THERMODYNAMICS

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Foundations of Engineering

Series Editor: G. E. Drabble

Thermodynamics

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To Maureen, Katharine and William

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SERIES EDITOR'S FOREWORD

This series of programmed texts has been written specifically for students meeting a subject for the first time on their engineering degree courses. Each book covers one of the core subjects required by electrical, mechanical, civil or general engineering students, and the contents have been designed to match either the first, or in the case of this volume, the first and second year requirements of most universities, both old and new.

The layout of the texts is based on that of the well-known text, *Engineering Mathematics* by K. Stroud (first published by Macmillan in 1970, and now in its third edition). The remarkable success of this book owes much to the skill of its author, but it also shows that students greatly appreciate a book which aims primarily to help them to learn their chosen subjects at their own pace. The authors of this present series acknowledge their debt to Mr Stroud, and hope that by adapting his style and methods to their own subjects they have produced equally helpful and popular texts.

Before publication of each text the comments of a class of students, of some recent engineering graduates, and of some lecturers in the field have been obtained. These helped to identify any points which were particularly difficult or obscure to the average reader or which were technically inaccurate or misleading. Subsequent revisions have eliminated the difficulties which were highlighted at this stage, but it is likely that, despite these efforts, a few may have passed unnoticed. For this the authors and publishers apologise, and would welcome criticisms and suggestions from readers.

Readers should bear in mind that mastering any engineering subject requires considerable effort. The aim of these texts is to present the material as simply as possible and in a way which enables students to learn at their own pace, to gain confidence and to check their understanding. The responsibility for learning is, however, still very much their own.

G.E. DRABBLE

AUTHOR'S PREFACE

The broad aim of this book is to cover the first two years' requirement in Thermodynamics in engineering degree courses. In this series of books the material is provided in short sections which the average student can simulate at his own pace and in his own time. In endeavouring to meet this aim within the allotted space, it was found that some of the intended second year material had to be omitted. The content, therefore, will be found to be strongest in the fundamentals of Thermodynamics upon which the various applications are built.

Since in a two year syllabus the course content will vary between institutions, some readers may find some topics surplus to their needs, while others may be left wanting more. However, many students find the applications of Thermodynamics rather easier to grasp than some of the fundamentals, and it is hoped that where there is a deficiency in meeting a particular syllabus, the student will be able to cope.

This book appears at a time when traditional subjects, like Thermodynamics, are gradually being reduced in contact time in engineering courses to make way for the inclusion of modern technologies. Since Thermodynamics involves concepts that are new and difficult for the average student, it becomes increasingly difficult, both for the teacher to get across his subject, and for the student to absorb it, in the limited time available. Consequently, it is hoped that this text will fill a need by providing the means whereby, in private study, students can grasp the fundamentals of this subject in their own individual way.

This book is not intended to replace a course of lectures, in which students should gain an overall view of the subject, probably illustrated with coloured slides of relevant hardware. Such pictures do not find a logical place in a much more detailed development of ideas, as in this book, and are not included. In any case, the keen student of engineering will read technical magazines, and will become a student member of his professional institution, and go on visits to places of engineering interest to see for himself such things as large gas turbine engines and steam power plant.

On the whole, the general approach to the subject follows traditional lines established over the last few decades. In general, writers of educational textbooks are indebted to those who wrote books before them, and my own teaching for 28 years was largely based on the earlier editions of Spalding and Cole [1] and Rogers and Mayhew [2]. However, readers of this book should be aware that if they turn to the 1992 edition of Rogers and Mayhew, they will find that, compared with their earlier editions and the previously accepted practice which is followed here, and for reasons stated by the authors, the sign convention for the work

interaction at a system boundary has been reversed. This means that the equation of the First Law in Frame 11 of Programme 3 would become:

$$Q + W = E_2 - E_1$$

The effects of this change then follow through the book.

In this book, following a suggestion by my colleague Dr Ian K. Smith, to whom I am very grateful, the importance of work ratio in engines and power plant is stressed. This is a parameter which will decide whether an engine will work or not, and in a historical perspective it is not surprising that early engines failed because they absorbed more work than they produced. Also the attainable thermal efficiency of any modern machine will be shown to be closely linked to its work ratio. After an initial study of Thermodynamics it is very instructive to read about the development of the subject, and about the evolution of power-producing machines: see for example, references [3] and [4]. The topic of work ratio is more fully developed in a recent paper by Dr Smith [5].

I am also grateful to WS Atkins Energy [6], for permission to use projected figures of future efficiencies of electrical power generation by gas turbine plant, combined cycle plant and composite plant involving fuel cells, given in Programme 10. The gradual, but continual, increase in thermal efficiency of power plant from the very low values in the early days of the Industrial Revolution, is a tribute to man's ingenuity within the limitations of the Second Law of Thermodynamics.

