Finite Time Thermodynamics of Power and Refrigeration Cycles

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Springer

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Foreword

I am pleased to introduce the book on *Finite Time Thermodynamics of Power and Refrigeration Cycles* by my learned colleagues Prof. Shubhash C. Kaushik, Dr. Sudhir K. Tyagi, and Dr. Pramod Kumar. The book presents the basic concepts of finite time thermodynamics and its application to heat engine and heat pump cycles, used in power generation and space conditioning. The book incorporates the research by Prof. Kaushik and his associates in the last 15 years or so. The expertise of the authors in research and teaching in this emerging field of finite time thermodynamics is reflected in the book.

The book is suitable for study by B. Tech./M. Tech./research students and can be used as a reference by researchers and others. I wish the book all the success in enlightening numerous readers.

Mahendra Singh Sodha

Centre for Energy Studies (CES),
Indian Institute of Technology Delhi,
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Lucknow University, and Bhopal University

Mahendra Singh Sodha
Padma Shri

Preface

Thermodynamics is one of the most interesting and important branches of thermal science and engineering, which plays a very crucial role in the design, development, and performance evaluation of thermal energy conversion systems including heat engine, refrigeration, and airconditioning systems.

Finite time thermodynamics (FTT) is a special branch of applied thermodynamics which deals mainly with external and internal irreversibilities associated with thermal energy conversion systems. With the increasing interest in power generation and space conditioning, FTT has become a very useful tool for the design and evaluation of these systems and gained a larger scope in the academic and scientific communities. In recent decades, it has been an interesting topic of discussion in many national and international conferences, but such material is scant and a comprehensive review on advanced systems is still lacking. Thus it was felt that there was a need for a comprehensive book on FTT of advanced and modified power and refrigeration cycles. The authors were inspired to write this book and are hopeful that it will be very useful for the research, design, and development of thermal energy conversion systems.

This book is mainly based on the research work carried out by the authors covering power and refrigeration cycles including basic, modified, and advanced versions of Carnot, Rankine, Brayton, Stirling, Ericsson, vapour compression, and vapour absorption cycles. However, relevant research papers and review articles were also consulted for the completeness of the book.

The content of the proposed book has been divided into 12 chapters. The first chapter presents the introduction of finite time thermodynamics, while the second chapter deals with its applications to the Carnot and Rankine power cycle. Chapters 3, 4, and 5 deal with the modified, advanced, and complex Brayton power cycles, respectively. The analysis of Stirling and Ericsson power cycles is presented in Chap. 6. Chapter 7 presents the finite time analysis of vapour compression refrigeration cycle, and Chap. 8 deals with the cascaded refrigeration cycle, while the Rankine cycle-operated vapour compression refrigeration cycles are presented in Chap. 9. Chapters 10 and 11 present the analysis and parametric study of Brayton and Stirling/Ericsson refrigeration cycles, whereas three heat reservoir-based (cooling and heating) cycles are given in Chap. 12 for a typical set of operating conditions. Finally, a list of references has been provided for further consultation to the readers.

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New Delhi, India Pramod Kumar

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- And above all, the Almighty God for giving intellect and strength to write this book with wisdom

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About the Authors

Shubhash C. Kaushik received his Ph.D. in plasma science from IIT Delhi after receiving his distinguished Master's degree in electronics from Meercut University, Meercut (UP). His research fields include the activities in plasma science and thermal science and engineering, energy conservation and heat recovery, solar refrigeration and airconditioning, solar architecture, and thermal storage and power generation. He has made significant contributions in these fields as evident by his more than 400 research publications in journals/conferences of repute at national and international levels. Dr. Kaushik has also completed several sponsored and consultancy projects from various government and private agencies. He has guided 50 Ph.D. theses and 75 M.Tech. projects and has authored several books. Dr. Kaushik has also been a postdoctoral fellow at Queensland University, Brisbane, Australia; visiting professor at LES-IIM-UNAM, Mexico; and Marie Skłodowska-Curie visiting fellow of the European Commission, Paris, France. Prof. Shubhash C. Kaushik has recently been awarded as top academic research performer (first rank holder) in all of India in the subject area of energy based on his research publication citations for the last 5–10 years and H-index as per Scopus data reported in NSTMIS-DST(GOI), New Delhi (2015).

