Compact Heat Exchangers – Analysis, Design and Optimization using FEM and CFD Approach

WILEY-ASME PRESS SERIES LIST

Primer on Engineering Standards: Expanded Textbook Edition	Greulich	April 2018
Robust Adaptive Control for Fractional-Order Systems with Disturbance and Saturation	Chen	December 2017
Stress in ASME Pressure Vessels, Boilers, and Nuclear Components	Jawad	October 2017
Robot Manipulator Redundancy Resolution	Zhang	October 2017
Combined Cooling, Heating, and Power Systems: Modeling, Optimization, and Operation	Shi	August 2017
Applications of Mathematical Heat Transfer and Fluid Flow Models in Engineering and Medicine	Dorfman	February 2017
Bioprocessing Piping and Equipment Design: A Companion Guide for the ASME BPE Standard	Huitt	December 2016
Geothermal Heat Pump and Heat Engine Systems: Theory and Practice	Chiasson	September 2016
Nonlinear Regression Modeling for Engineering Applications	Rhinehart	September 2016
Fundamentals of Mechanical Vibrations	Cai	May 2016
Introduction to Dynamics and Control of Mechanical Engineering Systems	To	March 2016

Compact Heat Exchangers – Analysis, Design and Optimization using FEM and CFD Approach

C. Ranganayakulu
Aeronautical Development Agency
Bangalore, India

K.N. Seetharamu
PES University
Bangalore, India

This Work is a co-publication between ASME Press and John Wiley & Sons Ltd.

WILEY

ASME PRESS

This edition first published 2018

Registered Offices
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customser services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data

Names: Ranganayakulu, C., author. | Seetharamu, K.N., author.
Title: Compact heat exchangers – analysis, design and optimization using FEM and CFD approach / By C. Ranganayakulu, K.N. Seetharamu.
Description: Hoboken, NJ : John Wiley & Sons, 2018. | Includes index. | Identifiers: LCCN 2017042879 (print) | LCCN 2017049499 (ebook) | ISBN 9781119424352 (pdf) | ISBN 9781119424376 (epub) | ISBN 9781119424185 (cloth)
Subjects: LCSH: Heat–Transmission. | Finite element method. | Computational fluid dynamics.
Classification: LCC QC320.22.F56 (ebook) | LCC QC320.22.F56 R36 2018 (print) | DDC 621.402/2–dc23
LC record available at https://lccn.loc.gov/2017042879

Cover Design: Wiley
Cover Image: © Devrimb/Gettyimages

Set in 10/12pt Warnock by SPi Global, Pondicherry, India

Printed and bound by CPI Group (UK) Ltd, Croydon, CR0 4YY

10 9 8 7 6 5 4 3 2 1

Contents

Preface

The importance of compact heat exchangers (CHEs) has been recognized in aerospace, automobile, process plants and other industries for 60 years or more. This importance is further demanded in the aerospace sector, with its requirements such as weight optimization, high compactness and high performance leading to the demand for cost-effective design and manufacturing techniques. While several books dealing mainly with heat exchangers have been published worldwide in English, no complete source of design data can be found on the many important aspects of CHE design, which an engineer can use as a comprehensive source of generalized design data for the most widely used fin surfaces. One of the first comprehensive books on the design of CHEs using primarily air or gases as working fluid was first published by Kays and London in 1967 with the SI unit edition appearing in 1984. This book is still widely used worldwide, with most design data referenced from 1967, for fin data experimentally generated. Because manufacturing technology has progressed significantly since the beginning of 21st century, many new and sophisticated forms of heat transfer surfaces have been used in CHEs. The design data for these surfaces is limited in the open literature and most of the aerospace industry CHE manufacturers keep their design data proprietary.

