Plantwide Process Control

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To my parents Anna-Stina and Jean, and to my wife Kerstin and our children Daniel and Martina for inspiring and encouraging.

BDT

To the loving memory of Beatrice D. Luyben.

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Preface

The goal of this book is to help chemical engineering students and practicing engineers develop effective control structures for chemical and petroleum plants. Our focus is on the *entire* plant, not just the individual unit operations. An apparently appropriate control scheme for a single reactor or distillation column may actually lead to an inoperable plant when that reactor or column is connected to other unit operations in a process with recycle streams and energy integration.

Our objective is to design a control system that provides basic regulatory control of the process; i.e., the plant will sit where we want it despite disturbances. Above this regulatory structure we can then build systems to improve plant performance: real-time on-line operations optimization (RTO), planning and scheduling, and expert systems, among others. But if the basic regulatory control does not work as the foundation of plant operation, none of the higher level objectives can be met.

Because of the problem's complexity, our approach is heuristic and experiential. The collected years of experience of the authors is rapidly approaching eight decades, so we have been around long enough to have had our tails caught in the wringer many times. But we have learned from the mistakes that we and others have made. The authors have had the good fortune to learn the basics of plantwide control from the grandfather of the technology, Page Buckley of DuPont. Page was a true pioneer in chemical engineering process control. We also have learned from the experience and inventiveness of many practicing control engineers: Greg Shinskey, John Rijnsdorp, Jim Downs, Jim Douglas, Vince Grassi, Terry Tolliver, and Ed Longwell, among others. These individuals have helped in the evolution of concepts and strategies for doing plantwide control.

Although the methods discussed are heuristic, we certainly recommend the use of algorithmic and mathematical techniques where this approach can aid the analysis of the problem. Methods such as singular value decomposition, condition number analysis, and multivariable Nyquist plots have their place in plantwide control. But the primary mathematical tool employed in this book is a rigorous, nonlinear mathematical model of the entire plant. This model must faithfully capture the nonlinearity and the constraints encountered in the plant under consideration. Any plantwide control scheme must be tested on this type of model because linear, unconstrained models are not adequate to predict many of the important plantwide phenomena. So mathematical modeling and simulation are vital tools in the solution of the plantwide control problem.

Fortunately we now stand at the dawn of a new era in which the computer-aided engineering software tools and computer horsepower permit engineers to assemble a flowsheet, perform the steady-state analysis (mass and energy balances, engineering economics, and optimization), and then evaluate the dynamic performance of the plant. Commercial software packages that combine steady-state and dynamic models represent a major breakthrough in the tools available to the process engineer and to the control engineer. Actually we predict that in not too many years these two functions will be combined and will be performed (as they should be) by the same individual. An appreciation of dynamics is vital in steady-state design and an appreciation of design is vital in process control.

Four detailed case studies of realistically complex industrial-scale processes are discussed in this book. Models of three of these have been developed by Aspen Technology and Hyprotech in their commercial simulators and are available directly from the vendors. These models may be obtained electronically from the Web sites: www.aspentec.com and www.hyprotech.com. We appreciate the efforts expended by these companies in making these case studies available to students and engineers. The methods developed in this book are independent of the simulation software used to model the plant.

The concepts presented in this book can be applied at all levels of control engineering: in the conceptual development of a new process, in the design of a grass-roots commercial facility, in debottlenecking and plant revamps, and in the operation of an existing process. However, the emphasis is on new plant design because this is the level at which the effect of considering plantwide control can have the most significant impact on business profitability. The cost of modifying the process at the design stage is usually fairly low and the effect of these modifications on the dynamic controllability can be enormous. Old war stories abound in the chemical industry of plants that have never run because of dynamic operability problems not seen in a steady-state flowsheet, with millions of dollars going down the drain.

This book is intended for use by students in senior design courses in which dynamics and control are incorporated with the traditional steady-state coverage of flowsheet synthesis, engineering economics, and optimization. A modern chemical engineering design course should include all three aspects of design (steady-state synthesis, optimization, and control) if our students are going to be well-prepared for what they will deal with in industry.

This book also should be useful to practicing engineers, both process engineers and control engineers. Most engineers have had a control course in their undergraduate and/or graduate training. But many of these courses emphasize the mathematics of the subject, giving very little if any coverage of the important practical aspects of designing effective control structures. Most of the control textbooks have very limited treatments of control system design, even for individual units. There are no textbooks that cover the subject of plantwide process control in a quantitative practical way. We strive to fill that gap in technology with this book.

We hope you find the material interesting, understandable, and useful. We have developed and applied the methods discussed in this book for many years on many real industrial processes. They work!

But don't expect this book to free you of the need to think! We do not provide a black box into which you simply feed the input data and out comes a "globally optimum" solution. The problem here is an open-ended *design problem* for which there is no single "correct" answer. Our procedure requires the application of thought, insight, process understanding, and above all, practice on realistic problems such as those provided in this book. These ingredients should lead you to an effective control structure. There is no claim that this control structure is necessarily the best. But it should provide stable regulatory control of the plant.

Thanks are due to a number of individuals who have contributed to the development of the technology outlined in this book. The legacy of Page Buckley is apparent on almost every page. Lehigh students, both undergraduate and graduate, have contributed significantly to the development of this book by their youthful enthusiasm, willingness to work hard, and interest in real engineering problems. They have provided the senior author with enough job satisfaction to offset the frustrations of dealing with university bureaucrats.

In addition to the legacy of Lehigh University (as well as Princeton University and Prof. C. A. Floudas), B. D. Tyréus and M. L. Luyben want to acknowledge DuPont and its culture of technological innovation and excellence. We have had the opportunity to work on and learn about many different processes, and we have tried in this book to synthesize in some coordinated way part of our experiences. Most of

this book is inspired by our work over the years with many outstanding process and control engineers at DuPont, who have taught us so much. Listing them all would require considerable space and leave us vulnerable to overlooking someone. Nonetheless, they know who they are and we thank each of them. We also could not have written this book without the leadership provided by James A. Trainham, Roger A. Smith, and W. David Smith, Jr.

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