Process Control Education: Past, Present, Future

Thomas F. Edgar
Department of Chemical Engineering
University of Texas
Austin, TX 78712

AIChE Centennial Session:
Systems and Process Control

Process Control: Changes in

- Hardware and software
- Industrial practice
- Curriculum
- Textbooks
- Faculty
- Students


CHANGE
WE NEED
WWW.BARACKOBAMA.COM
OBAMA
BIDEN

Goals of the Undergraduate Process Control Course

1. Understand the difference between dynamic and steady-state behavior
2. Become proficient in analysis of dynamic systems (open, closed loop)
3. Learn the effect of feedback control and how to tune PID controllers
4. Appreciate the benefits of advanced control technology
5. Be exposed to modern instrumentation and control hardware

Typical Course Outline for Process Control

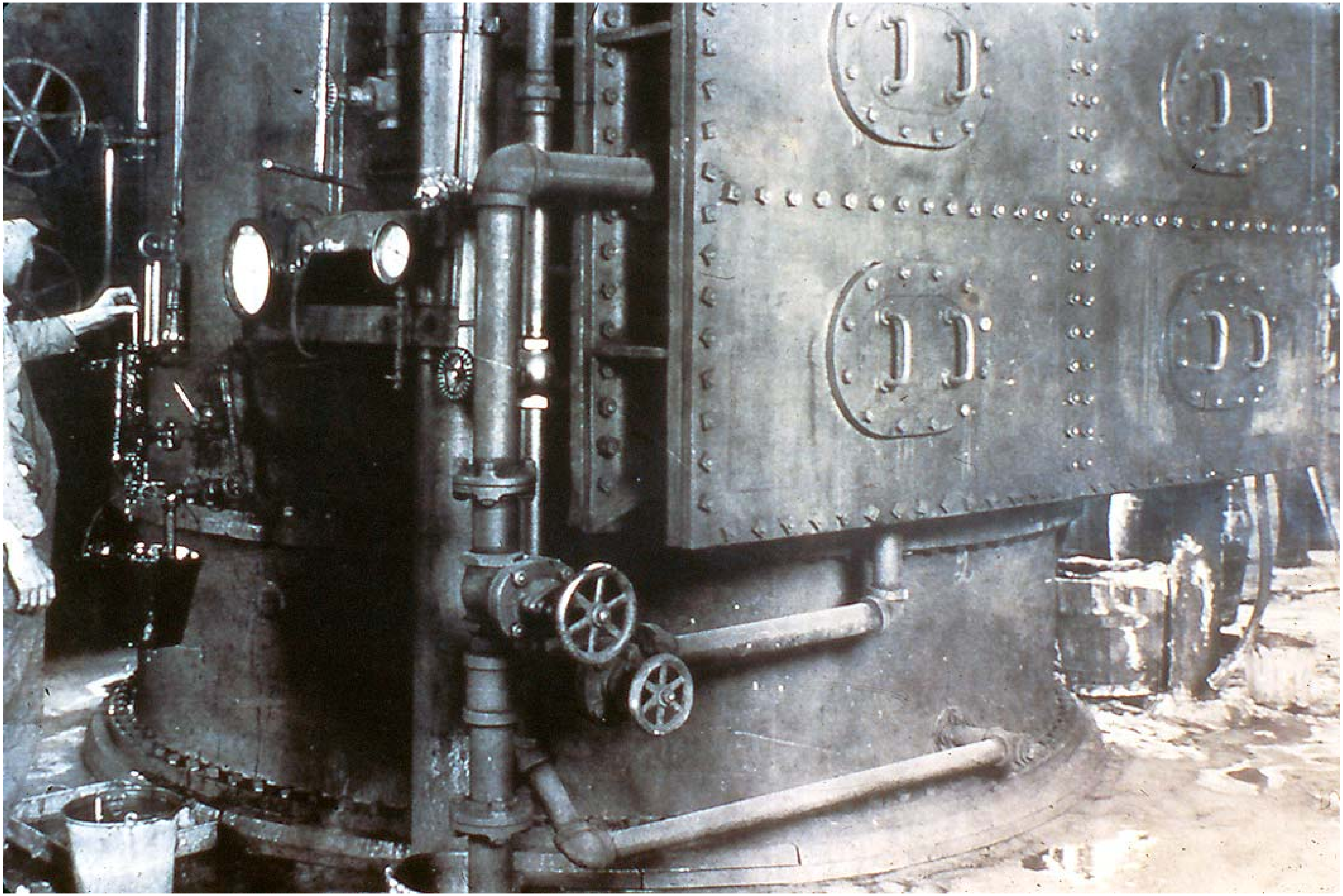
1. Introductory concepts – feedback vs. feedforward control
2. Mathematical modeling of physical systems
3. Linear system analysis – Laplace transforms
4. Response characteristics of typical process systems
5. Controller hardware, instrumentation
6. Closed-loop analysis, stability calculations

