ChE *classroom*

A REAL-TIME APPROACH TO PROCESS CONTROL EDUCATION

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The classical approach to process control education of chemical engineering[1-4] has been to employ the frequency response methods of process control that were originally developed as pen-and-paper methods for the modeling of process systems. It has been evident for some time that the way process control is taught to chemical engineers needs to be updated.[5-11]

There is an academic requirement that the fundamentals of process control be taught in a more practical and concrete way than afforded by the traditional classical approaches. The increasingly overloaded degree syllabus provides additional impetus to reorganize subjects and reduce superfluous detail. Brisk and Newell[5] recommended training students "in how to utilize process control systems with just enough theory that they can understand what they are using and maintaining." They went on to lament that "unfortunately most of our institutions are teaching too much theory, very little on utilization and maintenance." Doss[6] comments in Edgar's round-table discussion on process control education in the year 2000[12] that "students tend not to retain the mathematical theory but to remember the experiences from control laboratory experiments and simulations." Ramaker, et al.,[11] point out that "an undergraduate in a chemical engineering curriculum [studying] process control should be taught using concepts that fit with the rest of chemical engineering education . . . maintaining the undergraduate curriculum as closely tied as possible to the time domain."

There is also an industrial imperative to teach material that is of use to the practicing engineer. Downs and Doss[7] noted that "what the [graduating engineer] needs is a base level understanding of differential equations, process dynamics, dynamic modeling of basic unit operations, basic control algorithms (such as PID), cascade structures, and feed forward structures. With these basic tools and an understanding of how to apply them, he can solve most of his control problems himself. What he does not need is the theory and mathematics that usually surround process control." The industrial imperative is further reinforced by comments such as the following that come from practicing chemical engineers working in process control or process operations:[8]

- *"I never made use of Bode plots or root locus when I was designing a control loop."*
- *"There are no transfer functions out there in the real plant."*
- *"The material I had been taught was of no use in commissioning a control loop.*

Control education clearly needs to do better.

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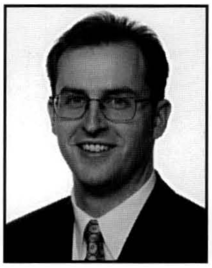

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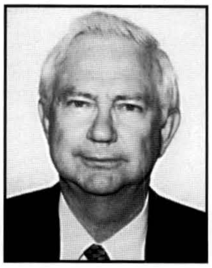

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CLASSICAL APPROACH

Classical control methods were developed between the 1940s and the 1960s in the mechanical and electromechanical engineering disciplines. Given the limitation of computer hardware and software at that time, it was impractical to solve large numbers of higher-order differential equations. Furthermore, since mechanical and electromechanical systems are typically linear and possess little dead time, they lend themselves to analytical and graphical techniques. Hence, there was the development and popularization of analytical and graphical techniques such as

- Transform methods (Laplace and Fourier Transforms)
- Graphical frequency domain methods (Bode, Nichols and Nyquist)
- Root locus analysis

Given the fit to their purpose, classical control techniques still prevail and remain relevant in these engineering disciplines today.

Although these methods make up almost half the content[4] of standard control texts,[1-3] they all share a number of deleterious characteristics. They all require a substantial amount of applied mathematics. In spite of the high level of mathematics required, in order to apply the analysis the system must first be made linear; the methods also have a transfer function basis, focus on individual units, and are generally good only for single loops and PID control. Limited multivariable and no plant-wide controls are possible.

Beyond the engineering deficiencies of classical techniques, there are also implications from a teaching and learning perspective. The abstraction of classical methods makes a difficult subject more difficult, and the methods lack physical meaning, obscuring the central problem of how to modify the system in order to achieve control.[8] These methods are also not suited to "what-if" studies, such as determining loop performance with parameter variation.

Today's ready availability of hardware and software has called into question the relevance of these classical methods for a primary course on process control. A number of previous workers have also identified this need for change. Many workers in the past decade have incorporated simulation software into the syllabus and deleted previous graphical procedures while retaining the classical methods. However, Brauner, et al.,[9] and then Stillman,[8] Bissell,[10] and Ramaker, et al.,[11] almost simultaneously proposed the more radical solution of complete replacement of classical methods with computer simulation, *i.e.,* not as an add-on, but as an integral part of the teaching and learning of process control. Ramaker, et al.,[11] possibly said it best when they said "this doesn't mean that the Laplace transform cannot be used as a tool to solve differential equations in the undergraduate course. Neither does it mean that frequency domain analysis and design are not useful in chemical engineering. It only means that we feel that frequency domain analysis and design should be taught at a graduate level, maintaining the undergraduate curriculum as closely tied as possible to the time domain."

