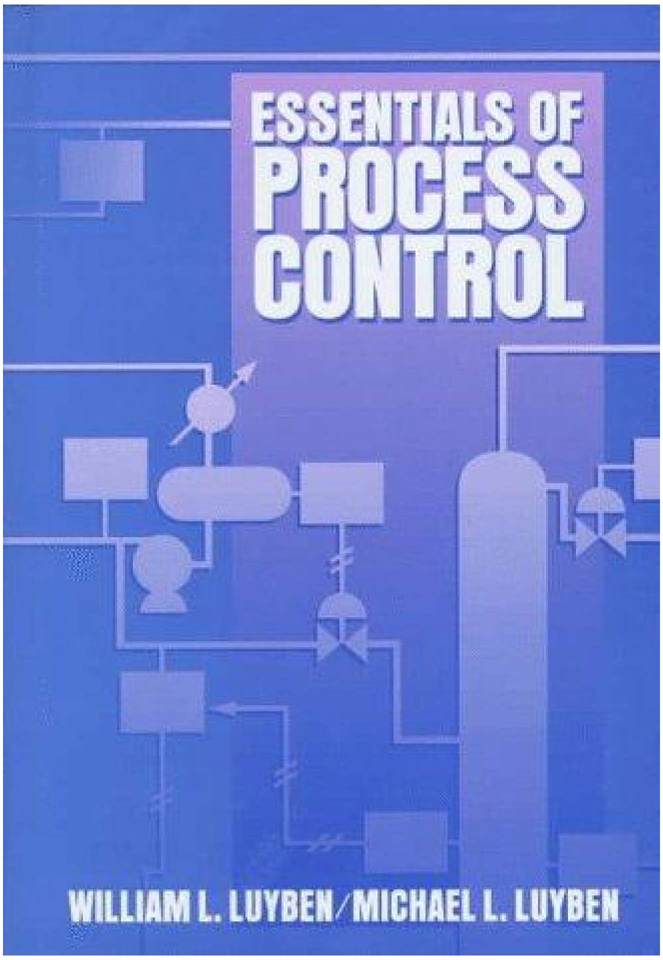
ESSENTIALS OF
PROCESS
CONTROL
WILLIAM L. LUYBEN/MICHAEL L. LUYBEN

Essentials of Process Control

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Fifteen prominent chemical engineers first met in New York more than 60 years ago to plan a continuing literature for their rapidly growing profession. From industry came such pioneer practitioners as Leo H. Baekeland, Arthur D. Little, Charles L. Reese, John V. N. Dorr, M. C. Whitaker, and R. S. McBride. From the universities came such eminent educators as William H. Walker, Alfred H. White, D. D. Jackson, J. H. James, Warren K. Lewis, and Harry A. Curtis. H. C. Parmelee, then editor of *Chemical and Metallurgical Engineering,* served as chairman and was joined subsequently by S. D. Kirkpatrick as consulting editor.

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Essentials of Process Control

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William L. Luyben has devoted over 40 years to his profession as teacher, researcher, author, and practicing engineer. Dr. Luyben received his B.S. in Chemical Engineering from Pennsylvania State University in 1955. He then worked for Exxon for five years at the Bayway Refinery and at the Abadan Refinery (Iran) in plant technical service and petroleum processing design. After earning his Ph.D. from the University of Delaware in 1963, Dr. Luyben worked for the Engineering Department of Du Pont in process dynamics and control of chemical plants.

Dr. Luyben has taught at Lehigh University since 1967 and has participated in the development of several innovative undergraduate courses, from the introductory course in mass and energy balance through the capstone senior design course and an interdisciplinary controls laboratory. He has directed the theses of more than 40 graduate-students and has authored or coauthored six textbooks and over 130 technical papers. Dr. Luyben is an active consultant for industry in the area of process control. He was the recipient of the Eckman Education Award in 1975 and the Instrumentation Technology Award in 1969 from the Instrument Society of America.

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Michael L. Luyben is currently a research Engineer with Du Pont's Central Research and Development Department.