Typical Course Outline for Process Control

7. Tuning of PID controllers
8. Frequency response analysis
9. Advanced control methods – feedforward, cascade, multivariable, adaptive, supervisory, etc.
10. Plant control strategies, case studies
11. Miscellaneous topics

The above outline excludes time spent in an associated process control laboratory.

Control in the Early Days



Early Process Control Textbooks (Not a Required Course)

1960's - Buckley (1964)
Harriott (1964)
Coughanowr and Koppel (1965)
Perlmutter (1965)
Johnson (1967)

1970's - Pollard (1971)
Douglas (1972)
Smith (1972)
Luyben (1973)
Weber (1973)
Shinskey (1979)
Hougen (1979)

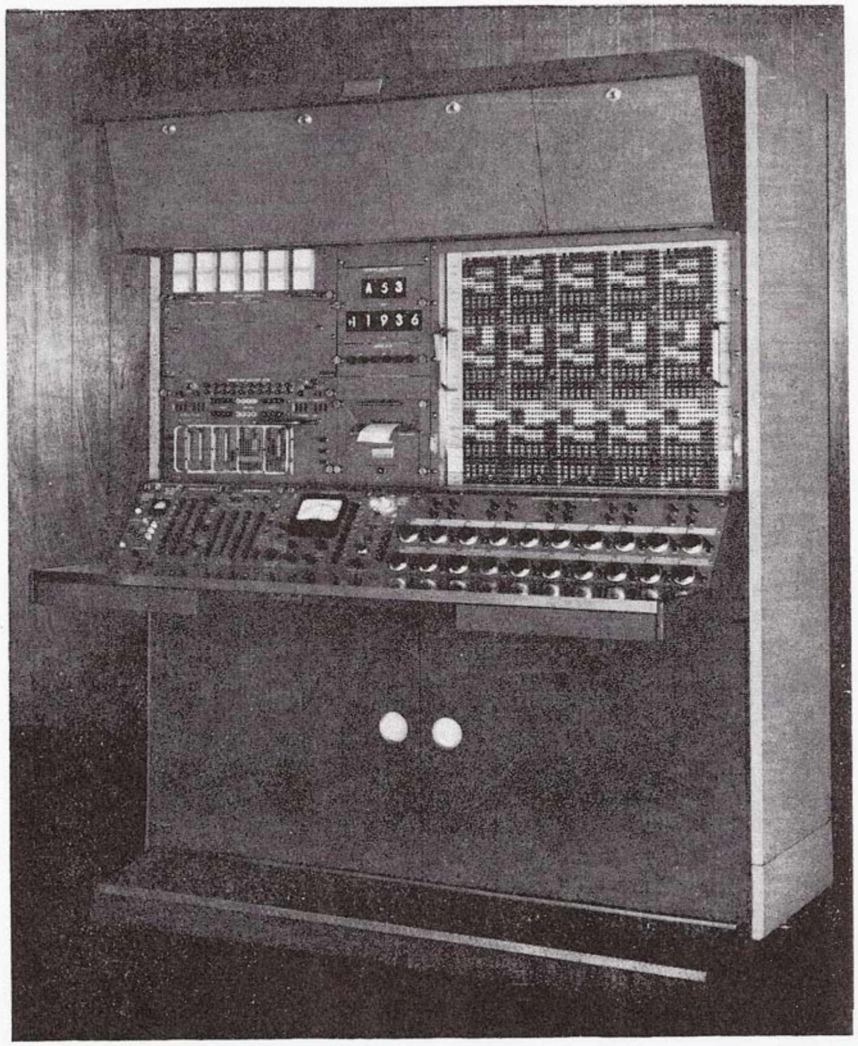


Fig. 30.8 **(*a*) A large-size (100-amplifier) computer. (Courtesy of Electronic Associates, Inc.)**

is removable; this feature offers a great advantage, for a wired computer circuit can be stored and used later. Also, problems can be wired on a spare patch board while the computer is operating on another problem.

In high-precision computers, the resistors and capacitors used to construct summers and integrators are not accessible to the user. These components are located inside the cabinet and wired so that certain ampli-

Computer Programs for Process Control (CACHE, 1972)

	Program Title	Author (s)
1.	Roots of the Characteristic Equation	E.H. Crum R.C. Gillespie
2.	Response of Noninteracting Tanks	Thomas W. Weber
3.	Bode Plots of Transfer Functions	W.L. Luyben
4.	Process Control of a Pure Time Delay	Thomas W. Weber
5.	Process Control and Simulation of a Stirred Tank	Kermit L. Holman Donald B. Wilson
6.	Simulation of Tank Level Control	Armando B. Corripio
7.	Simulation of Liquid level Control	Don M. Ingels
8.	DYNAM, A Teaching Aid for Dynamics and Control	H. Ted Huddleston Jr.
9.	Identification and Control of a Chemical Reactor	Ram Lavie
10.	Frequency Response Data via Pulse Testing using the Fast Fourier Transform	C.R. Dollar C.L. Smith P.W. Murrill
11.	Dynamic Process Identification in the Time Domain	William C. Clements, Jr.

