Preface

The energy industry is well known for being ponderous and slow-moving, but it is undeniable that the structure of a modern society, its social, economic and cultural growth, the tenor and quality of life, in fact, the degree of civilisation and political independence of a nation or a continent, depends also on its energy potential and on the efficiency of the systems employed for its conversion and use. The electrical system of a society, for example, developed and is still developing via complicated and intricate structures that need to meet a host of needs (civil and industrial uses, a demand that varies throughout the day and according to season) and numerous available sources (oil, coal, natural gas, nuclear energy, renewable sources—solar, biomass, geothermal—the availability of reusable heat). Widely resorting to renewable energy and the distributed generation associated with cogeneration (for technological uses or for air conditioning) would introduce not only further complications but also new opportunities.

Faced with an evolving situation, most of the energy resources are consumed in combustion processes that lead to thermo-mechanical use in energy cycles and it is worth recalling certain notes made in 1984 by Prof. Gianfranco Angelino (1938–2010), regarding heat engines, where he wrote

> However varied the final destinations of the mechanical energy, there are essentially just two fundamental thermodynamic cycles: the Rankine steam cycle and the internal combustion gas cycles. The relative paucity of instruments is exacerbated further by the fact that the gas cycles are severely limited with regard to the quality of the primary energy they can use, since they are inappropriate for feeding with solid fuels or thermal energy. The Rankine cycle, while enjoying an extreme adaptability towards fuels and heat sources, is unable to use heat efficiently at temperatures above 600–650 °C, the excess heat potential being lost as driving force of the heat transmission in the primary heat exchanger. To the basic limitations of the thermodynamic concept, there are others, linked to the consolidated tradition of designing and building, whereby steam turbines are inappropriate at low power levels and alternative engines are inappropriate for large power units. In an ideal "temperature-efficiency-power unit" space, the regions satisfactorily occupied by current conversion systems are so limited in extent that there is a clear interest, not to say necessity, for researching new instruments that can expand the zone of adequate coverage along all axes

These observations are both a good introduction and a justification for the content of this book, which is specifically dedicated to closed thermodynamic cycles and their numerous applications. The need for prime movers with highly variable power levels, the use of heat sources of differing quality and composition and the search for the highest possible conversion efficiency can all find an answer in the use of heat engines based on closed thermodynamic cycles.

Closed cycles certainly present their own problems, linked (1) to the need to transfer the primary heat to the working fluid and the waste heat from the working fluid to the environment, by means of large metal surfaces for the heat exchange, then (2) to the stack losses; if the primary heat in question comes from combustion, these constitute additional losses. On the other hand, closed cycles bring undeniable advantages: (1) they have good efficiency and (2) they can use either solid fuels or the waste heat directly from chemical and industrial processes or heat with nuclear or solar origin. Furthermore, closed cycles are indispensable if the surrounding environment is unable to supply a working fluid continuously (for example, extreme cases like dynamic systems for energy production in space or in underwater systems). Then, whilst an open cycle has a fixed minimum pressure, when designing a closed cycle there are two additional freedoms: the working fluid and the minimum pressure. In principle, closed cycles offer a good solution for each specific request, restricting the dimensions needed for the turbo-machinery and the heat exchangers, reducing the level of mechanical stress in static and moving components, simplifying the dynamics and control systems and offering advantages in the off-design performances. As in the refrigeration industry, different fluids are used for different temperatures and different power levels and purposes (even though, conceptually, a gas like helium could satisfy all these); the power generation sector, likewise, could benefit greatly from the use of different working media to fit differing needs. The Organic Rankine Cycles, in this sense, are a good example of success.

