Steven A. Treese
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Editors

Handbook of Petroleum Processing

Second Edition

Springer Reference

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With 571 Figures and 395 Tables

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Preface to the Second Edition

This Second Edition of the *Handbook of Petroleum Processing* follows in the footsteps and traditions of the First Edition. We have greatly updated and expanded the information and scope in this edition. We have included many new processes and unconventional feedstocks that are encountered in today's facilities. The book has been reorganized to better facilitate its use as a reference.

This Handbook provides a basic knowledge of petroleum refining and processing as a foundation. This general knowledge may be sufficient for many users, but we have continued to provide detailed, practical approaches to designing units and solving the most common challenges facing today's processing and design professionals. Where possible, we have included additional information for those who must operate the process units. Not all the information is at the same level of detail, but we have provided more detail in this edition about operation-related issues.

Most of the calculation techniques described here are manual. We authors and editors grew up using many of these methods; however, we recognize that computer process simulation and applications play the major roles in designing and operating plants today. Many of the methods provided here are behind the simulation software or can be converted easily to computer applications. These methods can quickly provide rough checks on computer results, or they can be used if you do not have a computer or simulation package readily available.

In different chapters, you will find the use of different units of measure. The units reflect those familiar to the chapter authors. Some chapters provide both English and metric units and some only English or only metric. The petroleum industry is accustomed to mixing units and converting between units. In fact, many product specifications use mixed systems. Several common conversion factors are provided in Appendix D.

This edition of the Handbook was structured with both electronic and print publication in mind. It is primarily conceived as a comprehensive book, and the organization of the chapters reflects that premise. For electronic publication, however, we have made the individual chapters as self contained as possible. This means that the information in a chapter generally includes the needed reference materials. The self-contained approach only takes us so far. Lest we have to repeat

large portions of other chapters or resources, individual chapters will still contain references to other chapters or appendices in this Handbook and to other resources.

The book is organized into six parts:

Part I: General Refinery Processes and Operations

This part describes crude oil and the processes used to convert it to finished products along with the design and operation of these processes.

Included here are

- A general understanding of crude and crude properties
- An understanding of products and their important properties
- How a refinery is configured to match the desired crudes and markets
- Detailed discussions of the processes, design, and operation of crude and vacuum distillation units, light ends processing, catalytic reforming, fluid catalytic cracking, hydroprocessing, alkylation, olefin condensation, isomerization, gas treating, residual oil upgrading, and hydrogen production
- How product qualities are specified, measured, and controlled
- Techniques for planning refinery operations and economic analyses
- How a petroleum processing project is executed

Part II: Variations

Today's petroleum processing facility typically runs or handles more than just traditional crude oil and may make more than just fuel products.

This part of the Handbook explores facilities that make

- Lube oils
- Petrochemicals
- Other chemicals

It also provides insights into nonconventional feedstocks which find their way into the processing scheme or are processed somewhat like petroleum, e.g., coal and gas liquids, shale oil, shale crude, bitumens, and renewable stocks.

One chapter discusses biorefineries, which are increasingly providing fuels and fuel blend stocks.

Part III: Support Systems

All process facilities need certain common support systems. These are discussed in some detail in Part III, along with many design and operating techniques.

Included here are discussions of

- Instrumentation and control systems
- Utilities (steam, condensate, fuel, water, air, power, nitrogen, others)
- Off-site facilities (storage, blending, loading, waste hydrocarbons, wastewater)
- Environmental controls and practices (air emissions, aqueous effluents, solid wastes, noise)

Part IV: Safety Systems

Today, it is an absolute requirement that process facilities operate safely. Facilities must not endanger employees or the community. Facilities that cannot do this

are usually not allowed to operate at all. While a large part of safety derives from the way a facility is operated, many features can be designed into the plant to enable safer operations.