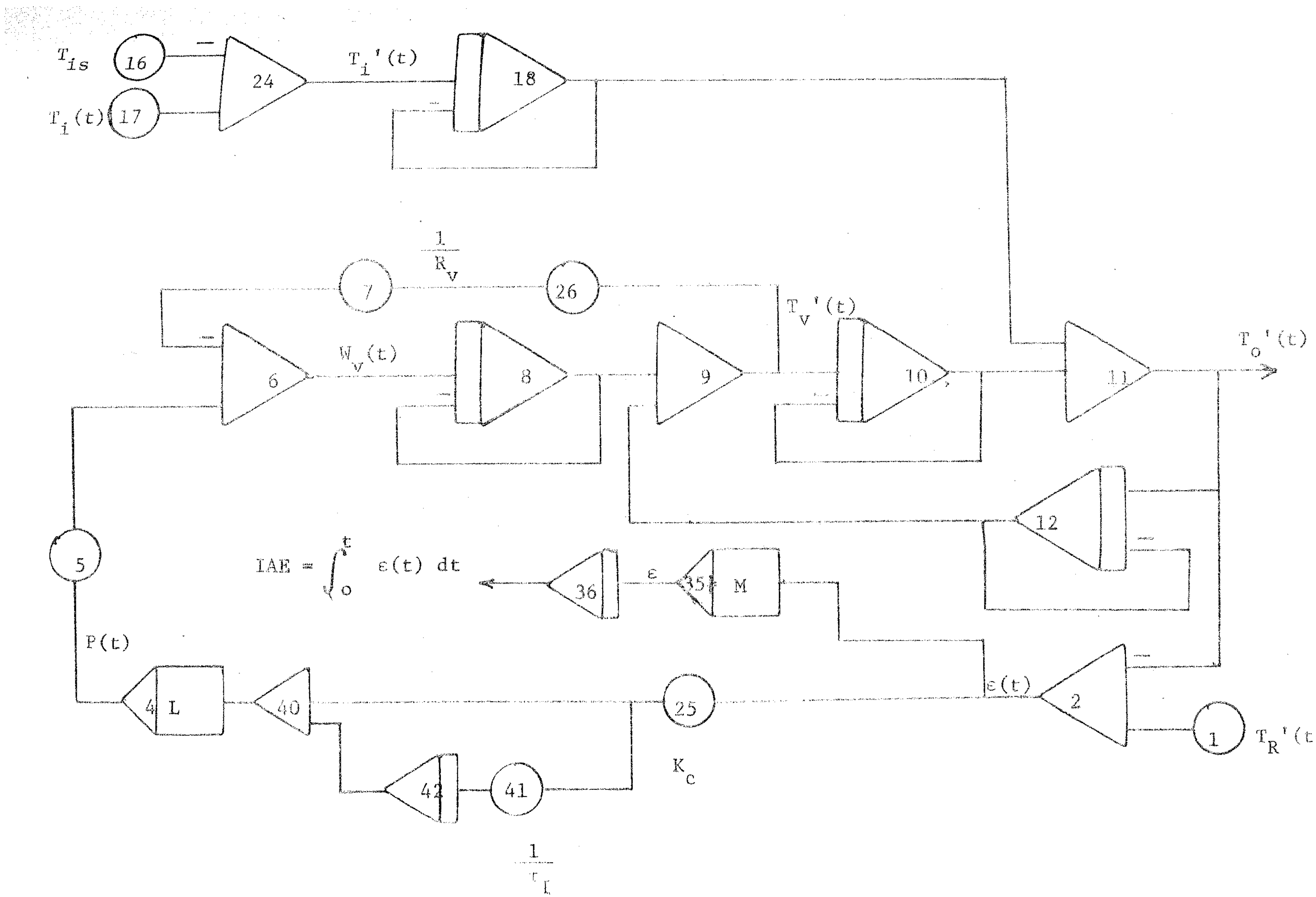


Figure 5. 1130/CSMP Flow Diagram for Proportional-Integral Control

TANK LEVEL CONTROL PROBLEM JANUARY 1971

PAGE 1

MINIMUM 0.0 H1 VERSUS TIME MAXIMUM 1.4704E+01

TIME	H1
0.0	0.0
5.0000E-01	2.7531E+00
1.0000E+00	5.2013E+00
1.5000E+00	7.4782E+00
2.0000E+00	9.6299E+00
2.5000E+00	1.1682E+01
3.0000E+00	1.3544E+01
3.5000E+00	1.4547E+01
4.0000E+00	1.4653E+01
4.5000E+00	1.4002E+01
5.0000E+00	1.2961E+01
5.5000E+00	1.2022E+01
6.0000E+00	1.1196E+01
6.5000E+00	1.0474E+01
7.0000E+00	9.8461E+00
7.5000E+00	9.3027E+00
8.0000E+00	8.8316E+00
8.5000E+00	8.4199E+00
9.0000E+00	8.0547E+00
9.5000E+00	7.7243E+00
1.0000E+01	7.4188E+00
1.0500E+01	7.1310E+00
1.1000E+01	6.8561E+00
1.1500E+01	6.7136E+00
1.2000E+01	6.7575E+00
1.2500E+01	6.9068E+00
1.3000E+01	7.0987E+00
1.3500E+01	7.2885E+00
1.4000E+01	7.4476E+00
1.4500E+01	7.5614E+00
1.5000E+01	7.6263E+00
1.5500E+01	7.6471E+00
1.6000E+01	7.6337E+00
1.6500E+01	7.5992E+00
1.7000E+01	7.5530E+00
1.7500E+01	7.5080E+00
1.8000E+01	7.4704E+00
1.8500E+01	7.4439E+00
1.9000E+01	7.4293E+00
1.9500E+01	7.4252E+00
2.0000E+01	7.4290E+00