In this paper we will outline and evaluate the actual implementation of such a complete real-time approach to process control.[13]

THE REAL-TIME APPROACH

Unlike mechanical and electromechanical systems, chemical processes are characterized by high degrees of nonlinearity, process interactions, and substantial dead time. Additionally, due to these non-idealities, chemical process control demands to be addressed with a multivariable and plant-wide view. As such, applying classical techniques to chemical process control is a bit like using a wrench to do a hammer's work. In an ideal world, the chemical engineer would have a "virtual plant" on which to experiment. It would capture most of the important non-idealities the real world imposes and would allow the engineer to readily test even the most outlandish of control structures with impunity.

Early attempts to realize this "ideal world" date back to the seventies and eighties[14] when dynamic simulators such as DYFLO, DYNSYS, or SPEEDUP first became available for the solution of nonlinear differential equations describing process dynamics. The hardware was slow at that time, however, and the software was impractical for students to learn and implement within a reasonable time frame. There was effectively no user interface in that the graphics were poor and the programs were run batch-wise.

In today's "simulation-rich" environment, however, the right combination of hardware and software is available for implementing a "real-time" approach to process control education.[14] The hardware and software, such as HYSYS, Aspen Dynamics, or MATLAB, is now fast and easy to use. Simple, complex, and/or user-defined process modules are available, and it is now easy to do "what-if" studies, multiloop, and plant-wide control simulations. The software user interface is now graphical and interactive, and the software can be painlessly run on a PC.

In short, the "virtual plant" has arrived.

This real-time approach also quite naturally lends itself to active, hands-on or resource-based learning.[15-16] In our course, we use a small number of lectures at the beginning to motivate students and to provide a fundamental understanding rather than simply transmitting information; we also use hands-on simulation tutorial sessions on case-study projects facilitated by the instructors, which we call workshops.[13] The syllabus covers the development of mathematical models to describe the transient real-time response characteristics of basic process elements, capacity, and dead time; fundamentals of single-input, single-output systems; use of a dynamic process simulator; block-flow diagram of a feedback-control loop; process-control hardware; basic control modes; tuning feedback controllers; cascade control; feedforward control; common control loops; distillation-column control; design of multiple single-loop controllers; and plant-wide modeling and control.

We also note that while computer simulations provide generally favorable experiences, real experiments are still necessary and desirable.[17] Therefore, we employ in our course a cascade of tanks and a heat exchanger in a pilot plant laboratory that allows students to perform process identification exercises on real plants and to tune real controllers. So that the student understands the underlying "physics" of process control, modeling exercises that require the student to write the describing differential equations and solve them numerically using MATLAB are associated with these laboratory plant experiences.

A CASE STUDY

The real-time methodology will now be illustrated and compared with the classical approach by application to the feedback control of liquid level in a separator (see Figure 1). The unit of Figure 1 is usually represented by a system of transfer functions as shown in the block diagram for the liquid level loop of the separator, shown in Figure 2.

It is obvious that, from a learning perspective, the transfer function block diagram of Figure 2 bears no obvious relationship to the real plant in Figure 1, *i.e.,* the representation lacks physical meaning. Many assumptions and empirical determinations are necessary in order to relate the two. It bears repeating that the abstract nature of these sorts of classical methods makes the subject unnecessarily difficult,[8] obscuring the key issue of real process control, *i.e.,* how to modify the system of Figure 1 in order to achieve control.

In pursuit of the real-time approach, we need to find a better, more intuitive representation of the real plant. A better start is the word-block diagram of the separator liquid level loop shown in Figure 3. Although no underlying mathematics has been introduced, the word-block diagram illustrates the real process control situation of Figure 1 in a more physically meaningful way. The underlying mathematical representation of the process is the set of non-linear differential equations that can be written for each block and solved numerically or simulated by current process simulators such as HYSYS.

In the simulation approach, the student can now easily construct a real-time simulation given the input flow, tank volume, temperature, and pressure. Figure 4 is the plant process-flow diagram simulated in HYSYS, which shows a one-for-one match with the real plant.

The student can then easily indulge in "what-if" studies to find an optimal control structure and set of control param-

