

# PROCESS SYSTEMS ENGINEERING

## *The Cornerstone of a Modern Chemical Engineering Curriculum*

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Today's chemical engineering students find employment in an increasingly wide variety of industries, many of which were not considered traditional twenty years ago. To meet the demands of these new employers, we are being asked by industry and accreditation boards to incorporate more and more material into the curriculum. The current approach by many department is to "jam" new material into the curriculum as best they can—with the result that while we are covering more material, we are doing a disservice to the students through the disjointed and rushed manner in which the material is taught.

It is evident that "something has to give," and the curriculum should give before we or the students give. Process systems engineering (PSE) is a partial, but significant, solution to the dilemma.

Process systems engineering can be defined as a systematic approach to the design, analysis, and operation of processes, ensuring they are

- ▶ optimal at the design and operation stage
- ▶ controllable
- ▶ flexible over a range of operating conditions
- ▶ environmentally acceptable
- ▶ safe

From this definition it can be seen that PSE is a multifaceted approach to the design and analysis of processes which incorporates all aspects of chemical engineering. As a result, it is difficult to teach. There are several different philosophies for teaching process engineering, and some people have strong feelings about which approach is most appropriate; some feel that process engineering should be taught via a final-year design course, while others try to integrate it into several courses. The use of computers is frequently even more of a contentious issue. Some believe that the use of

computers and sophisticated software (that students often don't completely understand) prevents them from gaining insight into chemical engineering problems. This can also lead to the "garbage in/garbage out" syndrome. On the other hand, others feel that process engineering can be approached as a mathematical programming problem, and they encourage the use of computers.

Clearly, the solution lies somewhere in the middle. PSE should be taught as a subject and used as a tool to aid in teaching other subjects.

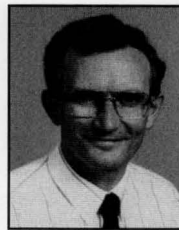
### INDUCEMENTS AND OBSTACLES

There are a number of inducements for the introduction of PSE on a wide scale as well as resistance to it. Some of the



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***Process systems engineering is the cornerstone of a modern ChE curriculum. By viewing processes as systems, students and faculty will be able to focus more clearly on the curriculum—thus streamlining the material presented.***

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inducements are

- *Chemical engineering departments are continually being asked to incorporate more material into their curriculum*
- *Many chemical engineering students seek careers in the process industries, and most end up working in the analysis and operation of processes where PSE approaches are common*
- *The variety of career possibilities is increasing, and the curriculum must be general enough to prepare students to adapt to technology that they may not have encountered in their undergraduate education*
- *Information processing has become important in all engineering disciplines as well as in business and commerce*
- *The PSE approach streamlines the curriculum by helping faculty and students to focus on the essence of chemical engineering*

The most often cited obstacles to incorporating PSE are

- *Lack of trained personnel*
- *Cost of implementing PSE in the curriculum*

The above reservations are important considerations. There is a lack of competent chemical engineering faculty who can implement and teach in a PSE-based curriculum. In addition, the cost of the necessary software and hardware is substantial. But the most significant resistance to change is the attitude of faculty members who take a lofty pedagogical view that PSE is simply using black-box programs that cloud student understanding of fundamentals, resulting in computer programmers rather than chemical engineers. The reality is, however, that PSE, when properly taught, actually enhances the students' understanding of the fundamentals.

Departments wishing to implement PSE will have to come to grips with faculty who are too set in their ways to contemplate overhauling their courses with new material, and who refuse to relinquish control of the curriculum to young faculty members who *will* change it. Only after those attitudes are changed can a successful implementation proceed.

## **A PSE CURRICULUM**

An outline for a PSE curriculum is presented below. It focuses on the specific courses that should be identified as PSE courses and that should have a high PSE content. PSE should play a significant part throughout the freshmen-

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to-senior years and should be implemented in existing courses where appropriate. The approach presented here incorporates several lecture courses, project courses, and the use of computers.

A good process engineering curriculum should

- ▶ Encourage team work
- ▶ Integrate various aspects of chemical engineering
- ▶ Provide exposure to process engineering technology
- ▶ Provide exposure to computer software and techniques
- ▶ Provide exposure to industrial process engineering problems
- ▶ Should not be taught in one course

Five key phases which need to be addressed in the curriculum are

1. *Process awareness*
2. *Process flowsheeting*
3. *Process synthesis and optimization*
4. *Process operations and control*
5. *Case studies*

Each of the above phases has one or more elements that can be addressed in one or more courses. The implementation of the elements into courses is a strong function of the current curriculum and other constraints within the department and the university.

The first phase, **process awareness**, involves an introduction to processes and unit operations. There are two elements that should be addressed in this phase: heat and material balances (often addressed in a single course) and qualitative topics and activities such as

- ▷ Basic process goals (technical, economic, health, safety, and environmental)
- ▷ The process as a system of inputs, output, recycle, interactions, etc.
- ▷ Plant tours
- ▷ Simple lab experiments
- ▷ Reading process blueprints and drawing process flow diagrams
- ▷ Demonstrations of various unit operations

(The second element above may be taught as a separate course or can be incorporated into the heat and material balance course as a lab.)

