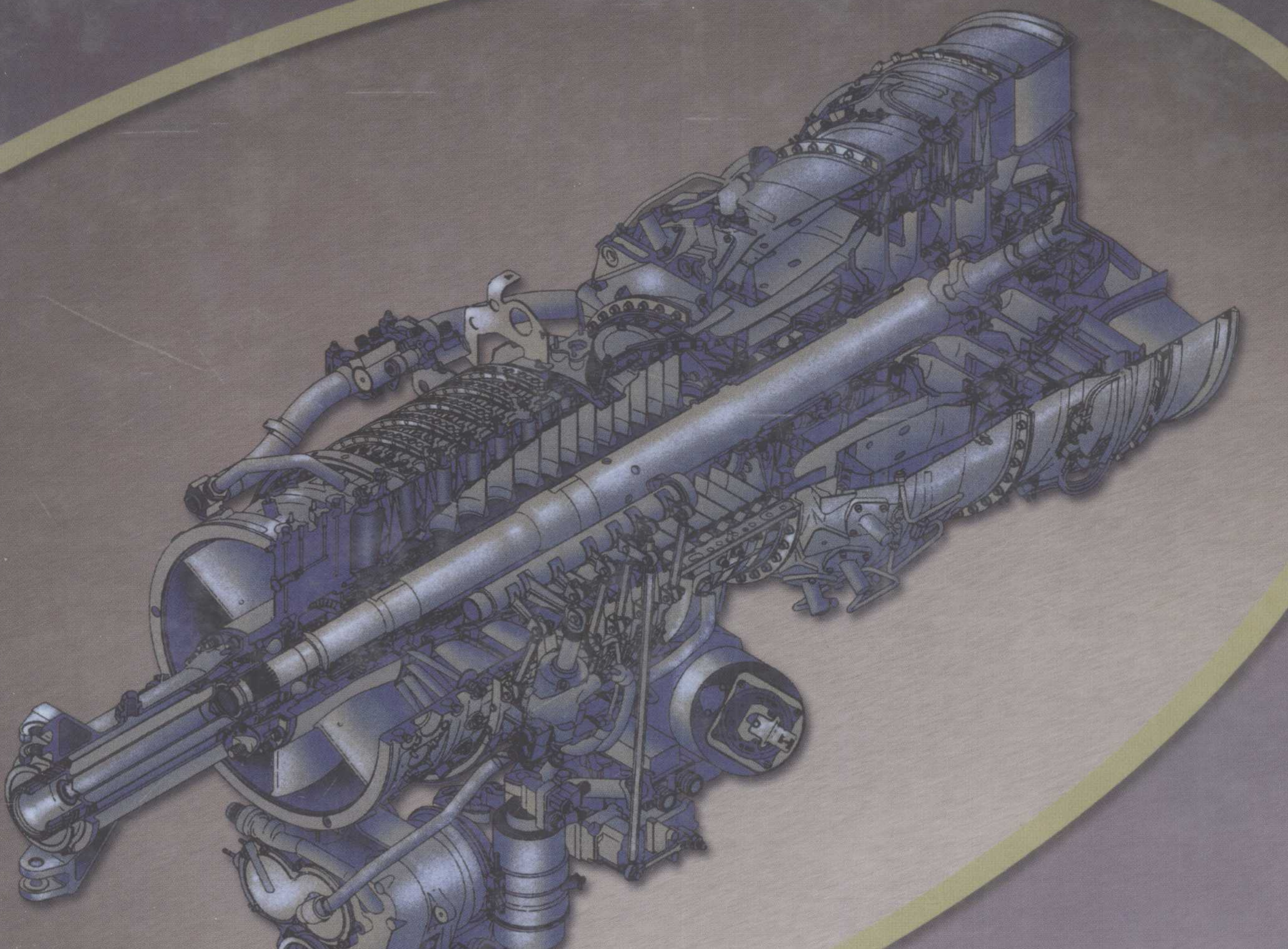
Thermodynamics and Heat Power

Seventh Edition



Irving Granet
Maurice Bluestein

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Thermodynamics and Heat Power

SEVENTH EDITION

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This book is dedicated to the memory of Irving Granet

Preface

Many colleges and universities require two semesters of thermodynamics for a bachelor's degree in engineering technology. Most students and faculty would, I believe, welcome having one good textbook for both courses. With this in mind, additional material has been added in this seventh edition. Principally, this includes:

- A Windows-based computer disk with thermodynamic properties of steam, air, other gases, and refrigerants, as well as psychrometrics.
- A discussion and additional problems involving the non-flow work integral.
- Extension of the analysis of the Rankine cycle to include regeneration with both closed and open feedwater heaters and an additional reheat cycle.
- Analysis of the maximum work Brayton cycle with calculus enrichment.
- Thermal analysis of the reciprocating compressor with additional homework problems.
- Metric unit equations for convection coefficients.
- A description of the heat pipe and how it functions.
- A discussion of the cooling of electronic components and how to determine the operating temperature of components.
- A description of state-of-the-art alternative energy sources, including fuel cells, solar energy, and wind power.