This part of the Handbook focuses on the systems and practices that allow for excellent safety. Included here, you will find discussions of

- Process safety management (PSM) basics
- Safety systems for pressure and temperature
- Oxygen deficiency protection practices
- Confined space entry practices
- Facility siting considerations
- Hazardous materials
- Fire prevention and protection

Part V: Reference

The Reference part of the book provides detailed discussion of several general equipment types and how to design them:

- Vessels
- Fractionation towers
- Pumps
- Compressors
- Heat exchangers
- Fired heaters
- Piping and pressure drop

This part also has a comprehensive (and in some cases fairly detailed) dictionary of abbreviations, acronyms, expressions, and terms you will hear around refineries and petroleum processing facilities. We have added many terms and eliminated most of the repetition in the first edition. Many of these terms we use in the industry without even realizing they have specific connotations in our business. Having them all in one place helps. Where appropriate, the definitions provide references back to specific chapters in the book for additional information.

Part VI: Appendices

The appendices include reference materials that either did not fit elsewhere or were needed in multiple chapters. The appendices are divided into four sections:

Appendix "Examples of Working Flow Sheets in Petroleum Refining" provides examples of various flow sheets and documents used in petroleum processing.

Appendix "General Data for Petroleum Processing" contains general data on petroleum properties and some equipment properties. Included here, you will find relationships for viscosity, specific gravity, °API gravity, boiling points, freezing points, and tray geometry.

Appendix "Selection of Crude Oil Assays for Petroleum Processing" has several examples of crude and other oil properties in the form of simple assays. This appendix has been expanded to include many of the newer stocks, such as shale crudes, bitumens, and synthetic crudes. Some of these assays are dated, so for

design or planning work, it is best to always get an updated assay from your supplier.

Appendix "Conversion Factors Used in Petroleum Processing" contains conversion factors. No Handbook worth its salt can get away without some common conversion factors. While we have not included all the factors you will need here, we have included those we found most useful or hardest to find in the literature. The tables include general factors plus pressure and viscosity interconversions.

We have tried to make this work as comprehensive as possible, but it is not feasible to conceive of or include everything you might want to know. There are numerous outside references provided, which can lead you to more references. Online searches often provide good information but can sometimes be misleading or wrong as well. Always apply your own judgment when looking online, or even when using information in this book for that matter. Things should make sense – processing of petroleum is not a great mystery.

This book has been edited by Steven A. Treese (retired from Phillips 66 Company) and Peter R. Pujadó (retired from UOP LLC, a Honeywell Company). Our fellow editor emeritus was David S.J. Jones (retired from Fluor Corporation), who passed away a few years ago. His contributions are found throughout this book, especially in the detailed techniques for calculation. He is missed.

We appreciate the help of Karin Bartsch with Springer Reference, who provided good guidance in making this an "electronic-friendly" work, as well as a useful reference book.

We would like to also acknowledge our many contributing authors for lending their excellent and invaluable expertise: Mark P. Lapinski, Stephen M. Metro, Mark Moser, Warren Letzch, Maureen Bricker, Vasant Thakkar, John Petri, Peter Kokayeff, Steven Zink, Pamela Roxas, Douglas A. Nafis, Kurt A. Detrick, Robert L. Mehlberg, Dennis J. Ward, Dana K. Sullivan, Bipin Vora, Greg Funk, Andrea Bozzano, Stanley J. Frey, and Geoffrey W. Fichtl. Hopefully, we have not missed anyone.

As a final disclaimer, we have made every effort to provide accurate information in this work, but we offer no warrantees in any specific application. The user assumes all responsibility when applying the information contained herein.

We hope you find this Handbook useful. It has been an interesting adventure for us (and a good review) in compiling it. Use it in safety and good health!

Peter R. Pujadó and Steven A. Treese
Editors and Authors

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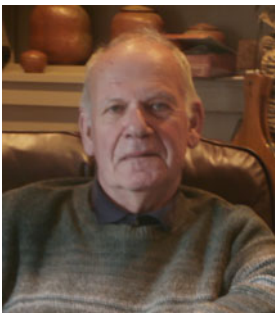
Volume 1

