chapter having 89—and about a quarter have solutions.

Strogatz's *Nonlinear Dynamics and Chaos* starts from the very beginning of dynamical systems, assuming a knowledge of little more than simple differentiation, and systematically but elegantly covers virtually the entirety of modern mathematical dynamics theory. It would be difficult to design a more concise coverage of the subject.

Initial chapters lay the foundations by explaining fundamentals of one-dimensional flow dynamics. The treatment is at once intuitive and rigorous, with copious, practical examples from the biological chemical and physical sciences. To illustrate uniqueness in simple flows, Strogatz brings up the "leaky bucket" problem. To explore fundamental bifurcations, Strogatz discusses transitions in the laser and the bead-on-a-rotating-hoop. Early on, Strogatz even touches on catastrophe theory using an example of budworm population dynamics. To complete his treatment of one-dimensional dynamics, Strogatz studies flows on a circle. Here, he introduces his forte, synchronization of coupled oscillators. Again, he illustrates his points with two intriguing examples. First, he introduces his own model for synchronization of Asian fireflies, which by itself is delightful. He follows this up with a second example, this time from condensed matter physics: the superconducting Josephson junction. Far from being daunting, Strogatz's treatment of even this potentially thorny subject is concise, simple, self-contained and, we think, fully comprehensible to any serious reader.

Having completed the preliminaries, Strogatz then turns to the heart of the book, where he investigates the dynamics of two-dimensional flows. Here, he really turns it on. He introduces the reader to many different types of flows in phase space and just when the going might get tough, he discusses the Romeo and Juliet problem. $R(t)$ defines Romeo's love/hate for Juliet, and $J(t)$ defines Juliet's love/hate for Romeo. Set up some simple equations, and the action begins. For some parameter values, the two fickle lovers enter an endless cycle of love and hate; for others the lovers can spiral in and out of love or interact explosively. While some readers may be put off by the light-hearted approach, most students who have sat through dry, unenlightening coverage of an important topic will be able to identify at once this inspired treatment.

The fun examples do not stop there: Strogatz studies the tracking by a dog of a duck in a pond; he recounts the history of the oscillatory Belousov-Zhabotinsky chemical reaction; he analyzes a model for genetic switching. Yet each of these examples is no more than a touch point. As readers travel from one to the next, they pick up new, fundamental, dynamical tools from bifurcation diagrams to two-timing to null clines to Lyapunov functions. All treated in a uniformly solid and concise manner.

Finally, Strogatz introduces chaos. Strogatz's treatment of chaos is self-contained, and the advanced or ambitious reader could start immediately in on the chaos chapters. Here, he studies the classic examples of dissipative chaos: the Lorenz, the Logistic and the Hénon equations. He first studies the Lorenz equation, and characteristically he introduces a simple water-wheel model which has been used to mimic the chaotic motion of Lorenz's equations. There is an entire chapter on the Lorenz equation, but remarkably the equations themselves are simply written without much discussion or derivation—not an entirely bad thing since these equations are rederived in many books. At the same time, however, in this very chapter there is lengthy derivation of an *ad-hoc* continuity equation and volume contraction formulae. Again, characteristically he skims the cream of the subject by recounting Cuomo's demonstration that two chaotic circuits can be synchronized and used to transmit speech. He explores quasiperiodicity only briefly, in an exercise, and then moves on to study universality in the logistic map. He stresses the important points in a clear-cut fashion, excising definitive plots from the literature, for example showing that an extreme magnification of the logistic bifurcation plot is virtually identical to its parent and that the sine map and the logistic map produce qualitatively very similar bifurcation plots. Thus the quantitative renormalization treatment—including mention of the seminal results of Libchaber and, of course, Feigenbaum—follows naturally.

Strogatz concludes with one brief chapter each on fractals, and on strange attractors. Many people would like to see more on these topics as well as spatio-temporal and Hamiltonian chaos, multifractals, pattern formation, and so on. As a text, this book already covers much more than a full semester of material. It is likely, however, that many novice readers will find the treatment of some of the most popularized topics in the field to be limited. For this reason, many readers and educators may want to complement Strogatz's enjoyable, mathematically inclined text with a broader and more phenomenogical treatment such as that provided by Hilborn.

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Control of Polymerization Reactors

By F. Joseph Schork, Pradeep B. Deshpande, and Kenneth W. Leffew, Marcel Dekker, 1993, 376 pp., $145.00.

Control of Polymerization Reactors is a book that fills a niche for a treatment of automatic control of polymerization reactors. Polymer reactor engineering and the control of polymer reactors have developed into core chemical engineering technologies of great commercial importance. Yet, few books on polymer reactor engineering and fewer still on the control of polymer reactors exist. This book treats the subject of polymer reactors more broadly than the title suggests. The first third of the book is a brief, but comprehensive, review of polymer kinetics and reactor design, and it is written very well. This unified treatment of the principles of polymer reactor engineering *and* the automatic control of polymer reactors is unique, since it is essential to understand completely the complexity and the framework of the control problem, while being cognizant of the difficult reactor engineering challenges for polymer reactors. From the perspective of an industrial practitioner, it is impossible to mutually satisfy the requirements of polymer reactor design *and* polymer reactor control if one engineers the solution of one exclusive of the other.