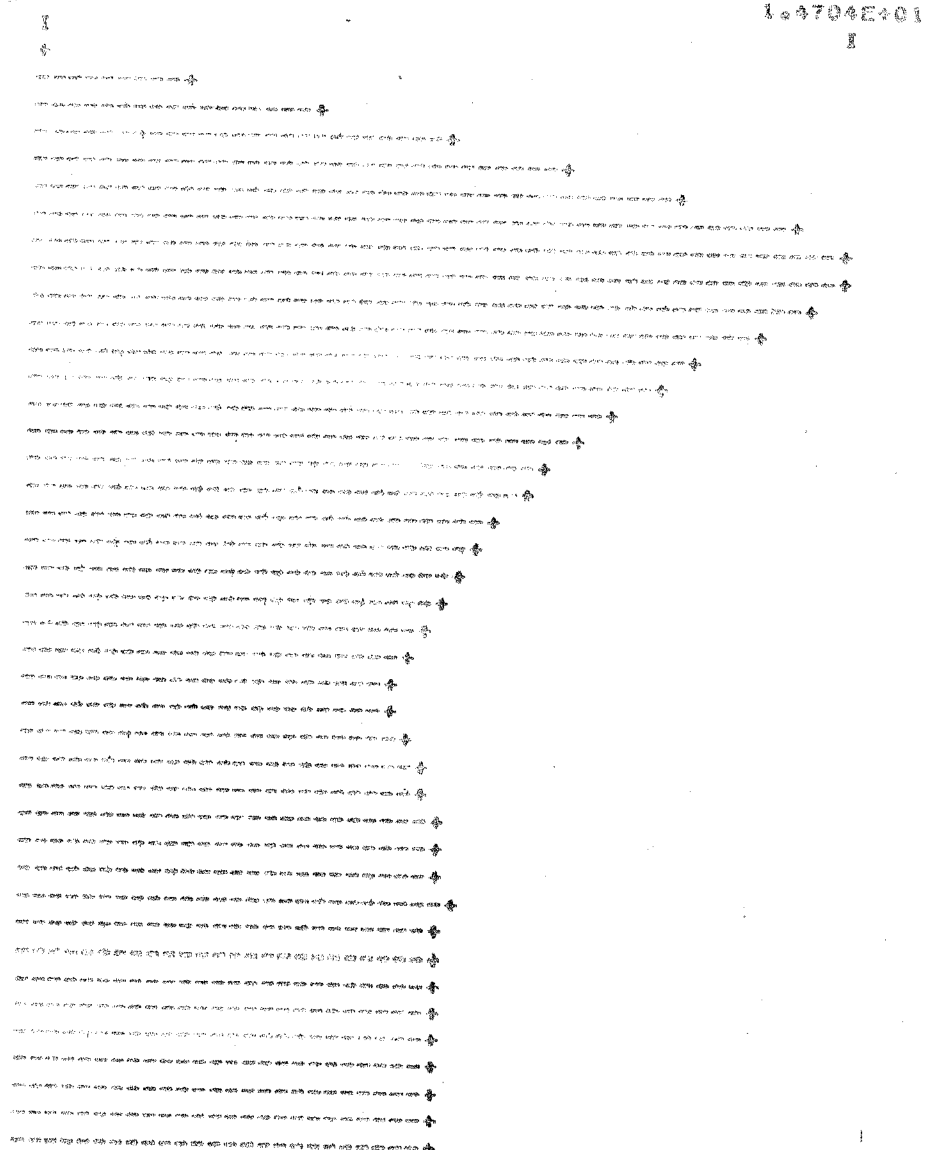
