Wolverine Tube, Inc.
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Engineering Data Book III

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Preface

Welcome to the new edition of Wolverine Tube Inc.'s *Wolverine Engineering Data Book III*. This book has been written primarily with heat transfer engineers in mind but also for research engineers who want to get caught up on the latest advances in heat transfer design methods for tubular heat exchangers. The objectives of the book are to present a limited review of the basic principles of heat transfer and then describe what I currently consider to be the best thermal design methods available. Hence, each chapter presents a detailed state-of-the-art review of heat transfer and fluid flow research of practical interest to heat exchanger designers, manufacturers and end users; however, for more exhaustive treatments the reader is recommended to go to the many references and other reviews cited.

The idea to make this a web-based book available on Wolverine Tube Inc.'s website is to make this information more readily available to the reader. New chapters will be added as they become ready and also the existing chapters will be updated with new methods as they appear in the literature every few years to keep this whole reference book up to date. Also, Chapter 1 presents a video gallery of heat transfer and flow phenomena that I think will be quite useful to heat transfer engineers who have never had the chance to see what is in fact happening inside their heat exchangers!

I, myself, have pulled *Wolverine Engineering Data Book II* down from the shelf many times over the years to look for design information to use my own engineering work. *Data Book II* is also available on the same website as *Data Book III* and contains much valuable information that has not been repeated in *Data Book III*.

Finally, I would like to thank Wolverine Tube Inc. for inviting me to write this new edition of *Data Book III*, in particular Massoud Neshan and Petur Thors of the Research and Development group.

John R. Thome, Author

About the Author

John R. Thome is Professor of Heat and Mass Transfer at the Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland since 1998, where he is director of the Laboratory of Heat and Mass Transfer (LTCM) in the Faculty of Engineering Science and Technology (STI). His primary interests of research are two-phase flow and heat transfer, covering boiling and condensation of internal flows, external flows, enhanced surfaces and microchannels. He received his Ph.D. at Oxford University, England in 1978 and was formerly a professor at Michigan State University. From 1984 to 1998, he set up and operated his own international engineering consulting company specializing in enhanced heat transfer surfaces and enhanced heat exchanger design methods. He is the author of several books: *Enhanced Boiling Heat Transfer* (1990) and *Convective Boiling and Condensation* (1994). He received the ASME Heat Transfer Division's Best Paper Award in 1998 for a 3-part paper on flow boiling heat transfer published in the *Journal of Heat Transfer*. The website of his laboratory is http://ltcm.epfl.ch and his e-mail address is john.thome@epfl.ch.

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Chapter 1: Video Gallery of Flow Phenomena
Chapter 1 provides a video gallery of flow and heat transfer phenomena and their descriptions, along with links to other chapters that pertained to it.

Chapter 2: Design Considerations for Enhanced Heat Exchangers
Chapter 2 covers the thermal design considerations, mechanical design considerations, cost considerations, parametric studies on thermal designs, case studies of actual interventions and other practical information.

Chapter 3: Single-Phase Shell-Side Flows and Heat Transfer
Chapter 3 presents the most recent open literature version of the stream analysis method for shell-side flows in addition to the older graphical presentation of the Delaware method in *Wolverine Engineering Data Book II*.

Chapter 4: Enhanced Single-Phase Laminar Tube-Side Flows and Heat Transfer
Chapter 4 provides a treatment of correlations for predicting heat transfer and pressure drop for intube flows in corrugated tubes, ribbed tubes, finned tubes and with twisted tape inserts. It covers laminar flow and laminar flow augmentation.

Chapter 5: Enhanced Single-Phase Turbulent Tube-Side Flows and Heat Transfer
Chapter 5 provides a treatment of correlations for predicting heat transfer and pressure drop for intube flows in corrugated tubes, ribbed tubes, finned tubes and with twisted tape inserts. It covers turbulent flow and turbulent flow augmentation.

Chapter 6: Heat Transfer to Air-Cooled Heat Exchangers
Chapter 6 provides design methods for heat transfer and pressure drop to plain, wavy, corrugated, etc. plate-fin geometries typical of air-conditioning coils.

Chapter 7: Condensation on External Surfaces
Chapter 7 provides detail on condensation outside low finned tubes and enhanced condensing tubes, condensation of mixtures, tube row effects and intertube flow patterns, etc. It also includes more fundamentals that designers are interested in on effects of vapor shear, interfacial waves, condensate retention, etc.

Chapter 8: Condensation Inside Tubes
Chapter 8 provides design methods for condensation inside plain and microfin tubes.

Chapter 9: Boiling Heat Transfer on External Surfaces
Chapter 9 provides design methods for boiling outside plain, low-finned and enhanced tubes, evaporation of mixtures, etc. as single tubes and tube bundles. It includes the most widely used plain tube correlations and presents methods available for enhanced tubes and describes the fundamentals of pool boiling (nucleation, bubble dynamics, peak heat flux, etc.).

Chapter 10: Boiling Heat Transfer Inside Plain Tubes
Chapter 10 provides details on vertical and horizontal plain tube design methods.

Chapter 11: Boiling Heat Transfer Inside Enhanced Tubes

Chapter 11 provides details on microfin tubes, twisted tape inserts, corrugated tubes and porous coatings. It also presents the concepts of vertical and horizontal boiling and design methods.

Chapter 12: Two-Phase Flow Patterns

Chapter 12 provides flow pattern maps for vertical and horizontal intube flows (including Thome's flow pattern map which is becoming increasingly popular for adiabatic and evaporating flows). It also presents a shell-side flow pattern map and some background theory on transition from one regime to another.

Chapter 13: Two-Phase Pressure Drop

Chapter 13 provides a complete treatment of prediction of two-phase pressure drops for intube flows and shell-side flows. It also addresses oil effects on two-phase pressure drops.

Chapter 14: Falling Film Evaporation

Chapter 14 presents a summary of the status of falling film evaporation on the outside of horizontal tubes and tube bundles for plain and enhanced tubes.

Chapter 15: Thermodynamics of Refrigerant Mixtures and Refrigerant-Oil Mixtures

Chapter 15 presents an introduction to phase equilibria of mixtures that is useful to mechanical engineers. It shows the use and preparation of enthalpy curves for designing evaporators and condensers with mixtures. It also covers Thome's Thermodynamic Approach for modeling refrigerant-oil mixtures to show oil effects on the bubble point and enthalpy change of evaporating refrigerants that are important to include in the calculation of LMTD and energy balances.

Chapter 16: Effects of Oil on Thermal Performance of Heat Exchangers

Chapter 16 covers the effects on heat transfer and pressure drops of oil on intube evaporation in plain and microfin tubes. It also covers the effects of oil on pool boiling and bundle boiling on plain and enhanced tubes.

Chapter 17: Void Fractions in Two-Phase Flows

Chapter 17 presents the basic theory and predictions methods for the two-phase flows in vertical and horizontal channels and over tube bundles.

Chapter 18: Post Dryout Heat Transfer

Chapter 18 covers the heat transfer process and prediction method for describing heat transfer in the post dryout regime.

Appendix A:

Appendix A provides a list of all nomenclatures and their definitions.

Appendix B:

Appendix B provides tables with properties of commonly used refrigerants (e.g. R-123, R-134a, etc.).

Appendix C:

Appendix C provides web links to related websites, programs, and enhanced tube descriptions of Wolverine Tube, Inc.

References:

References provide a list of resources that were used to write Wolverine Engineering Data Book III.