In such a context, not only the thermodynamic aspects acquire relevance but also the choice of suitable materials (for instance, for high temperatures applications with non-conventional fluids) and the choice of the most appropriate working fluids for best use in the proper thermodynamic regions all become questions of primary importance. The working fluids may be pure fluids or mixtures, with well-known thermodynamic and transport properties; they must possess good thermal stability and their compatibility with other materials must be well researched, considering also the presence of any highly common impurities. The fluid dynamics of the compressors and turbo-machinery must be clearly understood in order to ensure a good aerodynamic design and high efficiency. The heat exchangers, which are often extremely demanding, require technological solutions that are not always obvious. Therefore, the study of closed cycles includes numerous aspects and represents a cross-disciplinary activity.

Chapter 1 of this book contains introductions and descriptions of the most common closed cycle heat engines: the steam cycle, in Sect. 1.6, the closed gas-turbine cycle and the Stirling engine (in Sects. 1.7 and 1.8), as important examples of closed cycle engines using an ideal gas as their working fluid. Chapter 2, forming an introduction to those that follow, discusses the thermodynamic properties of fluids, with particular regard to those aspects most closely connected to the thermodynamics of closed cycles. Organic fluid Rankine cycles are discussed in Chap. 3, while real gas closed cycles (with carbon dioxide and with organic fluids) are described in Chap. 4. Finally, Chap. 5 is dedicated to binary cycles. Among the real gas closed cycles, Sect. 4.3 looks at the real gas Stirling engines, with their peculiar and interesting characteristics. The first part of Chap. 1 summarises the thermodynamic characteristics of the heat engine, including brief references to heat pumps and refrigerating machines. The thermodynamic characteristics of the heat engine are discussed with reference to the first and second laws of thermodynamics, that is, resorting to the energetic and exergetic balances detailed in Appendix B. Meanwhile, Appendix A contains the balance equations of mass, energy and entropy. Appendix C discusses the irreversibilities in thermodynamic cycles and heat engines, with examples relative to gas cycles with perfect gas and steam cycles.

The numerous examples developed and discussed in the various chapters have been carried out with the help of the Aspen Plus® program.[1]

I believe this book will be useful for any undergraduate or post-graduate student, lecturer or junior researcher interested in applied thermodynamics and the specific aspects of energy conversion with thermodynamic engines. The basic aspects, which have been treated, I hope, in clear and rigorous fashion, could also be useful to planners in R&D Departments, who should find useful clarification in this book on fundamental theoretical elements for their specific argument.

This book would undoubtedly have been better written by Prof. Gianfranco Angelino, a thorough expert on the topic and leading figure in the Italian technology of Organic Rankine Cycles, with whom I had the opportunity to collaborate for many years. I should have liked to write the book dedicated to this subject-matter together with him, but "...around us stand the dark goddesses, one bearing the curse of sad old age and the other, death"[2] and Gianfranco died prematurely in 2010. Consequently, it has now fallen to me to write this book. My thanks are rightly due to him, though, my unforgettable maestro, first and foremost.

Next, my heartfelt thanks to my wife, Tania. Without her encouragement (and her tolerance), I should never have found the strength to conclude the work in such a relatively short time: she has been, and remains, a great help. A wonderful companion through life, along this and other arduous paths.

My thanks to Andrea Salogni, Paola Bombarda and Paolo Iora, with whom I had the opportunity to discuss to varying degrees some of the themes present here. It goes without saying that any imprecision or errors this book may contain are wholly down to me.

My thanks are also due to Andrew Neil Harwood, who helped me prepare the text in English.

Brescia, Italy Costante M. Invernizzi
January 2013

[1]Aspen Plus is a registered trademark of Aspen Technology, Inc.

[2]Mimnermus (VII-VI century BC), elegy fr. 2 W, in Lirici Greci, edited by U. Albini, Le Monnier, Firenze 1972, transl. by G. Perrotta.

Springer

http://www.springer.com/978-1-4471-5139-5

Closed Power Cycles
Thermodynamic Fundamentals and Applications
Invernizzi, C.M.
2013, XVI, 264 p. 146 illus., Hardcover
ISBN: 978-1-4471-5139-5