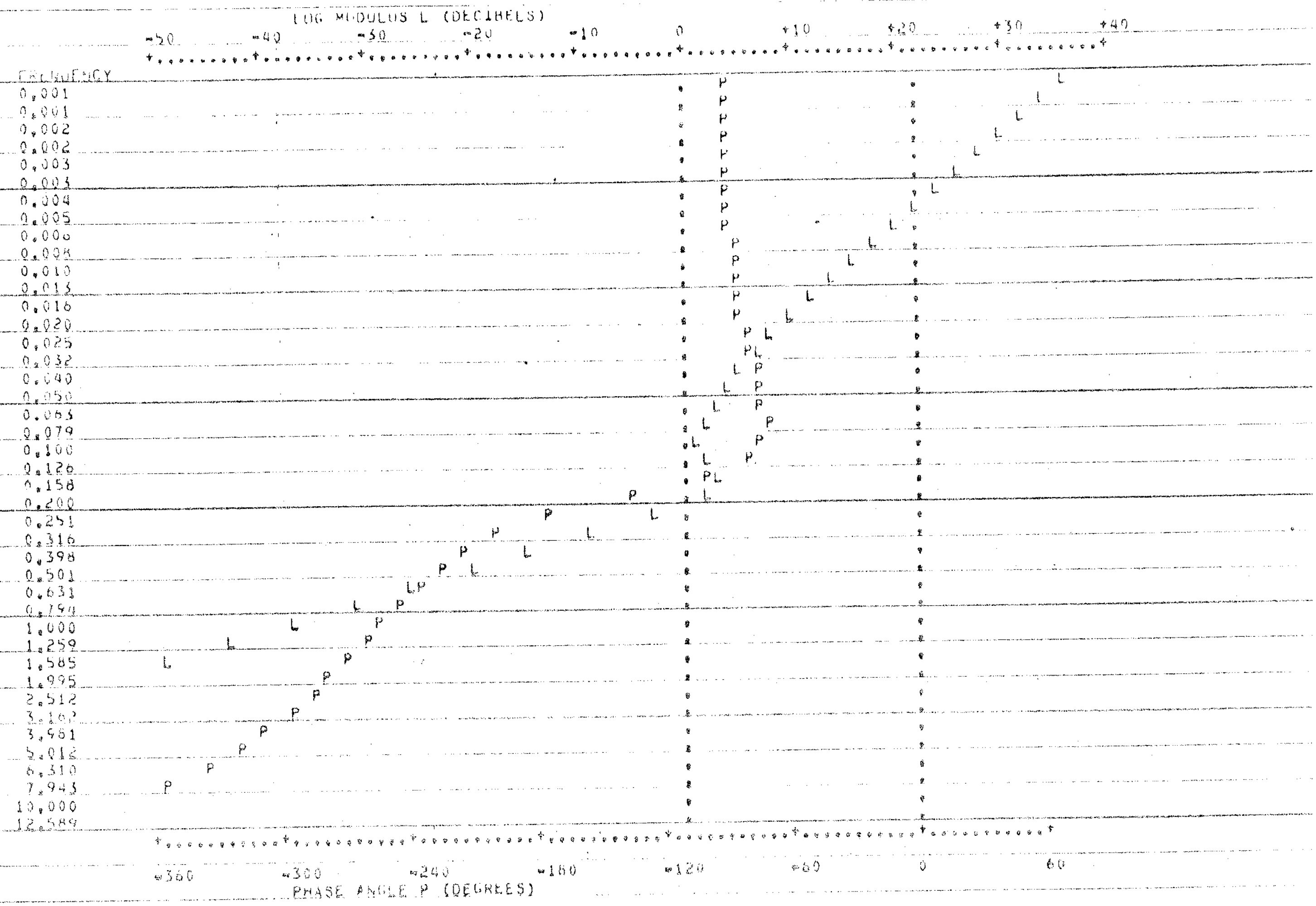


