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ICHEME



**FIFTH EDITION**

# **CHEMICAL ENGINEERING DESIGN**

**RAY SINNOTT & GAVIN TOWLER**

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# CHEMICAL ENGINEERING DESIGN

Fifth edition

RAY SINNOTT

GAVIN TOWLER



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*Ray Sinnott began his career in design and development with several major companies, including DuPont and John Brown. He later joined the Chemical Engineering Department at the University of Wales, Swansea, UK, publishing the first edition of Chemical Engineering Design in 1983. He is a Chartered Engineer, Eur. Ing. and Fellow of the Institute of Chemical Engineers.*

*Gavin Towler is Director of Development at UOP LLC. Gavin is accountable for managing technology development and delivery for UOP's businesses in oil refining, petrochemicals, gas processing, adsorbents, catalysts and renewable fuels and chemicals. As adjunct professor at Northwestern University, he teaches the final year chemical engineering design classes. He is a Chartered Engineer and Fellow of the Institute of Chemical Engineers.*

# Preface

When I wrote the preface to the fourth edition I said that unless a suitable co-author could be found, the fourth was likely to be the last edition of *Chemical Engineering Design*.

I was surprised and pleased when Gavin Towler approached the publishers with a view to carrying on the volume and, also, preparing a new version for the American market. I did not think a co-author would be found who had the necessary combination of engineering background, academic contacts and, above all, time. Fortunately, Gavin meets all these criteria and has produced an excellent fifth edition. In particular, he has brought the treatment of flow-sheeting, safety and costing up-to-date, reflecting current design practice. He has done this whilst maintaining the basic style of the book and my aim to produce a book that would be used. Thank you Gavin.

EUR. ING. R. K. SINNOTT

The most useful book I owned as an undergraduate was “*Coulson and Richardson’s Chemical Engineering, Volume 6: Chemical Engineering Design*” by Ray Sinnott. This book not only served as a manual for how to complete my design project, but was also the first place I would look for simple explanations, quick design methods and practical equipment details of every facet of chemical engineering. Throughout my career in process synthesis, design and development I have found Ray’s book to be a useful source of information. I have acquired several other design textbooks and though each has its merits, none is so comprehensive or practical. As an industrial practitioner of design I came to appreciate the emphasis that Ray gave to subjects such as instrumentation, safety, materials selection and mechanical design, which are often neglected in the more theoretical books written by academics.

Shortly after I began teaching design at Northwestern University, I contacted Elsevier to ask if Ray would consider writing a modified version of his book aimed specifically at a North American audience. The alterations that I proposed were to change the references from British codes and standards to the appropriate American design codes, add a discussion of U.S. and Canadian safety and environmental legislation, include more information on computer-aided design and make some minor changes in terminology. Ray had recently decided to retire and did not want to produce another edition; however, we agreed that I would take on the project and the resulting book was published in 2008 as “*Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design*”. In developing the American

edition I kept to Ray's original format and style, while updating the material and drawing on my own experience to provide additional examples.

This 5<sup>th</sup> edition of Volume 6 in the Coulson and Richardson series includes some of the updated material that was introduced in the American edition, as well as other additions that I thought would enhance the book. The main changes are discussed below, and I hope that educators, students and practitioners will find the new content valuable.

Most industrial process design is now carried out using commercial design software. Extensive reference has been made to commercial process and equipment design software throughout the book and new examples with screen shots from various programs have been added. Many commercial software vendors provide licenses of their software for educational purposes at nominal fees. I strongly recommend that students should be introduced to commercial software as early and often as possible. The use of academic design and costing software should be discouraged. Academic programs usually lack the quality control and technical support required by industry, and the student is unlikely to use such software after graduation. Detailed examples of the use of computer tools in process simulation, costing and detailed design of distillation columns and heat exchangers have been added to Chapters 4, 6 and 12. All computer aided design tools must be used with some discretion and engineering judgement on the part of the designer. This judgement mainly comes from experience, but I have followed Ray's philosophy of trying to provide helpful tips on how to best use computer tools.

Chemical engineers work in a very diverse set of industries and many of these industries have their own design conventions and specialized equipment. I have attempted to broaden the range of process industries represented in the examples and problems, but where space or my lack of expertise in the subject has limited coverage of a particular topic, references to design methods available in the general literature are provided. The treatment of unit operations in Chapter 10 has been expanded to include more separation processes practised in gas processing, fine chemicals and pharmaceuticals manufacture, with new sections on adsorption, membrane separations, chromatography and ion exchange. New example design projects from a range of process industries have been added in Appendix E.

Standards and codes of practice are an essential part of engineering. There have been substantial changes in the British codes and standards since the 4<sup>th</sup> edition, as older British standards have been replaced by common European standards. The references to design codes have been updated to reflect these changes. Although this edition is written primarily for a British and European audience, the book is widely used internationally, and in some cases I have also included references to American standards where these are the most commonly used worldwide. A discussion of British and European safety and environmental legislation has been added to chapters 9 and 14; similar information for the U.S.A. and Canada is given in the American edition. The section on safety in chapter 9 has been significantly expanded. Most chemical engineers now work in an international environment and many will work in several countries during their career. The design engineer should follow corporate policy or obtain legal advice on which codes, standards and laws apply locally, and should always refer to the original source references of laws, standards and codes of practice, as they are updated frequently.