About the Editors

Steven A. Treese retired from Phillips 66 in 2013 as the Hydroprocessing Team Lead after 40 years but continues to take on the occasional consulting assignment in process engineering and refining as a consultant with Puget Sound Investments, L.L.C. He started his professional career with Union Oil Company of California in 1973 as a Research Engineer after obtaining a B.S. in Chemical Engineering from Washington State University. He followed company heritages through Unocal, Tosco, Phillips, ConocoPhillips, and Phillips 66. Steve's range of experience includes catalyst development, hydroprocessing, hydrogen production, utilities, sulfur recovery, geothermal, shale oil, nitrogen fertilizers, process design, procurement, and licensing. He is a licensed Professional Engineer. Steve has several publications, a few patents, and was on the 1994 NPRA Question and Answer Panel. He is a member of the American Institute of Chemical Engineers. Steve's hobbies include woodworking, boating, fermentation, and photography. He is a mentor for FIRST Robotics Team 624, CRyptonite, in Katy, Texas.



Peter Pujadó retired from UOP LLC (a Honeywell subsidiary) in 2005 as Senior Manager/R&D Fellow responsible for the development and commercialization of technologies for the production of light olefins (ethylene and propylene) by the catalytic conversion of methanol. He started his career as a lecturer at the University of Manchester Institute of Science and Technology (UMIST) in Manchester, England; he then worked as a process engineer for SA Cros in Barcelona, Spain, in areas as diverse as chlorine, caustic, chlorinated hydrocarbons, ammonia, urea, nitric acid, and NPK fertilizers; he joined UOP LLC as an R&D process coordinator responsible for the production of cumene, phenol/acetone, aromatics isomerization, aromatics disproportionation and transalkylation, terephthalic acid, acrylonitrile, acetic acid, etc. After retirement from UOP LLC, he again worked as a lecturer at Northwestern University, Evanston, Illinois, and has done some consulting in the petrochemicals area. Peter had graduated with an M.S. in Chemical and Petroleum Refining Engineering from the Colorado School of Mines, a Ph.D. in Chemical Engineering from the University of Minnesota, and an MBA from the University of Chicago. He is a licensed Professional Engineer and a Fellow Member of the American Institute of Chemical Engineers. He is the author of over 95 papers and publications and of 44 patents. Peter's hobbies include travel, mountain hiking, and reading.

David S. J. Jones was from a small coal mining village (Ynystawe) in South Wales, UK. He left school at the age of 16 and joined the army, where he ended up in India as a Regimental Sergeant Major. After that, he returned to Wales and worked for BP in a quality control lab.

He had ambition, a remarkable ability, and dogged determination to study Chemical Engineering in order to improve on his lot in this world. He studied Chemical Engineering at night school and obtained a Bachelor of Science degree. He had a striking career and made it to the top of the tree, spending many years with Fluor as well as consulting.

When he retired, he occupied himself with the writing of several publications on chemical engineering, such as the *Elements of Petroleum Processing* (Wiley and Sons 1995) and the *Handbook of Petroleum Processing* (Springer 2006), mainly aimed at students and young graduate engineers with an emphasis on problem-solving.

Stan passed away in 2005.

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Part I

General Refinery Processes and Operations

Introduction to Crude Oil and Petroleum Processing

David S. J. Jones

Contents

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Abstract

This introduction to crude oil and petroleum processing provides a working knowledge of crude oil properties and refining to make the large array of petroleum-based products we enjoy today. Topics include the composition of crude oil, the crude assay, product properties, and the basic processes used to convert crude to useful products. This chapter sets the stage for the detailed discussions, descriptions, and calculation methods contained in the balance of this handbook.

Keywords

Refinery • Refining • Petroleum • Crude oil

Introduction

The wheel, without doubt, was man's greatest invention. However, until the late eighteenth century and early nineteenth century, the motivation and use of the wheel was limited either by muscle power, man or animal, or by energy naturally occurring from water flow and wind. The invention of the steam engine provided, for the first time, a motive power independent of muscle or the natural elements. This ignited the industrial revolution of the nineteenth century, with its feverish hunt for fossil fuels to generate the steam. It also initiated the development of the mass production of steel and other commodities.

Late in the nineteenth century came the invention of the internal combustion engine with its requirement for energy derived from crude oil. This, one can say,