A Course In THERMODYNAMICS & HEAT-ENGINES [THERMAL ENGINEERING]

KOTHANDARAMAN
DOMKUNDWAR
KHAJURIA
ARORA

A COURSE IN

THERMODYNAMICS & HEAT ENGINES
(Thermal Engineering)

[*For Degree, Diploma, AMIE & All Competitive Examinations*]
(IN S.I. & M.K.S. UNITS)

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PREFACE TO THE SECOND EDITION

We take this opportunity to express our sincere thanks to the students and teachers for the warm welcome given to the first edition of this book. We have retained the basic objective of the previous edition to present comprehensive and rigorous treatment of the subject while retaining an engineering perspective.

We have attempted to cover fairly comprehensively the basic subject-matter of Thermodynamics & Heat Engines and believe that the book provides adequate preparation for study of the application of thermodynamics to the various professional fields. We hope that this book will contribute to the effective teaching of thermodynamics to the students who face very significant challanges and opportunities during their professional careers.

An introduction of *SI-Units* throughout the book is another notable feature of this edition. This will help the students and teachers for smooth swift from *MKS to SI-Units.* The problems in *MKS and SI* units are separately given to avoid confusion of one unit from the other.

We acknowledge, with appreciation, the suggestions, counsel and encouragement from colleagues of many Engineering Institutions.

It is hoped that the text in the present form will be much useful to the readers.

We specially thank the following Professors who helped directly or indirectly to bring the book to the present status :

Prof. B. S. Murthy and Prof. M. C. Gupta (I.I.T., Madras), Prof. Laximan Rao (Engg. College, Anantapur), Prof. K. N. Rao (Osmania University, Engg. College), Prof. S. P. Sen and Prof. Pal (B.E. College, Calcutta), Prof. Sinha (Engg. College, Patna), Prof. B. Sahu (Engg. College, Muzzaffarpur), Prof. Mazzid and Prof. S. Nagrajan (R E C., Calicut), Prof. H. B. Mathur (I.I T., Delhi), Prof. R. C. Amin and Prof. Sundram (V.J.T.I., Bombay), Prof. M. B. Jain (L.D. College of Engg., Ahmedabad), Dr. C. P. Sarathy (Govt. Engg. College, Salem), Prof. K. J. Paul (Engg. College, Trichur), Prof. T. L. Sitharama Rao (R.E.C., Warangal), Prof. Bhatia (M.A.C.T., Bhopal), Prof B K. Sthapak (Engg. College, Ujjain), Prof. J. M. Gulati and Prof. C.K.C. Jaini (Engg. College, Jabalpur), Prof. T. R. Sathram and Prof Sampath Kumar (National Institute of Technology, Mysore), Prof. V. N. Dakshina-Murthy (University Engg. College, Bangalore), Prof. K. R. Gopalkrishan (B.M.S. College, Bangalore), Prof. G. S. Varma, (Govt. (Engg. College, Raipur), Prof. P. Soogappa and Prof. Bhaskar Rao (Engg. College, Gulbarga), Prof. B. S. Rao (A.U., Engg. College, Waltair).

The comments, criticism and suggestions for the improvement of the book will be highly appreciated.

—Authors

PREFACE TO THE FIRST EDITION

A PREFACE is a place where authors can dilate on their motive, explain their prejudices and if they can retain their readers' attention, incline them to look favourably on their work. Therefore, we state that the effort which has led to this book is intended for use by genineering students.

This book has been designed to fulfil the requirements of the course under the heading of "*Thermodynamics and Heat Engines*" or "*Thermal Engineering*" offered by Universities and professional bodies.

The subject 'Thermodynamics and Heat Engines' being the core subject is offered to an engineering student from the beginning of his career. Therefore, it is necessary to ground the concepts of the subject from the beginning. This book claims to help the beginners to build up the concept and address to amplify their concepts using the basic knowledge for practical problems.

Concepts form the basis of any subject. One can get used to the concept and make it his own to known situations. Then only extension and application under new situations are possible. To achieve this purpose, a beginner needs drill type problem situations in addition to those involving applications to new situations. Considering this aspect carefully, a large number of solved problems involving comprehension of concepts are included.

Another difficulty faced by the beginners is the judicious selection of problems from many available. Keeping this in mind, each solved problem is also headed by the title and they are arranged in graded manner to include the wide range and depth.