Chapters 1–4 comprise almost one-third of the book and cover the essential elements of polymer reactor engineering for free radical, step-growth and anionic polymerization. Beginning with the structure and characterization of polymers and the chemistries used to synthesize them, the reader is introduced to the mathematical modeling of polymer kinetics using mass and energy balances. Molecular weight development is modeled using the method of moments. Examples of mathematical models are derived for free radical, step-growth and anionic polymerization. These models are then used to highlight polymer characteristics unique to each type of polymer chemistry. Extensions of the mathematical models are then presented for each of the classical types of chemical reactors: batch, semibatch, plug-flow reactor, and CSTR. Emphasis is placed on the important interaction of the *process* and the *chemistry* in polymer synthesis.

One important topic not mentioned in this section is parameter estimation. These polymer models are complex models with many physical and kinetic parameters that are not found often in the literature. Some references to the problems of data reconciliation between process models and experimental data would have been helpful. The authors provide an excellent treatment on the criteria for selection of reactor type based on the polymer kinetics and practical operational considerations. This discussion is especially welcome given the poor coverage of this important topic in the existing polymer reaction engineering literature. A separate chapter is devoted to the special challenges and advantages of the heterogeneous polymerization processes, emulsion and suspension polymerization.

The issues and techniques of automatic control of polymer reactors are developed in Chapters 5–10. The primary topics addressed are process state measurement and estimation, polymer process modeling and identification, linear SISO and MIMO model-based control, and nonlinear control.

The authors adequately describe the problems encountered in obtaining good on-line measurements of many variables of interest such as conversion, composition, molecular weight distribution and particle size. However, given the fact that this is one of the principal problems in the control of polymer reactors, I was somewhat disappointed by the brief treatment on state estimation. Kalman filtering is outlined briefly, but the reader is referred to other works for the necessary details. This is unfortunate since there have been several successful experimental applications of Kalman filtering on polymer reactors published in the literature.

The discussion on process modeling and identification is a concise, yet thorough, review of the techniques used in industrial practice. Open-loop step and pulse testing, impulse response modeling, single variable and multivariable time series modeling are covered. A reader unfamiliar with time series analysis might need a more basic introduction to the subject before reading the sections in this text. Several excellent examples are referenced too briefly in the text. More detail in one or more of the examples would have been helpful to most readers.

Model-based controllers and response specification methods are emphasized in the chapters on linear SISO and MIMO control. Dahlin's algorithm, internal model control (IMC), and several flavors of model-predictive control including dynamic matrix control (DMC) are included. An excellent section on the design of time-delay compensators for SISO systems is provided. MIMO control begins by development of interaction analysis by RGA (relative gain array) and SVD (singular value decomposition) and leads to the design of multiloop controllers with explicit decouplers and complete multivariable control that includes inherent deadtime and interaction compensation using DMC. Ample examples from the polymer control literature are referenced covering a wide spectrum of polymer processes and chemistry. In a few cases, however, the examples used control techniques not explicitly discussed in the text.

As the authors properly point out, polymer reactor processes are highly nonlinear. Many of these processes exhibit open-loop unstable behavior, limit cycles and time-varying parametric sensitivity. Linear control techniques based on linearized models of the polymer process are effective only in a limited region of operation. As the authors discuss, these linear techniques can be improved by building adaptive features into the algorithm to help the controller track these nonlinear shifts in the process. A chapter in the book is dedicated to another approach, namely, the design of nonlinear controllers.

Nonlinear control is a very active area of research in the academic process control community. Only a few applications of nonlinear control of polymer reactors, primarily simulation studies, have been published. The text presents several methodologies including nonlinear IMC and two methods derived from differential geometry. The authors' stated purpose in this chapter is to introduce the concepts of nonlinear control to the polymer reactor control community with the hope of stimulating further application research in this promising area. This chapter provides clear descriptions, is well-referenced, and should satisfy this stated objective.

The final chapter in the book is an introduction to the field of polymer processing and is a guest contribution from V. M. Nadkarni. This chapter covers a variety of polymer processing topics and includes a section discussing polymer characteristics that govern polymer processibility. The last several pages of the chapter are devoted to the control issues in polymer processing which center primarily on the proper identification and regulation of the processing variables to get the desired end-use properties. While this chapter contains practical and useful information, it does not fit with the balance of the book and appears to have been an afterthought.

Overall, *Control of Polymerization Reactors* is a well-written, comprehensive book on the subject of polymer reactor engineering and control. The authors provide readers with a firm foundation in the principles of polymer reactor engineering to develop a broad background for understanding the challenges in polymer reactor control. The process modeling and control methods presented in the text have enjoyed practical application success in the industrial process control community. Most chapters can be read and understood by themselves by one with background in the field. The references in the book are very complete and most examples are taken from recent (1980–present) literature. A few typographical errors typical of first edition texts were found.

This book could be used as a textbook for an advanced undergraduate or graduate course in polymer reactor engineering and control. Familiarity with the concepts covered in undergraduate courses in chemical reaction engineering and process control (including sampled data systems) is assumed. I would enthusiastically recommend it as a reference book for industrial practitioners in the fields of both polymer reactor engineering and polymer reactor control.

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