Analysis of Engineering Cycles

3rd Edition

Revised and Updated

R. W. HAYWOOD
University of Cambridge, England

Thermodynamics and Fluid Mechanics

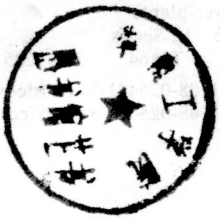
Analysis of Engineering Cycles

BY

R. W. HAYWOOD

Emeritus Reader in Engineering Thermodynamics in the University of Cambridge.

THIRD EDITION, IN SI UNITS



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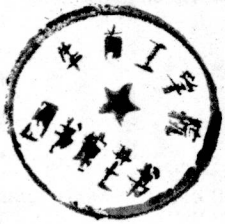

Preface to the Third Edition

THE principal modifications in this Third Edition arise from the updating and expansion of material on nuclear plant in Chapter 8 and on combined and binary plant in Chapter 9. In addition, in view of increased importance and topicality, new material has been added in Chapter 6 on gas-turbine plant for Compressed Air Energy Storage systems and in Chapter 7 on steam-turbine plant for the combined supply of power and process steam, including plant for district heating. The use of gas-turbine plant in association with district-heating schemes is also discussed in Chapter 8, in which the treatment of high-temperature and fast-breeder gas-cooled nuclear reactors has been extended. The material on combined gas-turbine/steam-turbine plant in Chapter 9 has also been expanded and updated, together with that on combined steam plant with magnetohydrodynamic and thermionic topping respectively.

Additions to the material on the simple steam cycle in Chapter 2, and the Problem in Chapter 9 relating to the ideal superregenerative steam cycle, give an opportunity to apply the important principles and concepts of thermodynamic availability, which feature prominently in a new book by the author.[5] New problems have been added in Chapters 2, 6, 7, 8 and 9, and there has been an appreciable addition to the list of quoted references.

In order to emphasise the fact that, in practice, economic assessments are just as important as thermodynamic analyses, a new Section dealing with Discounted Cash Flow has been added in Appendix C. For this I am indebted to my colleague, Dr. M. D. Wood, of Gonville and Caius College.

Cambridge
July 1979

R. W. HAYWOOD

Preface to the Second Edition (SI units)

ALTHOUGH the material in much of the text of the First Edition was not dependent on any particular set of units, the problems at the end of each chapter were set in British units. In this Second Edition, the problems have been reset (and a few new ones added) in the metric units of the *Système International d'Unités* (SI). In general, the answers given are based on data taken from the author's small volume of *Thermodynamic Tables*[1] in these units, but it has also been found convenient occasionally to use more extensive compilations of the properties of steam[2] and carbon dioxide.[3] In such cases, this is indicated in the text.

In preparing this Second Edition, the opportunity has been taken to bring the material up to date, where that was needed. To this end, a considerable part of Chapter 8 (Nuclear Power Plant) has been rewritten and some additions have been made to Chapters 9 and 10. Appendix A has also been completely rewritten and considerably extended, so that it now gives a more detailed treatment of thermodynamic availability and irreversibility in non-cyclic processes.

R. W. HAYWOOD

The Second Edition is available in Russian translation—
Р.В.Хейвуд, Анализ циклов в технической термодинамике. Перевод с английского Е.Я. Гадаса. Москва, «Энергия», 1979.

Preface to the First Edition

THIS book deals principally with an analysis of the overall performance, under design conditions, of work-producing power plants and work-absorbing refrigerating and gas-liquefaction plants, most of which are either cyclic or closely related thereto. The consideration of off-design performance is beyond the scope of the series in which this volume appears. Likewise, no attempt is made to describe the mechanical construction of the different kinds of plant considered, for it is assumed that the reader already has a knowledge of the associated "hardware".

The division of the work into two parts, dealing first with simple and then with more complex plants, has several advantages over possible alternative ways of handling the subject matter. It would have been possible to deal first with cyclic steam plant, both simple and complex, and to follow this by a treatment in turn of cyclic gas-turbine plant, internal combustion plant and finally refrigerating plant. The scheme adopted, however, enables attention to be drawn to the close similarities, and the differences, between steam and gas plant, before the reader is immersed in the complexities of advanced plant of either kind. A further advantage is the ease with which individual treatment, in Part II, of complex gas-turbine and steam plant can be followed by chapters on combined plant and nuclear power plant. Study of both power and refrigerating plants in the one volume makes it possible to apply the same techniques to an analysis of the performance of both without repetitive elaboration. Finally, division of the subject matter in this way makes the two parts suitable for study in consecutive academic years.