The Technical Education authorities have accepted in principle to change over from *MKS* units to *SI* units. A special chapter on *SI* units is included at the end of the book which also includes the solved problems in SI units covering all the chapters of the present text.

The authors are extremely thankful to the students, teachers, co-workers and many learned professors from different parts of the country who helped directly or indirectly for the preparation of this text giving their constructive criticism.

The authors will feel amply rewarded if this balanced text, written in simplified language, helps to lessen the burden of already overloaded and bewildered students.

Suggestions for further improvement are welcome.

—*Authors*

Dedicated to the

Teachers of Science

& Technology

To our Students
who have taught more
than we like to admit.

CONTENTS

Introduction to S.I. Units

A common system of units for international use has been accepted by all countries of the world. Technical authority of this country has also accepted the change over from M.K.S. to S.I. units. The S.I. units will be introduced in the country within coming few years. Looking to theneed for this change-over, an attempt has also been made to introduce SI system of units to the readers in this book.

S.I. Units and Derived Units in S.I.

There are seven basic units as given in the Table 1.

(*See Table 1 on Page 2*).

Some of the important derived units which are commonly used by the engineers are given in Table 2.

(*See Table 2 on Page 2*).

Conversion Factors.

(*a*) **Force :**

1 Newton $= 10^5$ gram-cm/sec^2 (dyne)

$= 1$ kg-m/sec^2.

$= 0{\cdot}012$ kg$_f$.

1 kg$_f$ $= 9{\cdot}81$ N.

(*b*) **Pressure :**

1 bar $= 750{\cdot}06$ mm Hg

$= 0{\cdot}9869$ atm

$= 10^5$ N/m^2

$= 10^3$ kg/m-sec^2

1 N/m^2 = 1 pascal

$= 10^{-5}$ bar

$= 10^{-2}$ kg/m-sec^2.

(Table 1) S.I.—Units

S. No.	Physical Quality	Unit	Abbreviation
1	Length	Metre	m
2	Mass	Kilogram	kg
3	Time	Second	S
4	Electrical current	ampere	A
5	Luminous Intensity	Candela	Cd
6	Thermodynamic Temperature	Kelvin	K
7	Amount	mole	mole

(Table 2)—Derived S.I. Units

S.No.	Physical Quantity	Unit	Abbreviation
1	Force	Newton	N=kg m/s^2
2	Pressure or stress	Newton per square mctre	N/m^2
3	Work, energy or heat	Joule	J=Nm
4	Torque	Newton-metre	Nm=J.
5	Power or heat flow rate	Watt	W=J/s
6	Dynamic Viscosity	Newton Second per square metre	Ns/m^2
7	Specific heat	Joule per Kilogram per degree Kelvin	J/kg K.
8	Thermal conductivity	Watt per metre per degree Kelvin	W/mK=J/s m K.
9	Heat Transfer co-efficient.	Watt per metre square per degree Kelvin	W/m^2-°K.=J/s-m^2 -°K.
10	Frequency	Hertz.	Hz=C/s

1 atm = 760 mm Hg
= 1·03 kg_f/cm^2 = 1·01325 bar
= $1·01325 \times 10^5$ N/m^2.

(*c*) **Work, Energy or Heat :**

1 Joule = 1 newton metre
= 1 watt-sec
= $2·7778 \times 10^{-7}$ kW-hr.
= 0·239 cal
= $0·239 \times 10^{-3}$ kcal.
1 cal = 4·184 joule
= $1·1622 \times 10^{-6}$ kW-hr.
1 kcal = $4·184 \times 10^3$ joule = 427 kg_f-m.
= $1·1622 \times 10^{-3}$ kW-hr.
1 kW-hr = $8·6042 \times 10^5$ cal.
= 869·42 kcal
= $3·6 \times 10^6$ joule.
1 kg_f-m = (1/427) kcal = 9·81 joules.

(*d*) **Power :**

1 watt = 1 Joule/sec = 0·86 kcal/hr.
1 h.p. = 75 m-kg_f/sec = 0·1757 kcal/sec
= 735·3 watt.
1 kW = 1000 watts = 860 kcal/hr.

(*e*) **Viscosity (μ) :**

1 gm/cm-sec (poise) = 0·1 kg/m-sec
= 3600 kg/m-hr.
1 N-sec/m^2 = 1 kg/m-sec
= 10 kg/cm-sec
= 3600 kg/m-hr.