To make room for these additions, some out-of-date material on other power plant cycles and nuclear reactors has been removed. Many of these changes have resulted from the input of reviewers. A special thanks goes out to the following reviewers of the previous edition: Ed Braun—University of North Carolina, Charlotte; Mohammad Hossain—York Technical College; and Charles Rondeau, Jamestown Community College. I am most grateful for those comments. Please keep them coming.

Thanks to the staff at Prentice Hall for their help with this new edition, especially Debbie Yarnell, Louise Sette, Adam Hirschberg, and most of all Kim Yehle. I also thank my family for their support and encouragement: Maris, Karen, Richard, Jennifer, Michaelbarry, and Jaxanna.

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Symbols

Symbol	Definition	Units: British Engineering	Units: SI
a	Acceleration	ft/s^2	m/s^2
a, A	Area	ft^2	m^2
A, B, C, D, E	Constants		
C_D	Discharge coefficient	dimensionless	
C_v	Velocity coefficient	dimensionless	
c	Clearance	dimensionless	
c	Specific heat	Btu/lb$_m$·°R	kJ/kg·°K
c_p	Specific heat at constant pressure	Btu/lb$_m$·°R	kJ/kg·°K
c_v	Specific heat at constant volume	Btu/lb$_m$·°R	kJ/kg·°K
c_n	Specific heat of any process	Btu/lb$_m$·°R	kJ/kg·°K
C_p	Total specific heat at constant pressure	Btu/°R	kJ/°K
C_v	Total specific heat at constant volume	Btu/°R	kJ/°K
COP	Coefficient of performance	dimensionless	
d, D	Diameter	ft	m
e	Base of natural logarithms	dimensionless	
F	Force	lb$_f$	N
F_A	Geometric factor	dimensionless	
F_e	Emissivity factor	dimensionless	
g	Acceleration of gravity	ft/s^2	m/s^2
g_c	Gravitational constant	32.174 ft·lb$_m$/lb$_f$·s^2	
Gr	Grashof number	dimensionless	
h	Height	ft	m
H	Enthalpy	Btu	kJ
h	Specific enthalpy	Btu/lb$_m$	kJ/kg
h_f	Specific enthalpy—saturated liquid	Btu/lb$_m$	kJ/kg

h_g	Specific enthalpy—saturated vapor	Btu/lb_m	kJ/kg
h_{fg}	Specific enthalpy of vaporization ($h_g - h_f$)	Btu/lb_m	kJ/kg
h^0	Stagnation enthalpy	Btu/lb_m	kJ/kg
h	Heat-transfer coefficient	$Btu/hr \cdot ft^2 \cdot °F$	$kW/m^2 \cdot °K$
h_r	Heat-transfer coefficient—radiation	$Btu/hr \cdot ft^2 \cdot °F$	$kW/m^2 \cdot °K$
i	Current	amperes	amperes
J	Mechanical equivalent of heat	$778\ ft \cdot lb_f/Btu$	
K	Proportionality constant		
k	Spring constant	$lb_f/in.$	N/m
k	Thermal conductivity	$Btu/hr \cdot ft \cdot °F$	$kW/m \cdot °K$
k	c_p/c_v	dimensionless	
K.E.	Kinetic energy	$ft \cdot lb_f/lb_m$	kJ/kg
l, L	Length	ft	m
m	Mass	lb_m	kg
$\dot{m}$	Mass flow rate	lb_m/s	kg/s
M	Mach number	dimensionless	
mep	Mean effective pressure	lb_f/in^2	kPa
MW	Molecular weight	$lb_m/lb_m \cdot mole$	$kg/kg \cdot mole$
n	Polytropic exponent	dimensionless	
n	Number of particles	dimensionless	
n	Number of moles	dimensionless	
Nu	Nusselt number	dimensionless	
n	Number of moles	mass/MW	mass/MW
p	Pressure	lb_f/in^2	kPa
p_m	Mixture pressure	lb_f/in^2	kPa
p_m	Mean effective pressure	lb_f/in^2	kPa
p_r	Reduced pressure	dimensionless	
p_r	Relative pressure	dimensionless	
P.E.	Potential energy	$ft\ lb_f/lb_m$	kJ/g
Pr	Prandtl number	dimensionless	
Q	Heat interchange	Btu	kJ
q	Specific heat interchange	Btu/lb_m	kJ/kg
$\dot{Q}$	Heat transfer rate	Btu/hr	kW
$\dot{Q}_r$	Radiant heat transfer rate	Btu/hr	kW
R	Universal gas constant	$ft\ lb_f/lb_m \cdot °R$	$kJ/kg \cdot °K$
R	Electrical resistance	ohms	ohms
Re	Reynolds number	dimensionless	
R_t	Thermal resistance	$°F \cdot hr/Btu$	°C/W
r	Radius	ft	m
r_e	Expansion ratio	dimensionless	
r_c	Compression ratio	dimensionless	
$r_{c.o.}$	Cutoff ratio	dimensionless	
r_p	Pressure ratio	dimensionless	
s	Specific entropy	$Btu/lb_m \cdot °R$	$kJ/kg \cdot °K$

