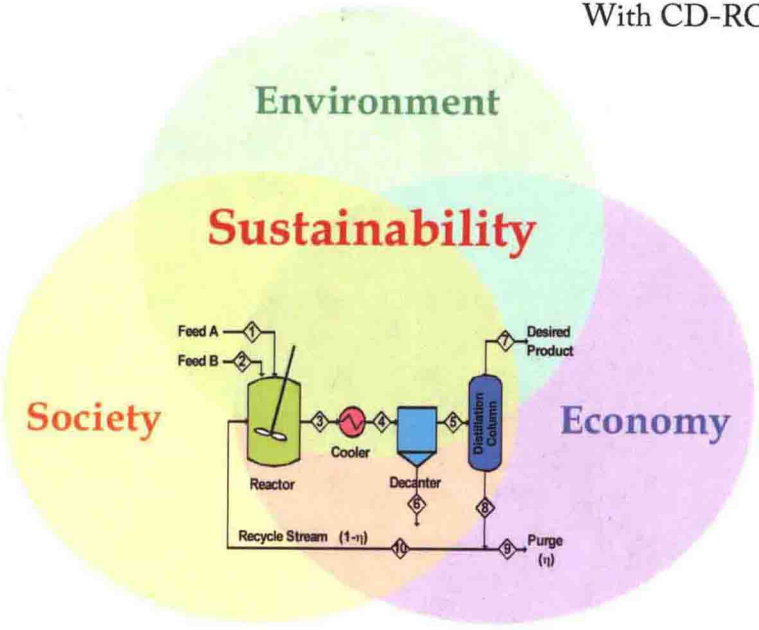
Advances in Process Systems Engineering – Vol. 3

RECENT ADVANCES IN SUSTAINABLE PROCESS DESIGN AND OPTIMIZATION

With CD-ROM



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editors

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Advances in Process Systems Engineering

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Vol. 3: Recent Advances in Sustainable Process Design and Optimization
eds: D. C. Y. Foo, M. M. El-Halwagi and R. R. Tan

PREFACE

Process engineers and designers of the 21st Century face challenges that were not considered particularly important a hundred years earlier, in the early days of the nascent field of chemical engineering. Nowadays, process industries face the need to conserve material and energy resources that were, in the past, considered so abundant as to be practically unlimited in supply. We now recognize that most of the resources modern industry relies on — fossil fuels, metal ores and water, for example — are in limited supply. As a result, sustained economic growth in the long term is only possible through improved efficiency in the use of these increasingly scarce resources. At the same time, increasing public concern about environmental issues, as reflected in ever more stringent environmental legislation, adds a new dimension to the design problems faced by process engineers. Pollution at the local, regional and global scales present unique design constraints that previous generations of chemical engineers did not need to deal with. In particular, anthropogenic climate change as a result of human industrial activity is now considered to be one of the most critical challenges facing mankind today. A multifaceted response involving energy conservation, carbon sequestration and utilization of renewables is likely to be needed to make any significant reduction in the world's greenhouse gas emissions. Such response requires the development and deployment of systematic and generally applicable design procedures that are aimed at the broad objective of sustainability. Recently, significant progress has been made in the development of such design procedures. The developed techniques are rooted in fundamental engineering principles and utilize a variety of graphical, algebraic, and mathematical programming tools.

This handbook outlines some of the state-of-the-art responses of the international process systems engineering community to these contemporary challenges. It deals with general environmental issues that arise both from the industrial consumption of scarce material and energy resources, and the generation of potentially polluting industrial waste

streams. The emphasis is placed on an integrated, preventive, systems-based approach to these environmental challenges, rather than the more traditional pollution control approach of waste treatment and secure disposal. This approach thus allows process engineers and designers to make environmental improvements that enhance, rather than compromise, the economic viability of the process industries.

This volume is comprised of twenty-one chapters outlining state-of-the-art advances in sustainable process design methodology from renowned experts and researchers from Africa, Asia, Europe and North America. Thus, it provides a broad cross-section of process systems engineering work done worldwide, using an array of approaches ranging from process integration techniques, life cycle analysis, mathematical programming and modeling, graph theory and heuristics. Many of the chapters also provide industrial case studies that illustrate how these new techniques may apply to problems in the real world. Appendices and supplementary electronic files are also provided for those interested in delving deeper into some of these topics.

This book consists of chapters most of which may be read independently of each other, or with no particular sequence. However, the chapters are classified into three broad areas, namely, process modeling, material resource conservation and waste reduction, and energy conservation and efficiency:

Synopses of Chapters in Section 1 (Process Modeling)

This section consists of four chapters. The first two chapters by L. T. Fan and T. Zhang, are entitled "Estimation of exergy dissipation and cost: the foundation for sustainability assessment in process design" and "Life cycle assessment (LCA)" and describe a generic framework for the systematic, quantitative analysis of sustainability in the process industries. Chapter 1 describes a rigorous thermodynamic framework for quantifying process sustainability, while Chapter 2 provides a description of the key concepts and computations that are entailed in LCA. Subsequent chapters focus on efficient resource use. The next two chapters deal with specific applications. M. F. Chong's Chapter 3, entitled "A Transport Model for Nanofiltration and Reverse Osmosis Systems Using Irreversible Thermodynamics" discusses key design principles for membrane-based processes that are becoming increasingly crucial for many industry sectors. Finally, Chapter 4 by H. Lou *et al.*, "Process Modeling of Inibition of Free Radical Polymerization Reactions" describes an approach to control

undesirable reactions in chemical plants to ensure that process safety and product quality are maintained.