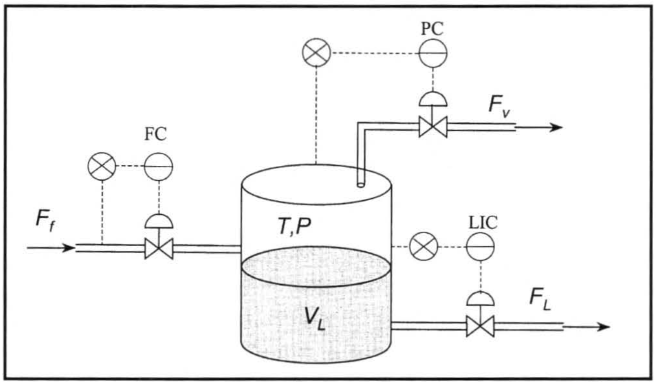

Figure 1. *Schematic of vapor-liquid separator with standard feedback controls.*

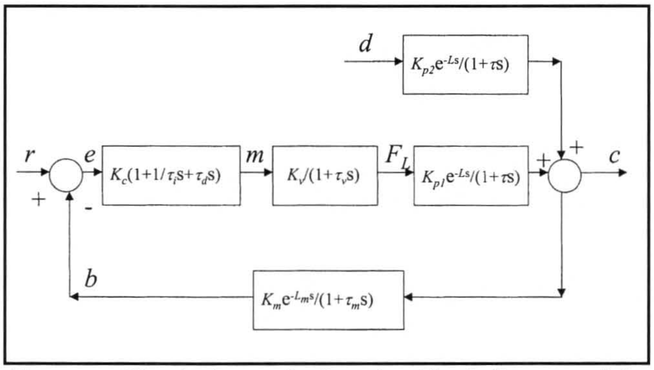

Figure 2. *Classical transfer function block diagram of the liquid level loop of the separator.*

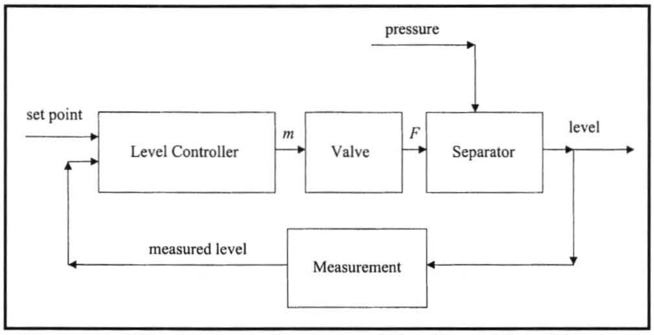

Figure 3. *Word-block diagram of the liquid level loop of the separator plant.*

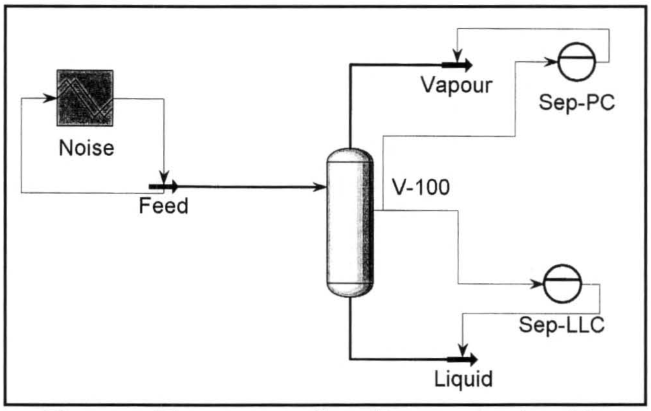

Figure 4. *Plant process-flow diagram simulated in HYSYS process.*

eters for the controllers—the fundamental air of process control. Figure 5 shows a screen shot of the simulated response of the separator to a step change in the set point of the liquid-level controller.

It bears mentioning again here that both the real-time and "what-if" studies described here are both difficult and extremely time consuming to perform when employing classical methods of process control instruction.

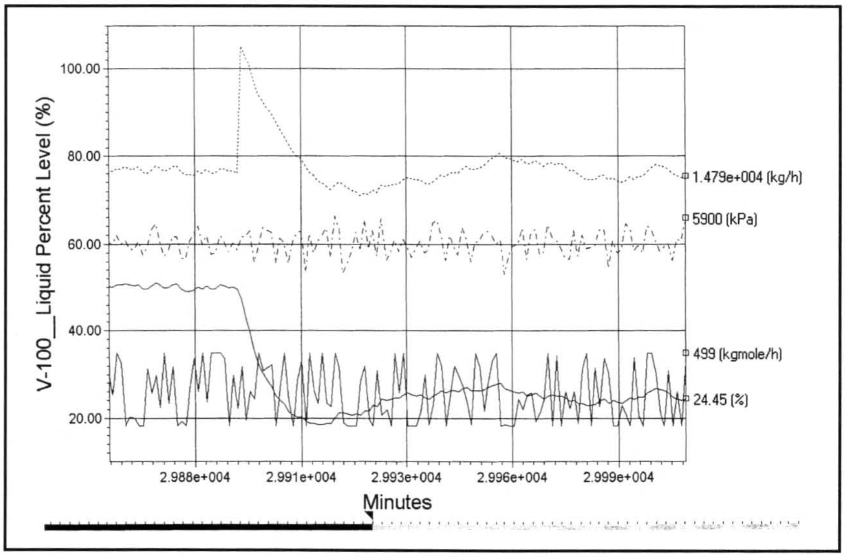

Figure 5. *Real-time simulator response to a set point change in the level controller.*