S	Total entropy	Btu/°R	kJ/K
s_f	Specific entropy of saturated liquid	Btu/lb_m·°R	kJ/kg·°K
s_g	Specific entropy of saturated vapor	Btu/lb_m·°R	kJ/kg·°K
s_{fg}	Specific entropy of vaporization $(s_g - s_f)$	Btu/lb_m·°R	kJ/kg·°K
sg	Specific gravity	dimensionless	
T	Temperature, absolute	°R	°K
T_c	Critical temperature	°R	°K
t	Temperature	°F	°C
t	Time	s (seconds)	s
T_r	Reduced temperature	dimensionless	
$(\Delta t)_m$	Logarithmic temperature difference	°F	°C
U	Internal energy	Btu	kJ
U	Overall heat transfer coefficient	Btu/hr·ft^2·°F	kW/m^2·°K
u	Specific internal energy	Btu/lb_m	kJ/kg
u_f	Specific internal energy—saturated liquid	Btu/lb_m	kJ/kg
u_g	Specific internal energy—saturated liquid	Btu/lb_m	kJ/kg
u_{fg}	Specific internal energy of vaporization $(u_g - u_f)$	Btu/lb_m	kJ/kg
V	Velocity	ft/s	m/s
V_a	Acoustic velocity	ft/s	m/s
V	Volume	ft^3	m^3
$\dot{V}$	Volume flow rate	ft^3/min	m^3/s
v	Specific volume	ft^3/lb_m	m^3/kg
v_r	Reduced specific volume	dimensionless	
v_r	Relative specific volume	dimensionless	
v_c	Critical specific volume	ft^3/lb_m	m^3/kg
v_f	Specific volume of saturated liquid	ft^3/lb_m	m^3/kg
v_g	Specific volume of saturated vapor	ft^3/lb_m	m^3/kg
v_{fg}	Specific volume of vaporization $(v_g - v_f)$	ft^3/lb_m	m^3/kg
w	Weight	lb_f	N
W	Weight	lb_f	kN
W	Humidity ratio	dimensionless	
W	Work	ft lb_f	kJ
$\mathbf{w}$	Work per unit mass	ft lb_f/lb_m	kJ/kg
$\dot{W}$	Power	Btu/min	kW
x	Mole fraction	dimensionless	
x	Quality	dimensionless	
x	Length	ft	m
z	Elevation above reference plane	ft	m
Z	Compressibility factor	dimensionless	
α	Absorptivity	dimensionless	
γ	Specific weight	lb_f/ft^3	kn/m^3
Δ	Small change of variable	dimensionless	
ε	Emissivity	dimensionless	
η	Efficiency	dimensionless	

η_V	Volumetric efficiency	dimensionless	
μ	Viscosity	$lb_m/ft^2 \cdot hr$	$N \cdot s/m^2$
ρ	Density	lb_m/ft^3	kg/m^3
ρ	Reflectivity	dimensionless	
σ	Stefan–Boltzmann constant	$Btu/hr \cdot ft^2 \cdot {}^\circ R^4$	$W/m^2 \cdot {}^\circ K^4$
τ	Transmissivity	dimensionless	
θ	A function of	dimensionless	
ϕ	Relative humidity	dimensionless	

In addition to the symbols listed above, the following notation is used:
Superscript ^{0} refers to the stagnation property.
Superscript * refers to the state where M = 1.
Subscript $_m$ refers to the mixture property.

Contents

1

Fundamental Concepts

Learning Goals

After reading and studying the material in this chapter, you should be able to:

1. Define thermodynamics as the study of energy and the conversion of energy from one form to another.
2. Use the observable external characteristics that are known as properties to describe a system.
3. Establish and convert from one system of temperature measurement to another, and understand the four methods of measuring temperature.
4. Use both the English and SI systems of units.
5. Use elementary kinetic theory of gases to establish the concepts of pressure, temperature, density, specific weight, specific volume, and Avogadro's law.
6. Use the concept of pressure in both English and SI units. Gage and absolute pressure definitions are important ideas that are necessary in engineering applications.
7. Use the concept that fluids exert pressures that can be expressed in terms of the height and specific weight of the column of fluid.
8. Describe the various methods of measuring pressure and the methods used to calibrate pressure-measuring devices.

1.1 INTRODUCTION

Thermodynamics is the study of energy, heat, work, the properties of the media employed, and the processes involved. Thermodynamics is also the study of the conversion of one form of energy to another. Because energy can be derived from electrical, chemical, nuclear, or other means, thermodynamics plays an important role in all branches of engineering, physics, chemistry, and the biological sciences.

In defining the word *thermodynamics,* we have used the terms *energy, heat,* and *work.* It is necessary to examine these terms in detail, and this will be done in subsequent chapters. In this chapter, certain fundamental concepts are defined and basic ideas are developed for future use.

The role of thermodynamics in modern life is of great importance. For example, Figure 1.1 shows a modern jet engine for use on commercial aircraft. This engine is capable of producing a