
Contents

Preface	xi
Acknowledgements	xv
List of Notations and Acronyms	xvii
Chapter 1. From Thermostatistics to Non-equilibrium Thermodynamics	1
1.1. Equilibrium thermodynamics, a brief history	1
1.1.1. Temperature and its measurement	2
1.1.2. Matter: chemical reaction and conservation	2
1.1.3. Heat–work equivalence	3
1.1.4. Steam engines	5
1.1.5. Other engines	6
1.1.6. S. Carnot: from engines to concepts	7
1.2. Essentials of thermostatistics	7
1.2.1. The notion of a thermodynamic system	7
1.2.2. State of a thermodynamic system	9
1.2.3. Thermodynamic processes	12
1.3. Further additions: analytical thermodynamics	17
1.3.1. Calorimetry and calorimetric coefficients	17
1.3.2. Thermoelastic coefficients	18
1.3.3. Thermodynamic characteristic functions	19
1.3.4. Real fluids – ideal gas	24
1.4. Major branches of thermodynamics	25
1.4.1. Fluid mechanics – mass transfers	25

1.4.2. Thermochemistry – chemical reactions	26
1.4.3. Thermokinetics – heat transfers	27
1.4.4. Statistical thermodynamics	28
1.4.5. Linear non-equilibrium thermodynamics and nonlinear thermodynamics	29
1.4.6. New trends in thermodynamics: finite time thermodynamics	31
1.5. Second and third laws of thermodynamics	32
1.5.1. Entropy balance for an open system	32
1.5.2. Energy balance for an open system	34
1.5.3. The third law of thermodynamics	37
1.6. First conclusions and perspectives	40
Chapter 2. Heat Exchangers	43
2.1. Heat exchangers – essential component of systems and processes	43
2.1.1. The world of heat exchangers.	44
2.1.2. Summary of heat transfer modes	47
2.2. Thermodynamic models of heat exchangers	51
2.2.1. Total surface heat transfer coefficient	52
2.2.2. Overall characterization of a heat exchanger.	55
2.2.3. The main calculation methods for heat exchangers	60
2.3. Heat exchanger optimization: a generic compromise	63
2.3.1. Optimizations in the sense of the first law of thermodynamics	64
2.3.2. Optimizations in the sense of the second law of thermodynamics	64
2.3.3. An example of entropy analysis	67
2.4. Transient of heat exchangers.	69
2.4.1. Long and short transient states	69
2.4.2. Example of transient state	70
2.4.3. Possible extensions	72
2.5. Conclusions of this chapter	73
Chapter 3. From Carnot Cycle to Carnot Heat Engine: A Case Study	75
3.1. Thermomechanical engine – a model	75
3.1.1. Application of the first law of thermodynamics	77
3.1.2. Application of the second law of thermodynamics	77
3.1.3. Application of thermokinetics	78
3.2. Thermomechanical engine: first power optimization	79
3.2.1. Variables ($T_H, T_C ; X_H, X_C$)	79

3.2.2. Variables ($\varepsilon_C, \varepsilon_H; a_C, a_H$)	80
3.2.3. Variables ($\dot{C}_C, \dot{C}_H; c, h$)	81
3.2.4. First conclusions	81
3.2.5. Energy consumption and efficiency	82
3.3. Thermomechanical engine: constrained optimizations	83
3.3.1. Analysis and methodology of technically constrained optimization	83
3.3.2. Main OFs of the engine	83
3.3.3. Main technical constraints on a thermomechanical engine	88
3.3.4. Main constrained optimizations of a thermomechanical engine	89
3.4. Reverse cycle Carnot machine.	90
3.4.1. The model and its specificities	90
3.4.2. Efficiency of a reverse cycle machine.	92
3.4.3. An example of optimization of an RM	93
3.5. Generalization of the Carnot machine model	95
3.5.1. Temperature optimization.	95
3.5.2. Finite-dimension optimization	96
3.6. Conclusions and perspectives	97
Chapter 4. Internal Combustion Engines Revisited	99
4.1. A brief review of internal combustion engines	99
4.1.1. History	99
4.1.2. From principles to practical achievements	100
4.2. From technique to the first models	106
4.2.1. Clapeyron diagrams	106
4.2.2. Entropic diagrams	107
4.2.3. First results of the models	108
4.3. Models revisited	110
4.3.1. Beau de Rochas and diesel cycles with two adiabatic processes.	110
4.3.2. Irreversible adiabatic ICE	114
4.3.3. Non-adiabatic ICE	117
4.4. Other variants	120
4.4.1. Dual cycle engine model	120
4.4.2. Numerical results	122
4.5. Conclusions and extensions	124
4.5.1. Main conclusions	124
4.5.2. Possible extensions	124

Chapter 5. Combustion Turbines and Other Heat Engines	125
5.1. Introduction.	125
5.1.1. Combustion turbine: a modern engine.	125
5.1.2. External Combustion Engine	125
5.2. The combustion turbine.	126
5.2.1. The dream of Icarus	126
5.2.2. Brief technical presentation	127
5.2.3. From technique to the basic thermodynamic model.	129
5.2.4. Joule–Brayton cycle with heat recovery	138
5.2.5. Perspectives	142
5.3. From CT to GT.	142
5.3.1. From internal combustion engines to ECEs	142
5.3.2. Thermodynamic model	143
5.3.3. Numerical application – results.	145
5.3.4. Conclusions and perspectives.	147
5.4. External combustion engines	147
5.4.1. Renewal of steam engine?.	148
5.4.2. Organic Rankine Cycles.	153
5.4.3. Stirling and Ericsson engines	161
5.5. Other engines.	166
Chapter 6. Reverse Cycle Machines	169
6.1. Introduction.	169
6.1.1. From engine to reverse cycle machine	169
6.1.2. Reverse cycle machine.	170
6.2. Classical thermodynamics of machines with steam compression	171
6.2.1. Diagram of refrigeration and refrigerant fluids	171
6.2.2. Balances on the machine and consequences	173
6.3. New thermodynamics contributions to machines with one source and one heat sink	177
6.3.1. Model particularization in entropy diagram	177
6.3.2. Optimization of an RM with one source and one heat sink	178
6.3.3. Possible extensions	184
6.4. Machines with three or four heat reservoirs.	191
6.4.1. Schematic diagram of a sorption machine	191
6.4.2. Generic model for sorption machines	194
6.5. Other machines.	196
6.5.1. Permanent gas machines.	197
6.5.2. Thermoelectric machines	199
6.5.3. Thermomagnetic machines	203

6.6. Conclusion and extensions	204
6.7. Illustrative exercises	206
6.7.1. Thermodynamic analysis of Ranque–Hilsch tube	206
6.7.2. Exergy efficiency of an RM.	212
Conclusion and Perspectives	215
Appendices	225
Appendix 1. Fluids	227
Appendix 2. Mathematics	231
Bibliography	239
Index	243