This book is an attempt to bring new concepts of design data generation numerically, which is cost-effective and more generic design data, which can be used more effectively by design and practising engineers. It is hoped that researchers and designers will find it of value, as well as academics and graduate students. The specialty of this book is numerical design data based on FEM and CFD. Numerical methods and techniques are introduced for estimation of performance deterioration such as flow non-uniformity, temperature non-uniformity and longitudinal heat conduction effects using FEM for CHE unit level and Colburn j factor and Fanning friction f factor data generation methods for various types of CHE fins using CFD at fin level. In addition, worked examples for single- and two-phase flow CHEs are provided, and the complete qualification tests are given for CHEs used in aerospace applications, typically, which are unavailable in open literature, as these are provided only in some standards. In order to keep the book to a reasonable size, some topics of relevance to CHE applications, which are available in other accessible books, such as *Compact Heat Exchangers* by Kays and London, 3rd edition, McGraw–Hill Book Company, New York [1984], *Compact Heat Exchangers* by J.E Hesselgreaves, Pergamon [2001] and *Plate-fin Heat Exchangers Guide to their Specification and Use* by M.A. Taylor, HTFS, UK, [1987] have been omitted, in particular those of transients (for regenerators), the effect of temperature dependent fluid properties and analytical solutions for flow in tubes.

The first three chapters of the book deal with the fundamentals of heat transfer, heat exchangers and numerical techniques of FEM and CFD. The application of FEM to compact heat exchangers is presented in Chapter 4, where heat conduction effects using FEM on evaporator tubes in pool boiling is also provided. Chapter 5 gives the complete information about CFD analysis of various fins of CHEs for generation of Colburn j and Fanning friction f factor correlations. In addition, the endurance life estimation of a typical CHE is also provided, based on FEM and CFD techniques. The basic concepts of sizing and design methodologies are provided for CHEs in Chapter 6 along with several worked examples for direct transfer type heat exchangers, boiling and condenser heat exchangers. Finally, in Chapter 7, the construction details and several qualifications tests are presented for qualification of CHEs especially for aerospace applications.

Many people have helped either directly or indirectly throughout the preparation of this book. Primarily, the authors are greatly indebted to their family members Lakshmi and Puji Krimmel (Dr C. Ranganayakulu) and Uma, Anil, Vani and Samartha Shastry (Prof. K.N. Seetharamu) for their unfailing support and patience during the development of this book. In particular, the authors wish to thank Aeronautical Development Agency and PES University, Bangalore for allowing us to work on this book. Dr C Ranganayakulu acknowledges his colleagues Mr R. Swaminathan, Mr A. Panigrahi and Mr Shahbaz Ulum for their support; in particular, Prof. Stephan Kabelac, Prof. Dieter Gorenflo, Prof. P. Nithiarasu and Prof. V. Vasudeva Rao for their guidance and encouragement; as well as Dr Saik L. Ismail, Dr A.C. Bhaskar, Dr R. Balasundar Rao, Dr M. Amaranatha Raju and Mr K.V. Ramana Murthy for their PhD works and Mr M.H. Prasad, Mr B. Mahesh and Mr C. Deepak Varma for book documentary works. Prof. Seetharamu also acknowledges Dr H.W. Lee, Dr Anvar Mydin, Dr G.A. Quadir, Dr Z.A. Zainal and in particular Dr T.R. Seetharam, Dr V. Krishna and Dr K.N.B. Murthy for their encouragement to write this book. Finally, the authors would like to thank the staff of John Wiley & Sons Ltd, UK, in particular Ms Anita Yadav and Mr Paul Beverley, for their constant support and encouragement during the preparation of the book.

C. Ranganayakulu
K.N. Seetharamu

Series Preface

The Wiley-ASME Press Series in Mechanical Engineering brings together two established leaders in mechanical engineering publishing to deliver high-quality, peer-reviewed books covering topics of current interest to engineers and researchers worldwide.

The series publishes across the breadth of mechanical engineering, comprising research, design and development, and manufacturing. It includes monographs, references and course texts.

Prospective topics include emerging and advanced technologies in Engineering Design; Computer-Aided Design; Energy Conversion & Resources; Heat Transfer; Manufacturing & Processing; Systems & Devices; Renewable Energy; Robotics; and Biotechnology.