Thermodynamic Principles of Energy Degrading

‘Each time we alter our investment in energy,
we have thus to pay a commission, and the
tribute thus enacted can never be wholly
recovered by us, and must be regarded *not*
as destroyed but as thrown on the waste heap
of the universe’

GRIFFITHS

THERMODYNAMIC PRINCIPLES OF ENERGY DEGRADING

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To my father

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Preface

The study of heat and work transfer in thermodynamic processes is not new, and many textbooks have been written on this fundamental subject. However, this is the first textbook at the time of writing which extends thermodynamic principles to energy grading and degrading, and which thereby quantifies precisely the deterioration in work-producing ability which occurs at each stage of energy conversion. The book is suitable for engineering students in their third and final years, and while desirable it is not essential that they have had previous exposure to elementary thermodynamics.

The book presents clearly the thermodynamic fundamentals leading to energy grading and degrading in progressive chapters on fundamentals, energy conservation, reversibility, entropy, available energy and energy degrading. There is no overlap between the chapters as is often the case with established textbooks on thermodynamics, and the subject matter has been developed in what appears to the author as the most logical manner possible. Although the text is relatively short, the treatment is thorough and complete and is presented in a simple and concise style.

All previous textbooks on thermodynamics fall short at the presentation of fundamental laws and relationships, and make no attempt at extending these laws into the realm of energy degrading which depends so critically on fundamental thermodynamics. The worldwide emphasis today on energy conservation measures requires a basic textbook which establishes guidelines for planning optimised energy flow patterns in industrial applications. It is believed that this book admirably fulfils such a need. One of the new concepts presented is that of internal and external entropy, and this is clearly shown to have advantages over the previous isolated system technique.

The author's true interest in thermodynamics began as a graduate student at the Massachusetts Institute of Technology during the late 1950s. Subsequently, this interest became a fascination while teaching the subject over a period of fifteen years at the State University of New York at Buffalo, West Virginia University and University College Dublin. In addition to its direct association with fundamental thermodynamics, the energy degrading concept is now also an

integral part of an energy conversion systems course given by the author to final-year electrical and chemical engineering students at University College.

The book in general must be considered as a very complete treatment of the Second Law despite its brevity. It is *not* a complete textbook on thermodynamics, however, since these already abound in the literature, but rather a concise and thorough exposition of energy conservation and energy degrading based on the First and Second Laws respectively. The subject matter will have appeal for engineering students, industrialists, researchers and practising engineers engaged in energy conservation. A word of thanks is due to Mrs Geraldine Brogan for typing the original manuscript and to Mr Alan Reid for preparing excellent line drawings.

DESMOND F. MOORE

Nomenclature

a	Specific availability	kJ/kg
A	Availability	kJ
b	Specific stream availability	kJ/kg
B	Stream availability	kJ
c	Heat capacity	kJ/kg K
C	Constant	
c_v	Specific heat at constant volume	kJ/kg K
c_p	Specific heat at constant pressure	kJ/kg K
e	Specific stored energy	kJ/kg
E	Stored energy	kJ
$E.D.$	Energy degrading	kJ
f	Specific Helmholtz free energy	kJ/kg
F	Helmholtz free energy	kJ
	Force	kN
f_i	Function ($i = 1, 2, 3, \text{etc.}$)	
g	Specific Gibbs free energy	kJ/kg
G	Gibbs free energy	kJ
h	Specific enthalpy	kJ/kg
	Gravitational height	m
H	Enthalpy	kJ
	Magnetic flux	
i	Specific irreversibility function	kJ/kg
I	Net irreversibility function	kJ
I'	Gross irreversibility function	kJ
K_i	Constants ($i = 1, 2, 3, \text{etc.}$)	
L	Length	m
$L.W.$	Lost work	kJ
m	Mass	kg
M	Molecular weight	kg/gm mole
	Magnetic moment	
n	Number of molecules	
	Polytropic index	

N	Number of moles	
p	Pressure	kN/m ²
P	Power	kW
	Property	
	Probability	
q	Specific heat transfer	kJ/kg
Q	Heat transfer	kJ
q_{av}	Specific available energy	kJ/kg
Q_{av}	Available energy	kJ
q_{in}	Specific heat inflow	kJ/kg
Q_{in}	Heat inflow	kJ
q_{out}	Specific heat outflow	kJ/kg
Q_{out}	Heat outflow	kJ
q_{unav}	Specific unavailable energy	kJ/kg
Q_{unav}	Unavailable energy	kJ
R	Particular gas constant	kJ/kg K
R^*	Universal gas constant	kJ/kg mole K
s	Specific entropy	kJ/kg K
	Distance	m
S	Entropy	kJ/K
t	Time	s
T	Temperature	°C, K
	Surface tension	kN/m
T_H	High reservoir temperature	°C, K
T_L	Low reservoir temperature	°C, K
u	Specific internal energy	kJ/kg
U	Internal energy	kJ
v	Specific volume	m ³ /kg
v^*	Specific molal volume	m ³ /kg mole
V	Velocity	m/s
	Voltage	V
	Total volume	m ³
w	Specific work	kJ/kg
W	Work	kJ
	Weight	kN
x	Coordinate	m
	Dryness fraction	
Z	Compressibility factor	
γ	Specific heat ratio, c_p/c_v	
δ	Infinitesimal change	
	Displacement	m
Δ	Finite change	
ϵ	Strain	
	Effectiveness	

η_{th}	Thermal efficiency	
η_{isentr}	Isentropic efficiency	
μ	Absolute viscosity	kg s/m ²
ρ	Density	kg/m ³
σ	Stress	kN/m ²
τ	Shear stress	kN/m ²
ϕ	Specific availability function	kJ/kg
	Mathematical function	
Φ	Availability function	kJ
ψ	Specific stream availability function	kJ/kg
Ψ	Stream availability function	kJ