The second phase, **process flowsheeting**, is a formalized treatment of process flowsheets. Now that students have an understanding of processes and heat and material balances, they can be introduced to the structure of process flowsheets and computer-aided process flowsheeting packages such as Aspen or Hysim. The important elements addressed in this phase are

- ▷ Structure of flowsheets
- ▷ Degree of freedom analysis
- ▷ Difference between manual and automatic solution

offflowsheets

- ▷ Recycle structure
- ▷ Solution techniques (equation oriented, sequential modular)
- ▷ Models (how they are created and used in the simulator)
- ▷ Thermodynamics
- ▷ Convergence promotion methods

This phase should be introduced through formal lectures, together with a computer lab that will allow students to study various flowsheeting problems. The course should be introduced as early as possible in the curriculum so that students have an opportunity to understand how process engineering is affected by all other chemical engineering courses and so they can use the software packages in their other courses. Students are often introduced to the flowsheeting packages in their final year in conjunction with a design course—it is too late at that point for them to use the system in courses such as thermodynamics, mass transfer, economics, heat transfer, etc. Also, the students gain a greater appreciation and understanding of these other courses by studying process engineering.

The third phase, **process synthesis and optimization**, focuses on more advanced techniques in process flowsheeting. The first two phases have focused on analysis of processes, first by hand calculations and then by simulation packages. Students are now ready to think about optimization. Conceptually, the optimization of process variables in a single unit (*e.g.*, temperature, pressure, reflux ratio) is easy for students to visualize. A more difficult problem is the synthesis problem. Optimization software routines are available in some flowsheeting packages as well as some stand-alone optimization software packages. There is little synthesis software available for teaching purposes, however. This phase should be addressed in a lecture course(s) with a computer lab, and the elements considered should include

- ▷ Single variable and multivariable optimization
- ▷ Linear, nonlinear, and mixed integer programming
- ▷ Unit optimization
- ▷ Process optimization
- ▷ Process synthesis (separation sequences, HX networks, and flowsheets)
- ▷ Design and analysis in the face of uncertainty
- ▷ Expert systems
- ▷ Loss prevention and hazard analysis

Phase four, **control and operation**, focuses on the continuous operation of process plants. By this time, students should have mastered the concepts of steady-state analysis and design and should be ready for operational issues. The key elements introduced here include

- ▷ Dynamics
- ▷ Process control

- ▷ Process variable interaction
- ▷ Stability
- ▷ Process planning and scheduling
- ▷ On-line optimization
- ▷ Control system synthesis

This phase involves a lecture component and a laboratory component. In the lab, students can study the dynamics and computer control of actual lab processes and/or work on computer simulations of processes.

Phase five is the use of **case studies**. It is paramount that the students be exposed to a variety of case-study problems designed to illustrate the various aspects of process engineering in the four preceding phases. Case studies can be implemented in a variety of ways: multiple assignments performed in the previous phases; research projects; a final-year design project; industrial design projects; a combination of the foregoing.

On its own, a final-year design project is not an adequate tool for teaching process engineering. In fact, the individual assignments in each of the phases are more important than the final-year design project. The ideal would be multiple assignments in each of the phases and a final-year design project supplied by industry since industrial design projects are more representative of what the student will face in industry. Often, faculty dream up large grass-roots design projects involving all aspects of process engineering in one design—although this may be interesting, few such projects exist and even fewer students are likely to work on the complete design of a large process. Process engineers are more likely to be faced with retrofit, analysis, optimization, or control problems involving one or two units.

## RECOMMENDATIONS

The development and implementation of a comprehensive process engineering curriculum is a strong function of the research interests of the faculty. It is therefore difficult, if not impossible, for all departments to implement all of the ideas presented here. But for those departments just starting out or those that want to make changes, the following relatively simple steps should be considered.

- ▶ *Clearly identify the courses where PSE is to be emphasized*
- ▶ *Contact local industry to give PSE lectures*
- ▶ *Introduce a computer simulation package such as the PC-based Hysim in an upper-year course (migrate to early-year courses later)*
- ▶ *Form collaborative links with other universities to share the teaching development load*
- ▶ *Run the same assignment in a process engineering course and a companion course, e.g., thermodynamics or separation processes.*



## SUMMARY

Process systems engineering is the cornerstone of a modern chemical engineering curriculum. Since the systems approach is fast becoming a fact of life in the worlds of business and commerce, it is imperative that our students and faculty become familiar with it. In addition, the use of PSE technology will allow us to effectively incorporate more material into the curriculum through computer-aided learning and simulation. By viewing processes as systems, students and faculty will be able to focus more clearly on the curriculum—thus streamlining the material presented.

A good understanding of PSE enhances student understanding of chemical engineering science since the PSE course material and software are based on chemical engineering fundamentals. Therefore, the PSE case studies actually reinforce the traditional course material. □

## HOLISTIC APPROACH

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than on their other courses, and they reported that their interest in the course was the main cause for spending extra time. Some students (less than 10%) said that they felt uneasy about making decisions independently. This minority also felt they could have learned more (contents) if the professor had assumed a more active and leading role. Most students were surprised by the importance that presentations have on the class' opinion about a given work, regardless of its intrinsic quality. All of the students thought that more time should be assigned to the project. Final reports exceeded expectations, however. The overall rating of the course was among the highest during its eight years of existence, with students placing great value on the instructor's efforts to bring the practicing world of the engineer into the classroom.

The opinion of other faculty and of industry about the performance of our students and graduating engineers after taking this course is favorable, as reported in the first part of this paper.<sup>[1]</sup> Also, the implementation of this introductory course increased enrollment in chemical engineering, particularly that of women.

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