A program on . . .

CHEMICAL PROCESS MODELING AND CONTROL

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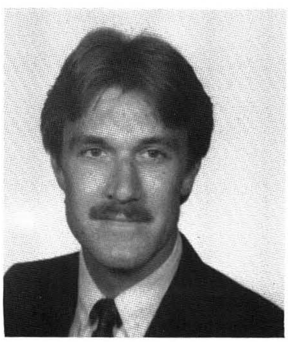
WHEN DECIDING TO go on to graduate school, the prospective student must face two crucial questions: What to study, and Where? Certainly, anyone's answer to these questions will reflect a natural self-interest, but this article will describe some features of studying process modeling and control at Lehigh University that are exciting to us.

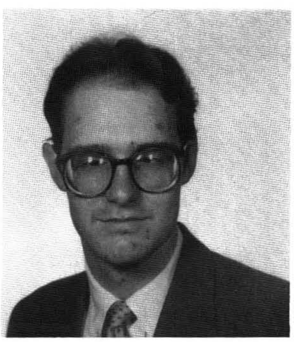
The combination of substantial economic incentives and profound intellectual challenges has motivated increasing emphasis on process control within the chemical process industries and chemical engineering academia. As the chemical process industry matures, business success depends more on optimizing the performance of existing or novel process technology and less on manufacturing new products with little attention to costs. No longer do overdesign and relaxed operating criteria make life easy. Even in biotechnology, specialty chemicals, and other frontier areas toward which the chemical process industry is migrating, profitable manufacturing requires the ability to understand and regulate dynamic processes. At the intellectual level, process control engineers are addressing issues that were once simply mathematical abstractions, but that now translate to real-world concerns like energy efficiency, manufacturing flexibility, product quality, safety, environmental protection, and computer-integrated manufacturing. For today's and tomorrow's chemical engineer, therefore, process modeling and control skills are important, regardless of his or her specific technical area of employment or research interest.

To meet this challenge to chemical engineering education, Lehigh University initiated the Chemical Process Modeling and Control Center (PMC) in 1984. PMC is an industry/academia consortium dedicated to the education of graduate students for advanced research in process modeling and control. Currently, PMC is sponsored by twelve companies (both U.S. and European), by the National Science Foundation, and by the Commonwealth of Pennsylvania. Its annual operating budget is in excess of $400K. Christos Georgakis and William Luyben are the center's founders and its co-directors.

As a result of the industry/academia partnership in PMC, the research work carried out by the students is neither all theoretical nor all applied, but is a delicate balance of both. PMC students can be confident that their research topic is novel and challenging in the context of the scientific literature and that it is relevent to professionals working at the highest technical levels of industry. The vigorous intermixing of the theoretical and the applied is reflected in the career goals of the current group of PMC students. Both industrial and teaching career aspirations are represented. We expect that a similar diversity of career goals will be maintained in future PMC teams.

With this introduction on why process control and the PMC program at Lehigh are exciting to us, let's examine the philosophy, the people, the technical program, and the environment of PMC.





R. Donald Bartusiak received his BS from the University of Pennsylvania and his MS from Lehigh University. He is currently completing PhD studies at Lehigh. Before returning to graduate school, he worked as a research engineer for Bethlehem Steel Corp. His industrial experience also includes employment with Exxon Chemicals. His research interests and publications are in the areas of nonlinear process control and environmental engineering. **(L)**

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THE PHILOSOPHY

Prior to establishing PMC, Lehigh faculty, in collaboration with industrial representatives, assessed the research needs in the area of process modeling and control. This assessment recognized that rapid technological advances are driving engineering towards cross-disciplinary interaction. It identified several important trends that have already affected, and will continue to affect, the chemical, petroleum, petrochemical and biochemical industries in the next decade. These trends, detailed below, justified the start-up of an intensive research effort.

- The trend to **improve the production efficiencies of existing chemical plants** has increased the need for more effective dynamic models, for improved real-time process measurements, and for more practical techniques for synthesizing multivariable, nonlinear and optimizing control structures. Research activities in this area have already been undertaken, but there still exists the strong need for practical, comprehensive methods that industry can effectively use.
- Efforts to **develop new technologies and processes** in growth fields, such as biotechnology and polymer engineering, have created the need for quickly constructing new process models and for developing more reliable control strategies. Modeling and control strategies in this area have barely scratched the surface of this very important problem. Traditional solutions influenced by past experiences are clearly not adequate. Novel ideas are needed in postulating the appropriate research problems and in providing fresh approaches for their solution.
- Increased process complexity, together with **strict industry and governmental standards for safety and the environment**, require more reliable methods for alarm system analysis, system design, and for new process fault diagnostic methods with predictive capabilities. Although industry has applied these concepts quite effectively with in-house approaches, there is a need for more systematic methods for the design and safe operation of the tightly integrated processes we will use in the future.
- Rapidly evolving technologies for **low-cost computer designs and VLSI systems fabrication** are creating new opportunities to apply powerful computer hardware and software for process control including real-time integrated plant transient simulation and optimization.
- Continuing advances in our ability to make **more accurate measurements of process variables**, especially under complex or harsh conditions, open up many possibilities for better understanding of process behavior and lead to improved techniques for process optimization and control. Research opportunities, for example, with respect to measurements in the processing of polymers and in biotechnology, are very numerous.
- Industry has **growing requirements for well-educated engineers** who possess a combined understanding of chemical process technology, up-to-date modeling and control approaches, and methods and theory for solving challenging process related problems. Furthermore, the growing use of computers in industry, coupled with the rapidly increasing power and distributed nature of the computer, is fundamentally altering the process of design, engineering, and process operation as well as the manpower needs of industry.