To Janet Nichol Luyben—mother, wife, friend, loving grandmother, avid gardener, community volunteer; softball queen extraordinaire-for 34 years of love, care, level-headed financial advice, and many pieces of Grandmother Lester's apple pie.

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PREFACE

The field of process control has grown rapidly since its inception in the 1950s. Direct evidence of this growth in the body of knowledge is easily found by comparing the lengths of the textbooks written over this time period. The first process control book (Cealgske, 1956) was a modest 230 pages. The popular Coughanowr and Koppel (1965) text was 490 pages. The senior author's first edition (1973) was 560 pages. The text by Seborg et al. (1989) was 710 pages. The recently published text by Ogunnaike and Ray (1994) runs 1250 pages!

It seems obvious to us that more material has been developed than can be taught in a typical one-semester undergraduate course in process control. Therefore, a short and concise textbook is needed that presents only the essential aspects of process control that every chemical engineering undergraduate ought to know. The purpose of this book is to fulfill this need.

Our intended audience is junior and senior undergraduate chemical engineering students. The book is meant to provide the fundamental concepts and the practical tools needed by all chemical engineers, regardless of the particular area they eventually enter. Since many advanced control topics are not included, those students who want to specialize in control can go further by referring to more comprehensive texts, such as Ogunnaike and Ray (1994).

The mathematics of the subject are minimized, and more emphasis is placed on examples that illustrate principles and concepts of great practical importance. Simulation programs (in FORTRAN) for a number of example processes are used to generate dynamic results. Plotting and analysis are accomplished using computer-aided software (MATLAB).

One of the unique features of this book involves our coverage of two increasingly important areas in process design and process control. The first is the interaction between steady-state design and control. The second is plantwide control with particular emphasis on the selection of control structures for an entire multi-unit process. Other books have not dealt with these areas in any quantitative way. Because we feel that these subjects are central to the missions of process design engineers and process control engineers, we devote two chapters to them.

We have injected some examples and problems that illustrate the interdisciplinary nature of the control field. Most control groups in industry utilize the talents of engineers from many disciplines: chemical, mechanical, and electrical. All engineering fields use the same mathematics for dynamics and control. Designing control systems for chemical reactors and distillation columns in chemical engineering has direct parallels with designing control systems for F-16 fighters, 747 jumbo jets, Ferrari sports cars, or garbage trucks. We illustrate this in several places in the text.

This book is intended to be a learning tool. We try to educate our readers, not impress them with elegant mathematics or language. Therefore, we hope you find the book readable, clear, and (most important) useful.

When you have completed your study of this book, you will have covered the essential areas of process control. What ideas should you take away from this study and apply toward the practice of chemical engineering (whether or not you specialize as a control engineer)?

1. The most important lesson to remember is that our focus as engineers must be on the process. We must understand its operation, objectives, constraints, and uncertainties. No amount of detailed modeling, mathematical manipulation, or supercomputer exercise will overcome our ignorance if we ignore the true subject of our work. We need to think of Process control with a capital *P* and a small c.
2. A steady-state analysis, although essential, is typically not sufficient to operate a chemical process satisfactorily. We must also understand something about the dynamic behavior of the individual units and the process as a whole. At a minimum, we need to know what characteristics (deadtimes, transport rates, and capacitances) govern the dynamic response of the system.
3. It is always best to utilize the simplest control system that will achieve the desired objectives. Sophistication and elegance on paper do not necessarily translate into effective performance in the plant. Careful attention must be paid to the practical consequences of any proposed control strategy. Our control systems must ensure safe and stable operation, they must be robust to changes in operating conditions and process variables, and they must work reliably.
4. Finally, we must recognize that the design of a process fundamentally determines how it will respond dynamically and how it can be controlled. Considerations of controllability need to be incorporated into the process design. Sometimes the solution to a control problem does not have anything to do with the control system but requires some modification to the process itself.

If we keep these ideas in mind, then we can apply the basic principles of process control to solve engineering problems.

Michael L. Luyben
William L. Luyben

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