Sudhir K. Tyagi is working as associate professor at the Centre for Energy Studies, IIT Delhi, and earlier he has worked as director/Scientist E at Sardar Swaran Singh National Institute of Renewable Energy, Kapurthala, an autonomous institution of the Ministry of New and Renewable Energy, Government of India. He has also worked as assistant professor at SMVDU, Katra, Jammu and Kashmir. Dr. Tyagi has worked as invited scientist at the Korea Institute of Energy Research, South Korea, and as postdoctoral fellow at the Hong Kong Polytechnic University, Hong Kong; Zhejiang University, Hangzhou; and Xiamen University, Xiamen, China, during 2002–2008. He has made a significant contribution in R&D activities as evident by more than 150 publications in journals/conferences of repute. He has guided 5 Ph.D. theses and 10 M.Tech. projects.

Pramod Kumar received his Ph.D. degree in the research field of finite time thermodynamics from IIT Delhi in 2003 and continued research work as postdoctoral fellow at IIT Delhi in the research field of exergy analysis. He had earlier completed his M.Sc. in physics, with specialization in electronics, from Meerut University in 1997 and also qualified in GATE-98 in physics and joint CSIR-UGC NET examination in December 2002 in physical sciences. His research areas include finite time thermodynamics, refrigeration and airconditioning systems, and energy and exergy analysis. Dr. Kumar joined the Defence Research and Development Organisation (DRDO), Ministry of Defence, directly as Scientist 'C' in 2005 at Naval College of Engineering, INS Shivaji, Lonavala, Pune, and taught at undergraduate level for about 4 years. In August 2008, he joined Solid State Physics Laboratory (SSPL) Delhi and is currently working as Scientist E. He has received the Commanding-in-Chief (C-in-C) Award – Commendation by Vice Admiral, Indian Navy, for his specific teaching ability. He has also received the Technology Group Award three times for his contribution at SSPL Delhi. He is a life member of the Solar Energy Society of India. He has made a significant contribution in R&D activities as evident by more than 25 research publications in journals/conferences of repute at national and international levels. He has also contributed towards the completion of four R&D projects and five technical reports and guided a couple of students at M.Tech./B.Tech. level. He is an expert reviewer in many national/international journals of repute.

Nomenclature

A	Heat exchanger area (m^2)
C	Heat capacitance rates (kW/K)
Cp	Specific heat (kJ/kg-k)
C-A	Curzon–Ahlborn
AE	Conductance on absorber side (kW/K)
CE	Conductance on condenser side (kW/K)
COP	Coefficient of performance
EE	Conductance on evaporator side (kW/K)
GE	Conductance on generator side (kW/K)
HP	Heat pump
h	Specific enthalpy (kJ/kg)
k	Conductance (kW\K)
L	Lagrangian operator
LMTD	Log Mean Temperature Difference
M	Mach number
M	Mass (kg)
$\dot{m}$	Mass flow rates (kg/s)
NTU	Number of transfer units
P	Power input/output (kW)
P_{c}	Condensation pressure (MPa)
P_{e}	Evaporation pressure (MPa)
P_{H}	Heating load (or output heat power) (kW)
P_{L}	Cooling load (or input heat power) (kW)
Q	Heat transfer (kJ)
$\dot{Q}$	Heat transfer rate (kW)
Ro	Gas constant (kJ/kmol·K)
$R_{\Delta S}, R'_{\Delta S}, R_{\mathrm{K-T}}$	Internal irreversibility parameters
R/AC/HP	Refrigeration/airconditioning/heat pump
r_c	Pressure/volume ratio

S	Entropy (kJ/K)
s	Specific entropy (kJ/K-kg)
t, t_{cycle}	Total/cycle time (s)
T	Temperature (K)
U	Overall heat transfer coefficient kW/(m^2–k)
V, V_s	Speed (m/s)
VC	Vapour compression
VCR	Vapour compression refrigeration VA Vapour absorption
VAR	Vapour absorption refrigeration
W	Work input/output (kJ)
x	Dryness fraction or the quality of the mixture

Subscripts

a	Absorber side
A	Absorber
c	Condenser side/compression
cy	Cycle
C	Condenser/heat sink side
C-A	Curzon–Ahlborn
e	Evaporator side
ea	Entropic average
E	Evaporator/heat source side
f	Fluid
g	Generator side
G	Generator
h	Heat source reservoir side
H	High temperature/hot side reservoir
in	Input
l	Sink/cold side
L	Low temperature/cold side reservoir
min	Minimum
max	Maximum
p	Pressure
s	Sound/source
wf	Working fluid
1, 2	Inlet, outlet
opt	Optimal
o	Output/optimal
r	Volume
w	Warm/hot side

Superscripts

HP	Heat pump
o, a	Environment/ambient
Ref	Refrigeration cycle
Rev.	Reversible
i	Initial
f	Final

Greeks

ε	Effectiveness/overall performance
λ μ	Lagrangian multipliers
γ	Specific heat ratio
η	Thermal efficiency
α, β	Thermal conductance (kW/K)
λ	Pressure/volume ratio