In a work which claims to deal with the analysis of engineering cycles, some justification is required for the inclusion of a chapter on non-cyclic internal-combustion plant, namely open-circuit gas-turbines and reciprocating internal-combustion engines. The inclusion of this chapter arises directly from the long-established practice of linking the performance of this type of **non-cyclic** plant with that of ideal **cyclic** plant operating on hypothetical cycles such as those of Joule, Otto and Diesel. The reader is not allowed, as in so many books, to skate over the highly arbitrary nature of this kind of exercise. As a result, he may well find Chapter 4 rather more difficult at first reading than the other chapters of Part I. However, the more rigorous treatment will bring to the persevering reader his own reward. The material in § 4.16 has little to do with cycle analysis, but it has been included to maintain the student's interest by enabling him to apply the preceding work to the problems of a more practical nature set at the end of the chapter. Whilst the gas-liquefaction plants discussed in Chapter 10 are also non-cyclic, they bear such a close affinity to cyclic refrigerating plant that their inclusion calls for no justification.

Throughout the work, emphasis is placed on the distinction between performance **parameters,** which merely provide a **measure** of plant performance, and performance **criteria,** which provide a **yardstick** against which the actual performance can be judged. Having designed, built and tested his plant, any engineer worth his salt will be curious to know how much better its performance could have been. Performance criteria, not performance parameters, provide the answers, and it is important to realise that these criteria do not result from practical experiment, since all real-life processes are in some degree imperfect. Only in Thermotopia, that idyllic land of the thermodynamicist in which all processes are reversible, are there no lost opportunities for producing work. Thus, to set up performance criteria against which to judge the excellence of performance of the plant that he has built, the engineer can only call upon the resources of the human intellect, unaided by experiment; this he does through the science and laws of thermodynamics. As an example of the power of abstract thought, such an exercise is of particularly high educational value.

This exercise will have added value if it is accompanied by a realisation that a striving towards Thermotopian perfection of man-made devices and machines, without regard to their social context, can be as much the mark of a well-informed barbarian as that of an educated engineer. The latter needs more than devilish ingenuity, for he must be as aware of the impact of his devices on society around him as he is to the fact, brought out clearly in this book, that their imperfections irretrievably leave their mark upon the environment. Said the judge, after a peroration by the great advocate F. E. Smith, first Lord Birkenhead:—"I am afraid, Mr. Smith, that I am none the wiser." "True, my Lord," snapped back F. E. Smith, "but you are better informed." It is the hope of the author that this book will not merely leave the reader in the same state as the learned judge.

Throughout this text, the aim has been to replace "custom and wont" by sound scientific argument and rigorous analytical treatment. If in this it succeeds, the book may be of value not only to students of engineering thermodynamics but also to other teachers of the subject and to practising engineers. A good textbook should not leave the reader with the impression, when he has reached the end, that all has been said; it should, instead, act as a stimulant to further reading, since the most exciting recent developments will always be found in periodicals and papers of the time rather than in standard texts. The reader is therefore well furnished, particularly in Part II, with a wide range of references into which he can dip as they take his fancy. They are in no way comprehensive.

This work is the result both of extensive practical experience in the power-plant industry and of experience gained in many years of lecturing to Cambridge undergraduates at all levels. Many of the problems originated in the same way, and the answers given are based on data taken from the author's small volume of *Thermodynamic Tables.*†

† *Thermodynamic Tables and Other Data,* edited by R. W. Haywood, Cambridge University Press, 2nd edition, 1960.

Second Edition footnote: These Tables were in British units. A more extensive set of Tables in SI units prepared by the Author is quoted under reference 1 on page 293.

Throughout the book, unless otherwise stated, the word "pressure" denotes absolute pressure when a numerical value is given.

In accumulating, over the years, the store of knowledge now put into this book, he owes much to help received from many people, in ways both direct and indirect, and not least from those whom he has taught. In not naming any, for fear of omitting the names of some, he thanks all who have in any way contributed towards its production.

R. W. HAYWOOD

Editorial Introduction

THE books in the Thermodynamics and Fluid Mechanics division of the Commonwealth Library have been planned as a series. They cover those subjects in thermodynamics and fluid mechanics that are normally taught to mechanical engineering students in a three-year undergraduate course.

Although there will be some cross-reference to other books in the division, each volume will be self-contained. Lecturers will therefore be able to recommend to their students a volume covering the particular course which they are teaching. A student will be able to purchase a short, low-price, soft-cover book containing material which is relevant to his immediate needs, rather than a large volume in which most of the contents are outside his current field of study.

The book meets the immediate requirements of the mechanical engineering student in his undergraduate course, and of other engineering students taking courses in thermodynamics and fluid mechanics.

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