Over the years many discussions on thermodynamic matters with colleagues past and present, and with many students in tutorial classes, have contributed in unseen ways to the development of this book, and I wish to thank them all. The text has gone through various revisions based on the editor's comments, on comments received from students testing the book, and on comments from a thermodynamics reviewer. I am grateful for all this help in compiling the material into its present form and in eliminating errors. No doubt some points may still not be absolutely clear and some possible errors may still remain, so any further comments from readers would be most welcome.

Finally, I am very pleased to thank William Simonson for his drawing in Frame 5 of Programme 1, and last but not least, I would like to thank my wife for her support and forbearance during the time it has taken to produce this book.

REFERENCES

- [1] D.B. Spalding and E.H. Cole, *Engineering Thermodynamics*, Edward Arnold, 3rd edition, 1973.
- [2] G.F.C. Rogers and Y.R. Mayhew, *Engineering Thermodynamics, Work and Heat Transfer*, 2nd edition, 1967 (4th edition, 1992).
- [3] D.S.L. Cardwell, *From Watt to Clausius. The Rise of Thermodynamics in the Early Industrial Age*, Heinemann Educational Books, 1971.

- [4] A.F. Burstall, *A History of Mechanical Engineering*, Faber & Faber, 1963.
- [5] I.K. Smith, Matching and Work Ratio in Elementary Thermal Power Plant Theory, *Proc. Part A, Journal of Power and Energy*, MEP, 1993.
- [6] M.R. Fry, *Fuel Cells – R&D Review and Assessment of Composite Generation Options*, WS Atkins Energy, Epsom, Surrey, KT18 58W, June 1990.

HOW TO USE THIS BOOK

Like other books in this series, the material, having been divided into programmes on each major topic, is presented in short sections called frames. Each frame comprises either the development of a new idea, or the working of a calculation. Sometimes either of these may be too long for a single frame and the work is split into two or more parts. Where appropriate (when sufficient material has been given), a frame concludes with a question, or the requirement to do a calculation. The answer to the question, or the result of the calculation and the working involved follow at the beginning of the next frame. Ideally this should remain hidden until the task set has been attempted, and only when all is fully understood should you move on to following frames.

Programmes 1 to 6, on fundamentals, up to and including the Second Law, follow in sequence and therefore should be read in that order. Programmes 7 and 8 deal with vapour power cycles, and reversed heat pump cycles, together with compressible flow and work transfer in turbine wheels. Programme 9 on combustion can be read after Programme 6, and most of Programme 10 on engines and gas turbines can follow Programme 9, without first reading Programmes 7 and 8. The format of frames means that in general the text lacks subheadings, but use of the index at the back of the book will prevent one feeling lost in looking for any particular topic.

In order to use this book, students will need *Steam Tables*, together with the enthalpy–entropy diagram for steam and the pressure–enthalpy diagram for the refrigerant R-12. It is logical that the tables recommended by your course tutor be used. There are, however, a number of different publications available, and in this book guidance is given on the use of the following:

Tables

- J.R. Cooper and E.J. Le Fevre, *Thermophysical Properties of Water Substance, Students' Tables in S.I. Units*, Edward Arnold, 1969. (Steam Tables only.)
- R.W. Haywood, *Thermodynamic Tables in S.I. Units*, Cambridge University Press, 3rd edition, 1990. (Properties of steam, and of refrigerants R-12, methyl chloride, ammonia and carbon dioxide. This publication also includes the enthalpy–entropy chart for steam, and the pressure–enthalpy chart for R-12.)
- G.F.C. Rogers and Y.R. Mayhew, *Thermodynamic and Transport Properties of Fluids, S.I. Units*, Basil Blackwell, Oxford, 4th edition, 1988. (Properties of steam and of refrigerants R-12, and ammonia.)

Diagrams or Charts

- D.C. Hickson and F.R. Taylor, *Enthalpy–entropy Diagram for Steam, S.I. Units*,

Basil Blackwell, Oxford, 2nd edition, 1980.

D.C. Hickson and F.R. Taylor, *Pressure–enthalpy Diagram for R-12, S.I. Units*, Basil Blackwell, Oxford, 1977.

D.C. Hickson and F.R. Taylor, *Pressure–enthalpy Diagram for Ammonia, S.I. Units*, Basil Blackwell, Oxford, 1978.

THERMODYNAMIC PROPERTIES ON DISC

As a complement to this book, thermodynamic properties of steam and a number of other substances, including the common refrigerants, are available on disc for use with personal computers. This disc will be of value to students and practising engineers undertaking project work on vapour power cycles and heat pump cycles, exploring the potentialities of the range of fluids represented. After selecting a particular fluid, any two properties at a given state may be typed in to obtain all the remaining properties of the fluid at that state. A particular advantage of the disc is that from an initial state, properties at a final state after an isentropic, isenthalpic, isobaric or isochoric change may be found. The processes involved can require considerable work, and once the principles have been mastered and understood, the use of a disc is justified in project work, and is recommended.

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