ENGINEERING THERMODYNAMICS

D. B. Spalding and
E. H. Cole

Third Edition
S.I. Units

ELBS
LOW-PRICED EDITION

Engineering Thermodynamics

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Preface to the Third Edition

The preparation of this new edition results primarily from the introduction of the Système International d'Unités.

The order of presentation and development of the subject matter remain as in the second edition; the text, figures, tables, worked examples and end-of-chapter problems have been revised to accommodate the use of SI units.

In Chapter 2 we have retained a general treatment of mechanical units, but with the emphasis now switched from British to SI units. We have done this not only to facilitate understanding but also because students and practising engineers will still need to interpret and use material presented in diverse unit systems; in particular our treatment allows the constant g_c in Newton's Second Law of Motion to be correctly assigned to suit the various unit systems encountered in practice. The tables of conversion factors have been retained, but with priority now given to SI units.

Similarly, in Chapters 3, 4, and 5, on work, temperature, and heat, priority has been given to the use of SI units; but where appropriate, the corresponding British units are also discussed.

In addition to the incorporation of the revisions necessitated by the use of SI units, the opportunity has been taken to re-write some of the other parts of the text; also a new page layout has been adopted.

The steam tables included in Appendix B are extracts based on the U.K. Steam Tables in SI units (1970) prepared by the United Kingdom Committee on the Properties of Steam. We acknowledge with thanks permission to use these data.

South Kensington, 1973

D.B.S.
E.H.C.

Preface to the Second Edition

The purpose of the present book is the same as that of the first edition: to present the fundamentals of classical thermodynamics, to students of all branches of engineering, in a manner that combines rigour with practical utility. The treatment is also unchanged: it rests on the laws governing the heat and work interactions between a system and its surroundings. The system is always large enough, i.e. contains a sufficiently large number of individual molecules, for heat and work to be easily distinguishable; no attempt is made to present the laws as consequences of the microscopic structure of matter. On this foundation, we erect the conventional framework: the properties energy, enthalpy and entropy are defined; we describe the relations between them for various substances of importance in power-plant engineering; and we present the analytical techniques by which the engineer employs the laws and the properties in the prediction of plant performance.

Some new material has been added, particularly in Chapter 2 (Mechanical Quantities and Their Units), which has been completely rewritten, and in Chapter 13 (Entropy), which now includes a section entitled "Understanding Entropy". Other material has been redistributed: the section on systems in motion has been transferred from Chapter 8 to Chapter 7, and the treatment of reversible and irreversible engines has been rearranged in Chapters 11 and 12. Further, the opportunity has been taken to bring our unit abbreviations and symbols more closely into line with the recommendations of the British Standards Institution. The remaining changes, though of detail rather than essence, are quite extensive. The whole book has been reset, with larger type and more generous margins; many of the figures have been enlarged, while others have been revised and redrawn; the English has been polished; and we have eliminated all the printer's and other errors to which readers of the 1958 edition have helpfully drawn our attention.

We have been assisted by many of our colleagues, who have participated in the use of the book as an undergraduate text; the comments of Dr. J. R. Singham have been particularly valuable to us. Miss E. M. Archer, Librarian, Mechanical Engineering Department, City and Guilds College, has given much assistance in the revision and extension of the list of references, and Miss M. P. Steele has checked some of the proofs; we wish

to thank them for their help. In the preface to the first edition we acknowledged out debt to Professor Keenan's *Thermodynamics* of 1941; this indebtedness has not diminished with the years. We also wish to record our gratitude to the following persons and organisations, who have assisted us with the provision of diagrams and other material: The Science Museum (Fig. 1.1 and Fig. 1.2); The General Electric Company Ltd. (Fig. 1.3); D. Napier & Son Ltd. (Fig. 1.4); Ruston & Hornsby Ltd. (Fig. 1.5); Hawker-Siddeley Group Ltd. (Fig. 1.6); Budenburg Gauge Co. Ltd. and the Society of Instrument Technology (Fig. 2.4); Dobbie McInnes Ltd. (Fig. 3.9); Griffin & George Ltd. (Fig. 16.6 and 16.7); Professor J. H. Keenan, Professor F. G. Keyes and John Wiley & Sons, Inc. (Extract from *Thermodynamic Properties of Steam*); British Standards Institution (Tables A.1 to A.14 inclusive).

D.B.S.

South Kensington, 1966. E.H.C.

Contents

1 Introductory Survey

Historical Introduction

Mechanical power as the basis of civilized life

Man is physically a weak animal; yet he dominates the globe. How has this come about? Man's dominion rests on his ability to control forces far greater than those which his own muscles can exert. Without this control, neither agriculture nor urban life could have developed; for water had to be pumped to irrigate the land and supply the towns; food and building materials required transportation; corn must be ground and wood sawn. Later, when valuable ores were discovered beneath the surface of the earth, these too had to be raised and processed; the deeper the mines became, the more difficult grew the task of keeping them free of water. Man's ability to provide sufficient power for these and similar purposes set limits to the rate of growth of civilization, as indeed it still does.