These six trends define the research mission of Lehigh's Chemical Process Modeling and Control Research Center.

THE PEOPLE

The cross-disciplinary nature of the PMC process control research effort is reflected in the human resources of the center. Of the sixteen faculty members participating in the center (Table 1), eleven are affiliated with the chemical engineering department, two with mechanical engineering, two with industrial engineering, and one with mathematics. Strong interactions exist between PMC, the Bioprocessing Research Institute, and the Emulsion Polymer Institute at Lehigh.

TABLE 1
PMC Research Center Faculty

Christos Georgakis, Director (ChE)	Andrew Klein (ChE)
William L. Luyben, Co-Director (ChE)	Janice A. Phillips (ChE)
Hugo S. Caram (ChE)	Matthew J. Reilly (ChE)
John C. Chen (ChE)	David A. Sanchez (Math)
Mohamed S. El-Aasser (ChE)	William E. Schiesser (ChE)
D. Gary Harlow (ME)	Harvey G. Stenger (ChE)
Arthur E. Humphrey (ChE)	Robert H. Storer (IE)
Stanley H. Johnson (ME)	John C. Wiginton (IE)

Two post-doctoral researchers are currently involved with furthering the work on specific research projects and with defining new projects. We also have three visiting research engineers from PMC industrial sponsors.

At present, twelve graduate students are enrolled in the activities of the center—eleven through the chemical engineering department and one through mechanical engineering. Two students will leave in 1987 with MS degrees, while the remaining ten are working towards the PhD. It is an international group. Some of the students have industrial experience, but most do not.

A special human resource of PMC is the close personal involvement of the company sponsors of the center. The twice-yearly meetings of the PMC Industrial Advisory Committee provide an opportunity for both formal and informal exchanges between the students and the practicing engineers. Direct lines of communication between students and practitioners invariably result from these meetings. In fact, essentially all of the PMC thesis committees include a member from industry.

THE TECHNICAL PROGRAM

The typical initial stages of the graduate student's program are dominated by course work. As evidence of Lehigh's emphasis on process control, the advanced level control courses are all cross-listed by the chemical, mechanical and electrical engineering departments. The core advanced courses include state-space and optimal control, multivariable control, process identification, and stochastic control. These courses supplement undergraduate courses in introductory process control and in sampled-data control. In addition, topical seminars are periodically offered, for example, on nonlinear control.

The choice of a graduate research topic is intimately related to the research projects of the PMC center. The vast majority of research undertaken by the center is of a generic nature addressing major research challenges not fully addressed and resolved in the process control literature. A listing of the ten generic research projects currently active is provided in Table 2. Typically, thesis topics derive from these generic research projects.

TABLE 2
Current PMC Research Projects

1. **Design of effective nonlinear controllers for chemical reactors**
2. **Design of practical multivariable process controllers**
3. **Design and control of energy-efficient distillation column systems**
4. **Development of software for dynamic process simulation and control system design**
5. **Bioreactor modeling, optimization and control**
6. **Modeling and control of semi-continuous emulsion polymerization reactors**
7. **Plant-wide control**
8. **Expert multivariable control**
9. **Batch reactor control**
10. **Statistical quality control**

The charter of PMC also provides for the conduct of suitable company-specific research projects. Although far less active than the generic research of the center, this work also provides potential topic areas for thesis research. As an example of the company-specific research, an MS thesis has been completed on "The Control of Low Relative Volatility Distillation Columns" making extensive use of real plant data from an industrial sponsor.

There is a liberal exchange of information among the projects. Students routinely share the software they have developed. Process models, including those derived from real industrial systems, are used by several researchers on different projects. Conversely, new control algorithms are tested in several different applications.

PMC-supported students are always able to publish their work in a timely manner according to the center's publication guidelines. Research is also reported at national meetings. Some restrictions pertain to the components of company-specific research projects involving proprietary information. PMC-supported students must file semi-annual progress reports to the Industrial Advisory Committee once they become active in project work. In general, one formal presentation per year is given by each student to the industrial sponsor. Of course, less formal presentations on research plans and results are given with greater frequency within the PMC tream.