STUDENT EVALUATION

This real-time approach to process education was first developed in 1996 as a text and an associated set of workshops. This version was used at the University of Calgary during the 1997 academic year as a pilot course for nine students as their senior-year controls course. Their comments motivated a revised second version of the notes and workshops. This second version was used as the basis for the classes of 1998, 1999, and 2000, totaling forty-five, sixty, and eighty students, respectively. A further revision has just been published.[13]

As a means of generating feedback, the students were asked to complete a questionnaire. Overall, the overwhelming majority of students preferred the "hands-on real-time approach" to learning process control. More than 80% of the students said the approach was clear, concise, useful, and applicable. The major complaints, but only from a minority of students, were that they did not like "hands-on" self-directed learning, found the workshops too involved and time-consuming, and would have preferred a standard course consisting of standard lectures, assignments, quizzes, and a written final exam. Our anecdotal feedback from former students in industry is also overwhelmingly positive.

CONCLUSIONS

There is a need for change to conventional process control education—a change from a classical frequency domain methodology to instruction using concepts that fit with the rest of chemical engineering education, *i.e.,* a real-time approach.

A real-time simulation approach to undergraduate process control education in chemical engineering with the aid of realistic "hands-on" workshops involving real-time simulation of chemical processes was presented. The workshops are based on fundamental process models of industrial unit operations using educationally affordable and readily available commercial process simulation software. The real-time simulation approach to process control education was presented with the aid of a case study and compared with the traditional classical approach.

Student feedback from four years of implementation evaluated the new "hands-on" real-time simulation workshop approach as effective, useful, and applicable.

NOMENCLATURE

b	measured variable	c	controlled variable, proc. variable
LIC	level indicating controller	e	natural logarithm
e	controller input error signal, r-b	F	flow
K	controller gain	L	dead time
m	manipulated variable, control effort	P	pressure
PC	personal comp. or pressure controller	r	set point
s	Laplace transform variable	T	temperature
τ	time constant	V	volume
Subscripts			
c	controller	d	derivative or disturbance
f	flow	i	integral
L	liquid	m	measurement
ν	valve	V	vapor

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ChE letters to the editor

To the Editor:

Professor Grossmann correctly points out errors that can occur when using citation statistics to compare graduate programs.[1] However, the differences between the results of the two studies that Professor Grossman considered (the National Research Council report[2] and Science Watch[3]) should not be used as a reason for discounting the value of citation statistics. The major difference in the results likely arises from a difference in what the two studies were designed to measure, rather than from errors. The NRC study attempted to measure quality of *departments or programs;* the Science Watch study compared *institutions.* Therefore, the NRC study reported citations arising from a single program or department within a university while Science Watch reported citations from the entire university. Furthermore, while the NRC study attempted to be inclusive and cover all journals, the Science Watch study covered a very narrow range of journals. For example, the Science Watch list included no electrochemical journals, no materials journals other than polymers (and only three of those), and only one biotechnology journal.

As a consequence, even without errors of the types noted by Professor Grossmann, the citation counts will vary greatly between the two studies. These differences could be in either direction. A university's chemical engineering activities would appear relatively weaker in the Science Watch study if it had major efforts in fields not included in the Science Watch journal list. Conversely, the chemical engineering activities would appear relatively stronger in Science Watch if the university had efforts in areas such a catalysis, surface chemistry, and combustion outside of the chemical engineering department. The Science Watch study is appropriate for comparing *universities* in the particular fields of applied chemistry and chemical engineering covered in the Science Watch database; it is not appropriate for comparing *chemical engineering departments* and should not be used for that purpose. The NRC study, which referred to programs rather than universities, has a more comprehensive database of publications and is appropriate for comparing chemical engineering programs.

Professor Grossmann is correct when he says we should use great care in interpreting countable indices such as citations and publications. However, it is possible to devise multiple, countable criteria that can give an alternative measure of graduate program quality.[4] Engineers, in particular, should not be reluctant to use countable indices rather than "reputational rankings." The "reputational rankings" give little more than historical perspective and cannot accurately portray a dynamic field such as modern chemical engineering.

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To The Editor:

At the risk of faning the flames of controversy concerning use of citation statistics in rankings of chemical engineering programs, I would like to add some comments engendered by the recent article by Ignacio Grossmann.[1] I do so from the point of view of a department that has admittedly fared reasonably well by current measures, as indicated below.

Professor Grossmann has pointed out some real and potential flaws in the citation statistics compiled by ISI and frequently used by one group or another to establish relative rankings of research programs in many fields, including chemical engineering. Assuming that errors arising from misspellings will tend to be randomly distributed, I would like to focus on some pitfalls that are far more serious.