TFS 115
3.6. International recognition of TFS and the direct method. 117
3.7. Conclusion 117
3.8. References 118

Chapter 4. Finite Physical Dimensions Thermodynamics 125
Michel FEIDT

4.1. Introduction. 125
4.2. The Carnot engine according to equilibrium thermodynamics. 126
4.2.1. Equilibrium thermodynamics and heat losses 126
4.2.2. Exo-reversible Carnot engine (endo-irreversible) 128
4.2.3. Power of the exo-reversible Carnot engine 129
4.3. The Chambadal engine model (1957) 130
4.3.1. Optimization of the modified Chambadal engine without source-converter heat transfer coupling constraint 131
4.3.2. Optimization of the modified Chambadal engine, with the transfer entropy constraint 133
4.3.3. Section conclusion 134
4.4. The Curzon–Ahlborn model (1975) 134
4.4.1. Optimization of mechanical energy 136
4.4.2. Optimization of mechanical power. 138
4.5. Finite speed thermodynamics 139
4.5.1. Introduction 139

4.5.2. Expression of the first law of thermodynamics for finite speed processes . . . 140
4.5.3. Extension of the method . . . 140
4.6. Finite physical dimensions optimal thermodynamics: case without coupling of sources and sinks with the converter . . . 141
4.7. Finite physical dimensions optimal thermodynamics: case with source and sink coupling with the converter . . . 143
4.7.1. Irreversible Carnot engine with finite source and sink . . . 145
4.7.2. Irreversible Carnot engine with finite converter . . . 145
4.8. Chapter conclusion . . . 147
4.9. Appendix . . . 148
4.10. References . . . 149

Chapter 5. Circular Thermoeconomics: A Waste Cost Accounting Theory . . . 151
Antonio VALERO-CAPILLA and César TORRES

5.1. Introduction . . . 152
5.1.1. Toward a general theory of process efficiency . . . 155
5.1.2. Basic concepts . . . 157
5.2. The exergy cost theory . . . 159
5.2.1. The principle of non-equivalence of local irreversibilities . . . 166
5.2.2. The cost formation process of waste . . . 168
5.2.3. Waste flows cost allocation . . . 172
5.2.4. Exergy cost computation . . . 175
5.3. Structural theory of thermoeconomics . . . 178
5.3.1. Marginal cost equations . . . 182
5.3.2. Linear model of characteristic equations . . . 184
5.4. Structural theory and exergy cost . . . 185
5.4.1. The flow-process model . . . 189
5.4.2. The characteristic equations of exergy cost theory . . . 194
5.4.3. The fuel impact formula . . . 197
5.4.4. Cost decomposition . . . 198
5.4.5. Efficiency and recycling . . . 201
5.5. Conclusion . . . 204
5.5.1. The structural theory . . . 204
5.5.2. Circular economy and industrial symbiosis . . . 206
5.6. References . . . 210

Chapter 6. The Relative Free Energy Function: A New Approach to Thermoeconomic Diagnosis 215
Antonio VALERO-CAPILLA and César TORRES

6.1. Introduction. 216
6.2. Drawbacks of exergy 219
6.3. The relative free energy function 220
6.4. h-s deterioration(s) path(s) of an energy system 223
6.5. The Legendre transform of a deterioration path 224
6.6. Conclusion 229
6.7. Epilogue. 232
6.8. References 236

List of Authors 239

Index 241