

THERMODYNAMICS FOR ENGINEERS

SI VERSION

JESSE S.
DOOLITTLE

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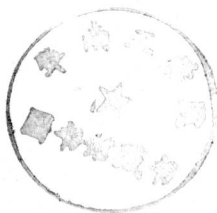
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JOHN WILEY & SONS

New York • Chichester • Brisbane • Toronto • Singapore

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Library of Congress Cataloging in Publication Data:

Doolittle, Jesse Seymour, 1903-
Thermodynamics for engineers.

Includes index.

1. Thermodynamics. I. Hale, Francis J. II. Title.
TJ265.D683 1983b 621.402'1 83-10316
ISBN 0-471-87384-5

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

THERMODYNAMICS FOR ENGINEERS

PREFACE

The scope of engineering thermodynamics is very broad. No one textbook can meet the needs of all undergraduate students in this field. As a general approach, we believe that all engineering students should gain an understanding of energy and energy transformations as formulated in the first and second laws of thermodynamics.

We present the first and second laws first from the macroscopic or classical viewpoint. This approach enables the students to relate these concepts to ideas with which they are familiar. In the discussion of these laws the necessary material is introduced relative to the properties and the behavior of matter. Particular consideration is given to gases and vapors, whenever matter is involved in energy transfers and transformations.

We believe that this approach will enable engineering students in one semester to gain a basic understanding of the subject and to recognize its importance. A very meaningful one-semester course can be devised by studying Chapters 1 through 6 and Chapters 9 and 10. Time permitting, Chapters 13 and 14 may be added.

For those students taking a two-semester course, it may be desirable to include Chapters 7 and 8 in the first semester work. For second semester students, applications of basic thermodynamic principles are directed to engineering areas such as chemical thermodynamics, thermodynamics of fluid flow, gas and vapor cycles, refrigerating cycles, and air conditioning. Because we believe that kinetic theory, microscopic thermodynamics, and statistical thermodynamics are essential for students to gain a deeper understanding of the subject, we present the fundamental aspects of these topics.

In addition to conventional power-producing devices, an ever-growing emphasis is being placed on direct energy conversion, particularly photovoltaic cells, magnetohydrodynamics, and fuel cells. The thermodynamics of direct-energy conversion is discussed on an elementary basis for the benefit of those students who do not wish to take elective courses in the subject, or who do not plan to go on to graduate school.

The last Chapter deals with the elementary concepts of heat transfer. It is made available here for the benefit of those students who do not intend to take a separate course in the subject. Furthermore, since so much of thermodynamics is concerned with heat transfers to and from systems, it is helpful to understand the basic principles of this process.

Many problems are given at the end of each chapter. In general, they are designed to teach students to use fundamental concepts in solving engineering problems as well as to illustrate fundamental principles. Many of the prob-

vi Preface

lems have been devised to show the effects of changes in various parameters on the performance of engineering devices. For example, the answers to various problems in the vapor cycles chapter show the precise effect of initial conditions, exhaust pressure, reheating, and feedwater heating on the efficiency of steam cycles. Because many instructors believe that students should not be given answers to problems ahead of time, no answers are given in the text. However, if some instructors wish to give answers to their students, they can find answers in the solution manual that will be available to them.

Recognizing the trend toward the use of the International System of Units (SI), we use these units throughout the book. Although changes are being made, the dimensions of much industrial equipment are still given in inches or feet. For example, common pipes are manufactured to specified dimensions (both the nominal and actual diameters) in inches. In Appendix 15, the nominal diameter is given in inches. The equivalent diameter and also all other dimensions are given in centimetres.

We express our appreciation to Linda Jackson for her excellent help in the preparation of the manuscript.