Synopses of Chapters in Section 2 (Material Resource Conservation and Waste Reduction)

This section consists of seven chapters in total. Chapter 5, by D. C. Y. Foo and entitled "Resource Conservation through Pinch Analysis", describes insight-based pinch analysis techniques with emphasis on the targeting and design of process networks for efficient utilization of scarce resources, such as fresh water and utility gases. Chapter 6 by X. Feng *et al.*, entitled "Optimal Water Network with Internal Water Mains and Its Industrial Application" introduces the concept of internal water mains which result in simplified configurations for process water reuse networks. The next chapter, A. Chakraborty's "Mathematical Models for Optimal Resource Utilization in Process Industries", introduces a variant for waste stream reuse and describes an application in pharmaceutical processing. While the previous three chapters describe methodologies appropriate for continuous-flow process plants, the next two chapters entitled "Wastewater Minimisation in Batch Chemical Plants: Single Contaminant Media", by T. Majozi, and "Wastewater Minimisation in Batch Chemical Plants: Multiple Contaminant Media", by T. Majozi and J. Gouwes, describe modeling techniques for batch-wise operations of various degrees of complexity. The optimization models in Chapters 6–9 are dealt with in a deterministic manner, but alternative approaches using heuristic algorithms have been extensively described in literature (and also in Chapter 5). Chapter 10, "Adaptive swarm-based simulated annealing for the synthesis of water networks" by R. Tan, and Chapter 11, "Optimal wastewater network design" by J. Jezowski *et al.*, describe alternative solution methods for optimization models using stochastic approaches, with the former on simulated annealing/swarm intelligence hybrid technique and the latter on adaptive random search.

Synopses of Chapters in Section 3 (Energy Conservation and Efficiency)

This final section consists of ten chapters. Chapter 12 by M. S. Ba-Shammakh *et al.*, is entitled "Clean Energy and CO_2 Capture, Transport and Storage" and describes a methodology for designing clean fossil energy-based systems with carbon sequestration, which are widely considered as an

essential interim technology for transition to a low-carbon infrastructure. In contrast, Chapter 13, by P. Varbanov and entitled "P-graph: an Efficient Process Synthesis Tool. Application to Fuel Cell-Based Energy Generation", describes a graph theoretic approach to the design of renewable energy networks. Chapter 14 by R. Mahmud *et al.*, entitled "A Process Integration Framework for the Optimal Design of Combined Heat and Power Systems in the Process Industries" introduces a novel approach to enhancing industrial energy efficiency through integrated generation of thermal and electrical energy. The next chapter, J.-K. Kim's "Design of Low Temperature Energy Systems", focuses on energy efficiency through heat integration of processes at sub-ambient temperatures.

Chapter 16 is contributed by C. L. Chen *et al.*, and entitled "Indirect Heat Integration of Batch Processes", which deals with the added complications incurred by the time aspect in conducting heat integration for batch operations. Recent shifts in the process industries away from large-scale production of commodity chemicals, towards the use of small, flexible plants producing relatively small quantities of high-value goods, require such methodologies. Next, the contribution by J. J. Klemes *et al.*, entitled "Energy Efficiency and the Integration of Waste and Renewable Energy Sources" describes an approach to design energy networks making use of a range of biomass feedstocks. Chapter 18, by S. Bandyopadhyay, is entitled, "A Novel Design Procedure for Solar Thermal Systems" and describes a methodology for design solar thermal system using a design space approach.

The final three chapters provide a different perspective based on industrial applications. Chapter 19 is C. L. Law and A. S. Mujumdar's "Energy Saving in Drying Processes" which provides a survey of current drying techniques for various applications. In Chapter 20, "Two Birds with One Stone — Simultaneous Waste Heat Recovery and Emission Reduction in Gas/Oil Separation Plants", B. Noureldin describes an industrial application of heat integration. Economic and carbon emissions issues are encountered in a case study that is typical of those found in traditional process industries. The final chapter of this handbook is A. Rossiter's "Energy Management for the Process Industries", which again provides a practical perspective on reduction of industrial energy use, as well as corresponding emissions and costs.

Together, these twenty-one chapters provide a framework of tools and techniques for the quantitative analysis and design of clean, efficient and sustainable systems in the process industries.

Acknowledgments

First and foremost, we wish to thank the authors who contributed their invaluable expertise in the form of chapters covering state-of-the art developments in the field of sustainable process design. The value of this book is based primarily on their inputs. In particular, we wish to dedicate this work to the memory of our departed colleague, Prof. Jacek M. Jeżowski, who passed away earlier this year, and whose work appears in Chapter 11 of this book. We are also grateful to the staff of World Scientific Publishing, who provided invaluable assistance throughout the long process of publication. Finally, we would like to thank our family members for their support throughout our professional careers. In particular, Dominic Foo would like to thank his wife Cecilia Cheah for tremendous support, especially in taking care of their daughters Irene and Jessica Foo. Mahmoud El-Halwagi would like to acknowledge his parents, his wife Amal, and sons Omar and Ali for their constant support and unlimited love. Raymond Tan thanks his wife, Jenny, and daughters, Denise and Dana, for providing inspiration and for patiently tolerating hectic workdays.

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