(*f*) **Specific Heat :**

1 kcal/kg-K = 0·4184 Joules/kg-K.

(*g*) **Thermal Conductivity (K) :**

1 watt/m-K = 0·8598 kcal/hr-m-°C
1 kcal/hr m-°C = 1·1623 watt/m-°K
= 1·1623 joule/s-m-°K.

(*h*) **Heat Transfer Coefficient :**

; watt/m^2-°K = 0·86 kcal/m^2-hr-°C.
1 kcal/m^2-hr-°C = 1·163 watt/m^2-°K.

Important Engineering Constants and Expressions in S.I. Units :

1. **The value of g_0 in M.K.S. and S.I. units are given as :**

   $g_0=9{\cdot}81$ kg-m/kg_f-sec^2 in M.K.S.

   $g_0=1$ kg-m/N-sec^2 in S.I.

2. **Universal Gas Constant :**

   In metric units, the universal gas constant is

   $G=848$ kg_f-m/kg-mole-°K

   ∴ In S.I. Units.

   $G=848\times9{\cdot}81=8314$ J/kg-mole-°K. as 1 kg_f-m$=9{\cdot}81$ joules

3. **Gas-Constant :**

   $R=\frac{G}{M}=\frac{8314}{29{\cdot}27}=287$ joules/kg-°K for air

   Similarly the specific heats of air in S.I. units

   $C_v=0{\cdot}17$ kcal/kg-°K.

   $=0{\cdot}17\times4{\cdot}184=0{\cdot}71128$ kJ/kg-°K.

   $C_p=0{\cdot}24$ kcal/kg-°K.

   $=0{\cdot}24\times4{\cdot}184=1$ kJ/kg-°K.

4. **Work done :**

   $=[\int pdv]$ Nm or J.

5. **Capacity of Machine :**

   Power developed by Reciprocating machine

   $=\left[\frac{p_m LAn}{1000}\right]$ kW where p_m is in N/m^2, L is in m and A is in m^2 and n are working strokes per second.

   $=100\ p_mLAn$ when p_m is in bars.

6. **Flow through Nozzle :**

The exit velocity through the nozzle neglecting inlet velocity in metric and S.I. units are given as

$V_2=91{\cdot}5\sqrt{\triangle H}$ m/sec in M.K.S. where $\triangle H$ in kcal.

$=44{\cdot}7\sqrt{\triangle H}$ m/sec in S.I. when $\triangle H$ in kJ.

7. **Refrigration :**

   1 ton$=50$ kcal/min. in M.K.S.

   1 ton$=210$ kJ/min. in S.I.

8. **Heat Transfer :**

   The Stefan Boltzman law is given by

$Q=\sigma T^4$ kcal/m^2-hr. when $\sigma=4{\cdot}9\times10^{-8}$ kcal/hr-m^2-k^4

$=\sigma T^4$ watts/m^2-m

when $\sigma=5{\cdot}67\times10^{-8}$ w/m^{2}k^4

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Basic Concepts of Thermodynamics

1·1. Introduction

Thermodynamics is concerned with (*i*) the concept of energy, (*ii*) the laws that govern the conversion of one form of energy into another, and (*iii*) the properties of the working substance or the media used to obtain the energy conversion. Though the study of thermodynamics started with the analysis of heat engine processes to improve the engine efficiency, today the scope has widened and there are important applications of thermodynamic principles outside the field of heat engines.

In engineering or applied thermodynamics the scope is restricted to the study of heat and work and the conversion of one into the other. Thermodynamic laws are applied to work producing and work absorbing devices in order to understand their functioning and improve their performance. In these days of fuel shortage and energy crisis, the importance of such a study can be well appreciated. Also there is a need to study new work producing devices using unconventional energy sources like solar heat. Efficient practical apparatus have to be designed and developed using such energy sources. This will be possible only with a basic understanding of thermodynamics.

1·2. Macroscopic and Microscopic Aspects

The description of a system or matter using a few of its measurable bulk properties constitutes a point of view called "Macroscopic". For example consider a diesel engine cylinder with air in it. The air occupies a certain volume for each position of the piston. The volume for any position is easily measured. The pressure and temperature are also easily measured. The state or condition of the system (air in the cylinder) is completely described by means of the above large scale characteristics or properties of the system. Such properties are called macroscopic properties and