Jesse S. Doolittle

Francis J. Hale

SYMBOLS AND ABBREVIATIONS

SYMBOL	MEANING
A	Area
A	Ampere
A	Helmholtz function
a	Specific Helmholtz function
a	Absorptivity
a	Acceleration
a	Acoustic velocity
B	Magnetic field strength
C	Constant (general)
c	Specific heat
c_v	Specific heat for a constant-volume process
c_p	Specific heat for a constant-pressure process
c_x	Specific heat for a polytropic process
cm	Centimetre
C.O.P.	Coefficient of performance
$(C.O.P.)_r$	Coefficient of performance for refrigeration
$(C.O.P.)_{h.p.}$	Coefficient of performance for a heat pump
Chem. E.	Chemical energy
D	Diameter
E	Voltage
E	Emissive power
eV	Electron volt
F	Force
F_A	Shape factor
F_e	Emissivity factor
f	Fugacity
f	Saturated liquid (as a subscript)
fg	Change in properties during phase change (as a subscript)

SYMBOL	MEANING
ft	Foot
G	Mass rate of flow per unit area
G	Gibbs function (free energy) = $H - TS$
g	Specific Gibbs function
g	Gram
g	Acceleration due to gravity
g	Saturated vapor (as a subscript)
g_i	Possible number of quantum states
Gr	Grashof number
H	Enthalpy
h	Specific enthalpy
h	Hour
h	Planck constant
h	Surface or film heat-transfer coefficient
h_c	Convective surface or film heat-transfer coefficient
h_r	Radiant surface or film heat-transfer coefficient
I	Moment of inertia
I	Electric current
I	Intensity of radiation
J	Current density
J	Joule
J	Quantum number
J_s	Entropy current
K	Kelvin
K	Combined thermal conductivity
K_p	Chemical equilibrium constant
K.E.	Kinetic energy
k	Boltzmann constant (gas constant per molecule)
k	Specific heat ratio ($= c_p/c_v$)
k	Thermal conductivity
kg	Kilogram
kg mole	Kilogram mole
kW	Kilowatt
lb-mole	Pound mole
l	Distance
ln	Natural logarithm
log	Common logarithm

SYMBOL	MEANING
LMTD	Log mean temperature difference
M	Mach number
m	Mass
m	Metre
mm	Millimetre
\dot{m}	Mass rate of flow
\bar{m}	Mass per mole
MW	Megawatt
N	Newton
N	Number of moles
N	Number of cells
\bar{N}	Cycles per minute
n	Number of molecules
n	Polytropic process exponent
n_0	Number of molecules per mole
\bar{n}	Quantum number
Nu	Nusselt number
0	As a superscript refers to stagnation
P	Power
P.E.	Potential energy
Pa	Pascal
Pe	Peclet number
Pr	Prandtl number
p	Pressure
Q	Heat
\dot{Q}	Heat flow rate
Q	Heating value
Q_{comb}	Heat of combustion
q	Charge per electron
R	Rankine
R	Specific gas constant
R_0	Gas constant per mole
R	Electric resistance
Re	Reynolds number
r	Distance between magnetic poles
r	Compression ratio
r	Radius

SYMBOL	MEANING
r_t	Combined electrical resistance
r	Rotational (as a subscript)
S	Entropy
s	Specific entropy
s	Second
T	Absolute temperature
\bar{T}	Torque
t	Degrees Celsius or Fahrenheit
\bar{t}	Time
t	Translational (as a subscript)
U	Internal energy
U	Overall coefficient of heat transfer
U_k	Internal molecular kinetic energy
U_p	Molecular potential energy
u	Specific internal energy
V	Volume
V	Volts
v	Specific volume
v	Vibratory (as a subscript)
v	Vapor (as a subscript)
W	Work
W_m	Mechanical work
W_e	Electrical work
\dot{W}	Rate of doing work
W'	Possible number of macroscopic states
W	Watt
\bar{W}	Weight
w	Specific weight
X or x	Unknown (general)
x	Quality, mass fraction of vapor in a two-phase mixture
x	Thickness
y	Moisture content, mass fraction of liquid in a two-phase mixture
Z	Compressibility factor
Z	Figure of merit
Z	Quantum partition function
z	Height
β	Coefficient of volume expansion

SYMBOL	MEANING
ϵ	Emissivity
ϵ	Energy level
η	Efficiency
η_m	Mechanical efficiency
η_n	Nozzle efficiency
η_t	Thermal efficiency
λ	Wavelength
ν	Kinematic viscosity
ν	Frequency
μ	Viscosity (absolute)
μ	Joule-Thomson coefficient
Ω	ohm
ρ	Density
ρ	Reflectivity
\mathcal{V}	Velocity
\tilde{V}_{rms}	Root mean square velocity
τ	Transmissivity
τ	Thomson coefficient, thermoelectricity
α	Seebeck coefficient, thermoelectricity
π	Peltier coefficient, thermoelectricity
ϕ	Work function, thermionic generation
\mathcal{P}	Possible number of microscopic states
ϕ	Relative humidity
ω	Specific humidity
σ	Symmetry number (molecular)
σ	Internal electric conductivity
Π	Product of