The treatment of costing and process economics in Chapter 6 has been updated and the cost correlations reflect recent price data rather than index updates of older data. Most of the costs have been given in U.S. dollars on a U.S. Gulf Coast basis, as this was the basis of the source data and most international engineering companies develop costs in U.S. dollars. Examples and problems have also been given in Euros and British Pounds Sterling and the section on converting prices from one location basis to another has been expanded. Where possible, the terminology used in the international engineering and construction industry has been used. All the examples are given in metric units, but some also use the American conventional units for illustrative purposes, as it is important for students to learn to convert data from American sources.

I have continued to follow Ray's model of describing the tools and methods that are most widely used in industrial process design and deliberately avoiding idealized conceptual methods developed by researchers that have not yet gained wide currency in industry. The reader can find good descriptions of these methods in the research literature and in more academic textbooks. A short section on optimization has been added to chapter 1, and several of the examples and problems have been modified to illustrate how experienced industrial designers optimize their designs.

In the preface to the 1<sup>st</sup> edition, Ray wrote: *"The art and practice of design cannot be learned from books. The intuition and judgement necessary to apply theory to practice will come only from practical experience. I trust that this book will give its readers a modest start on that road."* I certainly got my start in design using Ray's book and I hope that this new edition will prove as useful to future readers.

Gavin Towler



# How to Use This Book

This book has been written primarily for students on undergraduate courses in Chemical Engineering and has particular relevance to their design projects. It should also be of interest to new graduates working in industry who find they need to broaden their knowledge of unit operations and design. Some of the earlier chapters of the book can also be used in introductory chemical engineering classes and by other disciplines in the chemical and process industries.

## **As a Design Course Textbook**

Chapters 1 to 9 and 14 cover the basic material for a course on process design and include an explanation of the design method, including considerations of safety, costing, and materials selection. Chapters 2, 3 and 8 contain a lot of background material that should have been covered in earlier courses and can be quickly skimmed as a reminder. If time is short, chapters 4, 6 and 9 deserve the most emphasis. Chapters 10 to 13 cover equipment selection and design, including mechanical aspects of equipment design. These important subjects are often neglected in the chemical engineering curriculum. The equipment chapters can be used as the basis for a second course in design or as supplementary material in a process design class.

## **As an Introductory Chemical Engineering Textbook**

The material in Chapters 1, 2, 3 and 6 does not require any prior knowledge of chemical engineering and can be used as an introductory course in chemical engineering. Much of the material in chapters 7, 9, 10 and 14 could also be used in an introductory class. There is much to be said for introducing design at an early point in the chemical engineering curriculum, as it helps the students have a better appreciation of the purpose of their other required classes, and sets the context for the rest of the syllabus. Students starting chemical engineering typically find the practical applications of the subject far more fascinating than the dry mathematics they are usually fed. An appreciation of economics, optimization and equipment design can dramatically improve a student's performance in other chemical engineering classes. If the book is used in an introductory class, then it can be referred to throughout the curriculum as a guide to design methods.



## Supplementary Material

Many of the calculations described in the book can be performed using spreadsheets. Templates of spreadsheet calculations and equipment specification sheets are available in Microsoft Excel format on-line and can be downloaded from <http://Elsevierdirect.com/companions>.

Additional supplementary material, including Microsoft PowerPoint presentations to support most of the chapters, can be downloaded from a restricted site for instructors <http://textbooks.elsevier.com>.

# Acknowledgements

As in my prefaces to the earlier editions of this book, I would like to acknowledge my debt to those colleagues and teachers who have assisted me in a varied career as a professional engineer. I would particularly like to thank Professor J. F. Richardson for his help and encouragement with earlier editions of this book. Also, my wife, Muriel, for her help with the typescripts of the earlier editions.

EUR. ING. R. K. SINNOTT  
*Coed-y-bryn, Wales*

I would like to thank the many colleagues at UOP and elsewhere who have worked with me, shared their experience, and taught me all that I know about design. Particular thanks are due to Dr. Rajeev Gautam for allowing me to pursue this project and to Dick Conser, Peg Stine and Dr. Andy Zarchy for the time they spent reviewing my additions to Ray's book and approving the use of examples and figures drawn from UOP process technology. Ray has provided me with many thoughtful review comments and suggestions and I am of course very grateful that he allowed me to take on this edition and gave me complete freedom to make the changes I felt were necessary. My regular job at UOP keeps me very busy and I worked on this book in evenings and weekends, so it would not have been possible without the love, support and understanding of my wife, Caroline, and our children Miranda, Jimmy and Johnathan.

GAVIN P. TOWLER  
*Inverness, Illinois*

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We are grateful to Aspen Technology Inc. and Honeywell Inc. for permission to include the screen shots that were generated using their software to illustrate the process simulation and costing examples. Laurie Wang of Honeywell also provided

valuable review comments. The material safety data sheet in Appendix I is reproduced with permission of Fischer Scientific Inc. Aspen Plus®, Aspen Kbase, Aspen ICARUS and all other AspenTech product names or logos are trademarks or registered trademarks of Aspen Technology Inc. or its subsidiaries in the United States and/or in other countries. All rights reserved.

The supplementary material contains images of processes and equipment from many sources. We would like to thank the following companies for permission to use these images: Alfa-Laval, ANSYS, Aspen Technology, Bete Nozzle, Bos-Hatten Inc., Chemineer, Dresser, Dresser-Rand, Enardo Inc., Honeywell, Komax Inc., Riggins Company, Tyco Flow Control Inc., United Valve Inc., UOP LLC, and The Valve Manufacturer's Association.

Jonathan Simpson of Elsevier was instrumental in launching and directing this project and provided guidance and editorial support throughout the development of the book. We would also like to thank Renata Corbani for her excellent work in assembling the book and managing the production process.

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