Provision of this power is nowadays one of the main tasks of the mechanical engineer.

Sources of power

Animals, wind and water. When civilization began, during the sixth millennium BC, the only available sources of power were animal: heavy tasks were performed by gangs of slaves, or by domestic animals. This division of labour was a prerequisite for the establishment of collective life.

The wind was the next source of power, at first used only for driving sailing vessels. Not until the tenth century AD, however, was the wind harnessed, by means of windmills, to mechanical tasks such as milling and sawing.

Water-wheels were invented earlier, probably in primitive form before the beginning of the Christian era. For centuries they remained man's main source of mechanical power. But animals were slow and winds uncertain; water power was not always found in the right places. Particularly for mining, more concentrated, reliable and disposable sources of power were needed and urgently looked for throughout the Middle Ages.

The beginnings of steam power. The seventeenth century saw the rise of modern science in Europe. Observations were recorded and communicated; novel experiments were planned and executed; above all, quantitative measurements were systematically carried out.

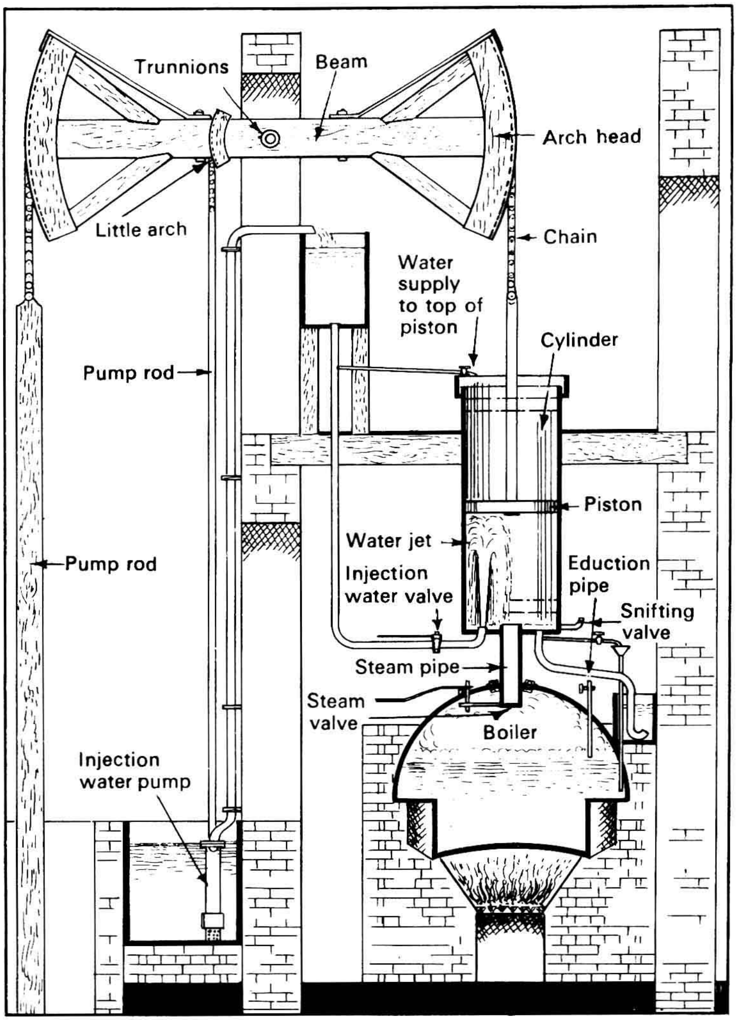

Fig. 1.1 Newcomen's pumping engine, 1712.

This diagram shows a section through a typical "atmospheric" pumping engine, as built by Newcomen, with the piston in the middle of the downward or working stroke. Steam, generated at atmospheric pressure in the boiler, fills the cylinder during the upward stroke of the piston. The steam valve is closed at the end of the stroke, and the steam is condensed by a jet of cold water; this reduces the pressure under the piston. The atmospheric pressure acting on the top of the piston forces it down (hence the name "atmospheric" engine); this constitutes the working stroke. The piston is raised again by the overbalancing weight of the pump-rods, when steam is again admitted to the cylinder.

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The treatment rests on the laws governing the heat and work interactions between a system and its surroundings; the properties energy, enthalpy and entropy are defined; the relations between them for various substances of importance in power-plant engineering examined; and the various analytical techniques used by the engineer employing the laws and the properties in the prediction of plant performance fully treated.