CONTENTS

SYMBOLS AND ABBREVIATIONS

xv

Chapter 1 Introduction

1

1-1 The Nature of Thermodynamics	1
1-2 Thermodynamic Systems	7
1-3 Thermodynamic Properties	9
1-4 Units	11
1-5 Mass, Force, and Weight	12
1-6 Pressure	14
1-7 Temperature	17
1-8 Other Thermodynamic Properties	24
1-9 Processes	25
1-10 Pressure, Temperature, and Molecular Kinetic Energy	26
Problems	27



Chapter 2 The First Law

29

2-1 Introduction	29
2-2 Basis of the First Law	29
2-3 Energies Involved in the First Law	30
2-4 Evaluation of Potential and Kinetic Energies	32
2-5 Evaluation of Transferred Energies	33
2-6 The First Law Applied to Systems	39
2-7 Power	41
2-8 Enthalpy	42
2-9 First-Law Applications	43
Problems	49

Chapter 3 Ideal and Actual Gases

53

3-1 Introduction	53
3-2 Ideal Versus Actual Gases	57

viii Contents

3-3	The Mole	61
3-4	Equations of State for Actual Gases	64
3-5	Van der Waals Equation of State	64
3-6	Accuracy of the van der Waals Equation	67
3-7	Other Equations of State	72
3-8	Virial Equations of State	73
3-9	Corresponding States and Reduced Properties	74
3-10	Summary	80
	Problems	81

Chapter 4 Changes in State of Gases 83

4-1	Equilibrium and Reversibility	83
4-2	Polytropic Processes	88
4-3	Evaluation of Work for Polytropic Processes	91
4-4	Internal Energy Changes	93
4-5	Enthalpy Changes	95
4-6	Relationship Between c_p and c_v	96
4-7	The p - v Relationship for a Reversible Adiabatic Process	97
4-8	Specific Heats for Polytropic Processes	98
4-9	Variable Specific Heat	100
4-10	Internal Energy and Enthalpy Changes of Gases	104
	Problems	107

Chapter 5 The Second Law and Entropy 111

5-1	Introduction	111
5-2	The Carnot Cycle	113
5-3	The Reversed Carnot Cycle	117
5-4	The Clausius Inequality	120
5-5	Entropy	122
5-6	Entropy and Irreversibility	125
5-7	Uses for Entropy	126
5-8	Various Forms of the Second Law	128
	Problems	130

Chapter 6 Some Consequences of the Second Law 134

6-1	Temperature and the Second Law	134
6-2	Available and Unavailable Energy	136

6-3 Availability of Energy Entering a System	136
6-4 Loss in Available Energy During Heat Transfer	138
6-5 Change in Available Energy of Systems	140
6-6 Availability of a Closed System	144
6-7 Entropy and Unavailable Energy	146
Problems	148

Chapter 7 Probability and the Nature of Entropy 151

7-1 Introduction	151
7-2 The Microscopic Approach	151
7-3 Probability	152
7-4 Probability and Entropy	156
7-5 Entropy and the Third Law	158
Problems	160

Chapter 8 General Equations of Thermodynamics 161

8-1 Introduction	161
8-2 Internal Energy and Enthalpy	163
8-3 Entropy Changes	166
8-4 Specific Heat Relations	167
8-5 Clapeyron Equation	169
8-6 Joule-Thomson Coefficients	170
8-7 Other General Equations	174
8-8 Summary	175
Problems	176