THE ENVIRONMENT

A dramatic new development at Lehigh has occurred within the past year. A substantial portion of Bethlehem Steel's Homer Research Laboratory, located less than a mile from Lehigh's main campus, was acquired by Lehigh University. Acquisition of this beautiful facility nearly doubled the amount of space for research (laboratory and office) available to the university. PMC, the Chemical Engineering Department, the Bioprocessing Research Institute and the Emulsion Polymer Institute were among the first groups to occupy the new facility.

Foreshadowing the doubling of the research space, a doubling of the technical library space was accomplished during 1984-85. The E.W. Fairchild-Martindale Library currently houses 435,000 volumes, with a total capacity of 650,000 volumes. The Lehigh University library system receives more than 9,000 periodicals and serials. The library system fully utilizes computer database technology for cataloging and literature-searching. More than sixty-five full-time staff are available to serve the research needs of faculty and students.

In the area of computer resources, PMC researchers have access, through the campus-wide telecommunications network, to all university mainframes (CDC Cyber 850; Digital DEC-20 and VAX-8530; IBM 4381). Furthermore, PMC is equipped with its own CDC Cyber 810 computer—a $500,000 grant from Control Data. For input/output, there are six Tektronix 4109 graphics terminals, three Control Data 722 terminals, a Tektronix 4692 ink-jet plotter, and a Control Data 533 line printer dedicated to PMC users exclusively. Specialized software for process modeling and control research is available both from in-house development and from external sources. To further the work on expert systems, PMC has acquired a Symbolics 3620 machine with LISP and other advanced software systems. We plan to purchase a Sun Engineering Workstation this summer to support the Batch Reactor Control project. Public microcomputers are widely distributed about campus.

CONCLUSION

These are exciting times at Lehigh and the Chemical Process Modeling and Control Research Center. The chemical process industry is very much interested in stimulating research in process control, and in attracting engineers who are well-educated in the field. The university has responded to this challenge by initiating an intensive industry/academia cooperative research program to bring to light new knowledge in areas of practical importance. The net result for graduate students is that their research must satisfy conditions both of novelty and of practical reality. In our judgment, such a program yields engineers capable of succeeding in either academic or in industrial careers. □

ChE book reviews

MULTIPHASE SCIENCE AND TECHNOLOGY Volume 2

Edited by G. F. Hewitt J. M. Delhaye, N. Zuber
Hemisphere Publishing Co., New York 10016; 1986.
479 printed pages, $62.50

Reviewed by
Y. Y. Hsu
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This book covers six subjects on multi-phase flow: *Chapter 1.* Flow Pattern Transition in Gas-Liquid Systems, Measurement and Modeling (A. E. Dukler, Y. Taitel); *Chapter 2,* A Critical Review of the Flooding Literature (S. George Bankoff, Sang Chun Lee); *Chapter 3,* A Comprehensive Examination of Heat Transfer Correlations Suitable for Reactor Safety Analysis (D. C. Greenoveld, C. W. Snoek); *Chapter 4,* Reboilers (P. B. Walley and G. F. Hewitt); *Chapter 5,* Flow of Gas-Solid Mixtures Through Standpipes and Valves (L. S. Leung, P. J. Jones); *Chapter 6,* Core-Annular Flow of Oil and Water Through a Pipeline (R. V. A. Olieman, G. Ooms).

Chapter One on flow patterns in liquid-gas two phase flow is a comprehensive review of many years of significant contributions made by Professor Dukler and his colleagues at the University of Houston. Two-phase flow behavior is very much affected by the interfacial transport, which in turn is affected by the flow patterns. Determination of flow pattern has been of fundamental importance to two-phase flow studies. The authors' contribution is to treat flow pattern transition through modeling instead of the many empirical approaches previously prevalent in the industry. Dukler and Taitel are to be lauded for their more scientific and mechanistic approach to establish the flow pattern transition criteria. However, a major class of flow patterns that are absent are those related to vertical pipe or bundle with boiling/condensation which are very important in reactor safety analysis and in chemical processes.

The second chapter on flooding covers the subject relating to counter-current flow in a vertical channel. Since the flooding phenomena are very much affected by the entrance geometry—the boundary conditions (such as channel geometry heating or no heating), the steam or air flow conditions and physical properties (steam or air with water being subcooled or saturated), *etc.*—it is very difficult to give an unified and systematic treatment. The authors did a good job in this attempt.

After the analytical models, some experimental results and empirical correlations were introduced. In this section, unfortunately, a great deal of work carried out in reactor safety research was only briefly cited.

Chapter Three is a comprehensive examination of heat transfer correlation used for reactor safety analysis. The heat transfer package is the heart of thermal-hydraulic codes developed to predict the coolability of a reactor core during accidents and transients. Choice of proper heat transfer correlations for each heat transfer mode is the key to the success of a code. The authors of this chapter made a valiant effort to critically examine the heat transfer correlations and succeeded in giving a comprehensive review and provided readers with a fairly complete list of correlations currently being considered for reactor analysis. But the reviewer thinks that bundle data should be given more weight than tube data in assessing the correlations since bundle geometry is what is encountered in a reactor.

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