Chapter 9 Vapors 178

9-1 Introduction	178
9-2 Vaporization of Liquids	179
9-3 Vapor Tables	183
9-4 Compressed Liquids	184
9-5 Properties of a Wet Vapor	186
9-6 Determination of Vapor Properties	188
9-7 Vapor Charts	189
9-8 Throttling of Vapors and Liquids	191
9-9 Changes in State of Vapors	192
9-10 Measurements To Determine the State of Vapors	196

x Contents

9-11 Nonequilibrium States for Two-Phase Mixtures	198
Problems	202

Chapter 10 Nonreactive Gaseous and Vapor Mixtures	206
--	------------

10-1 Introduction	206
10-2 Properties of Ideal Gaseous Mixtures	206
10-3 Irreversible Mixing of Gases Within a System	211
10-4 Mixing of Ideal Gases During Flow	214
10-5 Volumetric and Gravimetric Analysis	215
10-6 Gas-Vapor Mixture	216
10-7 Air-Vapor Mixtures	217
10-8 Psychrometric Charts	223
10-9 Simple Heat Transfer	224
10-10 Humidification and Dehumidification	226
10-11 Cooling by Evaporation	229
Problems	233

Chapter 11 Elements of Chemical Thermodynamics	236
---	------------

11-1 Introduction	236
11-2 Combustion	236
11-3 Combustion of Actual Fuels	240
11-4 Uses of Analyses of Products	245
11-5 Combustion in General	248
11-6 Heat of Reaction	248
11-7 Heating Values	249
11-8 Heat of Formation	255
11-9 Chemical Energy	256
11-10 Combustion Temperatures	258
11-11 Chemical Equilibrium	259
11-12 Equilibrium in a Reactive Mixture	260
11-13 Fugacity and Activity Coefficient	266
Problems	269

Chapter 12 Thermodynamics of Fluid Flow	272
--	------------

12-1 Introduction	272
12-2 Laminar and Turbulent Flows	273

12-3	Continuity of Flow	276
12-4	Energy Equation and Pressure Changes	276
12-5	Stagnation Properties	279
12-6	Acoustic Velocity and Mach Number	281
12-7	Adiabatic Flow with Constant-Area Passage	283
12-8	Adiabatic Flow with Varying Area	286
12-9	Flow in Ideal Nozzles	291
12-10	Nozzle Efficiency	294
12-11	Shock Waves in Nozzles	296
12-12	Diabatic Flow	300
12-13	Summary	304
	Problems	306

Chapter 13 Gas Cycles and Applications 310

13-1	Introduction	310
13-2	Criteria for Cycles	311
13-3	The Otto Cycle	312
13-4	The Diesel Cycle	316
13-5	The Brayton or Joule Cycle	319
13-6	Stirling and Ericsson (Regenerative) Cycles	322
13-7	Internal Combustion Engines	326
13-8	Internal Combustion Engine Performance	329
13-9	Gas Compressors	332
13-10	Gas Turbines	338
13-11	Actual Gas Turbines	340
13-12	Jet Propulsion	343
	Problems	347

Chapter 14 Vapor Cycles and Applications 351

14-1	Introduction	351
14-2	Carnot Vapor Cycle	351
14-3	Rankine Vapor Cycle	353
14-4	Reheating Cycle	360
14-5	Regenerative Feedwater Heating	362
14-6	Additional Vapor Cycles	366
14-7	Refrigeration	367

xii Contents

14-8 Vapor Compression Refrigeration	371
14-9 Other Refrigerating Systems	374
Problems	379

Chapter 15 Kinetic Theory of Gases 383

15-1 Introduction	383
15-2 Pressure, Temperature, and Kinetic Theory	383
15-3 Temperature and the Root Mean Square Velocity	387
15-4 Maxwell Speed Distribution	389
15-5 Evaluation of the Function α and b	394
15-6 Validity of the Maxwell Speed Distribution	396
Problems	398

Chapter 16 Elementary Statistics and Quantum Mechanics 399

16-1 Introduction	399
16-2 Energy Levels	399
16-3 Maxwell-Boltzmann Statistics	400
16-4 Bose-Einstein Statistics	404
16-5 Fermi-Dirac Statistics	406
16-6 Examination of the Three Models	407
16-7 Evaluation of the Constant β	408
16-8 Applications to Internal Energy, Entropy, and Specific Heats	409
16-9 Energy of Translation and Specific Heat	411
16-10 Rotational Energy and Specific Heat	413
16-11 Atomic Vibratory Energy and Specific Heat	418
16-12 Hydrogen at Low Temperatures	422
16-13 Gases at Extremely High Temperatures	422
16-14 Solids and Liquids	423
16-15 Application to Entropy Determinations	425
Problems	428

Chapter 17 Introduction to Irreversible Thermodynamics 429

17-1 Introduction	429
17-2 Entropy Production	429