FIGURE 2. Level in the First Tank (Case 1).


LOG MODULUS L (DECIBELS)
-50 -40 -30 -20 -10 0 +10 +20 +30 +40
FREQUENCY
0.001
0.001
0.002
0.002
0.003
0.003
0.004
0.005
0.006
0.008
0.010
0.013
0.016
0.020
0.025
0.032
0.040
0.050
0.063
0.079
0.100
0.126
0.158
0.200
0.251
0.316
0.398
0.501
0.631
0.794
1.000
1.259
1.585
1.995
2.512
3.162
3.981
5.012
6.310
7.943
10.000
12.589
-360 -300 -240 -180 -120 -60 0 60
PHASE ANGLE P (DEGREES)

A Tektronix 4014 computer terminal (ca. 1975)

Major Developments Influencing Acceptance of APC in Late 1970s and 1980s

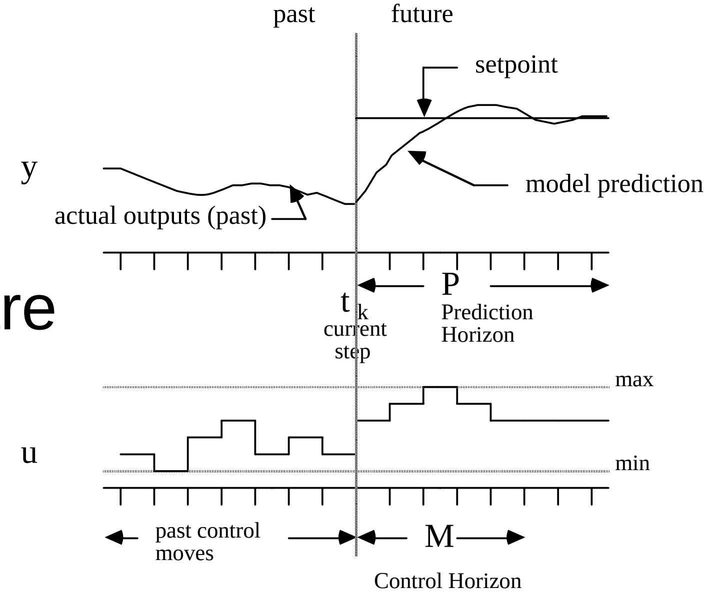
- Energy crisis
- Distributed control hardware
- Environmental and safety restrictions
- Quality control (international competition)
- Computing speed

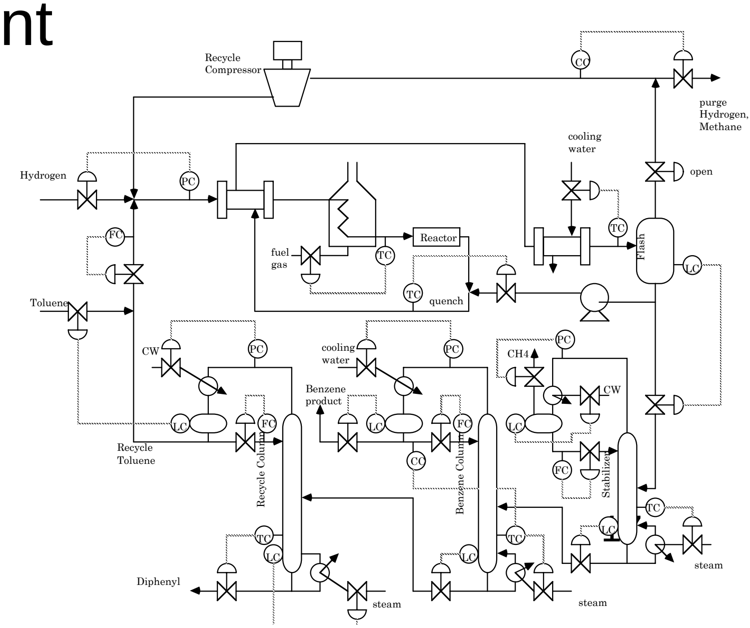
First ABET Requirement on Teaching Process Control

In the mid-1980’s, the American Institute of Chemical Engineers (AIChE) modified the criteria for accreditation used by the Accreditation Board for Engineering and Technology (ABET) to include a required component in the undergraduate program in *process dynamics and control*.

Increasing Scope of Process Control

Alarms and safety
Model predictive control
Simulation
Distributed control software and hardware
Unit operations control applications
Batch sequence control, PLC's
Process control languages
Statistical process control and monitoring
Process control data base management
Real-time computing
Expert systems, artificial intelligence
Digital control algorithms
State space analysis
Real-time optimization
Model Identification

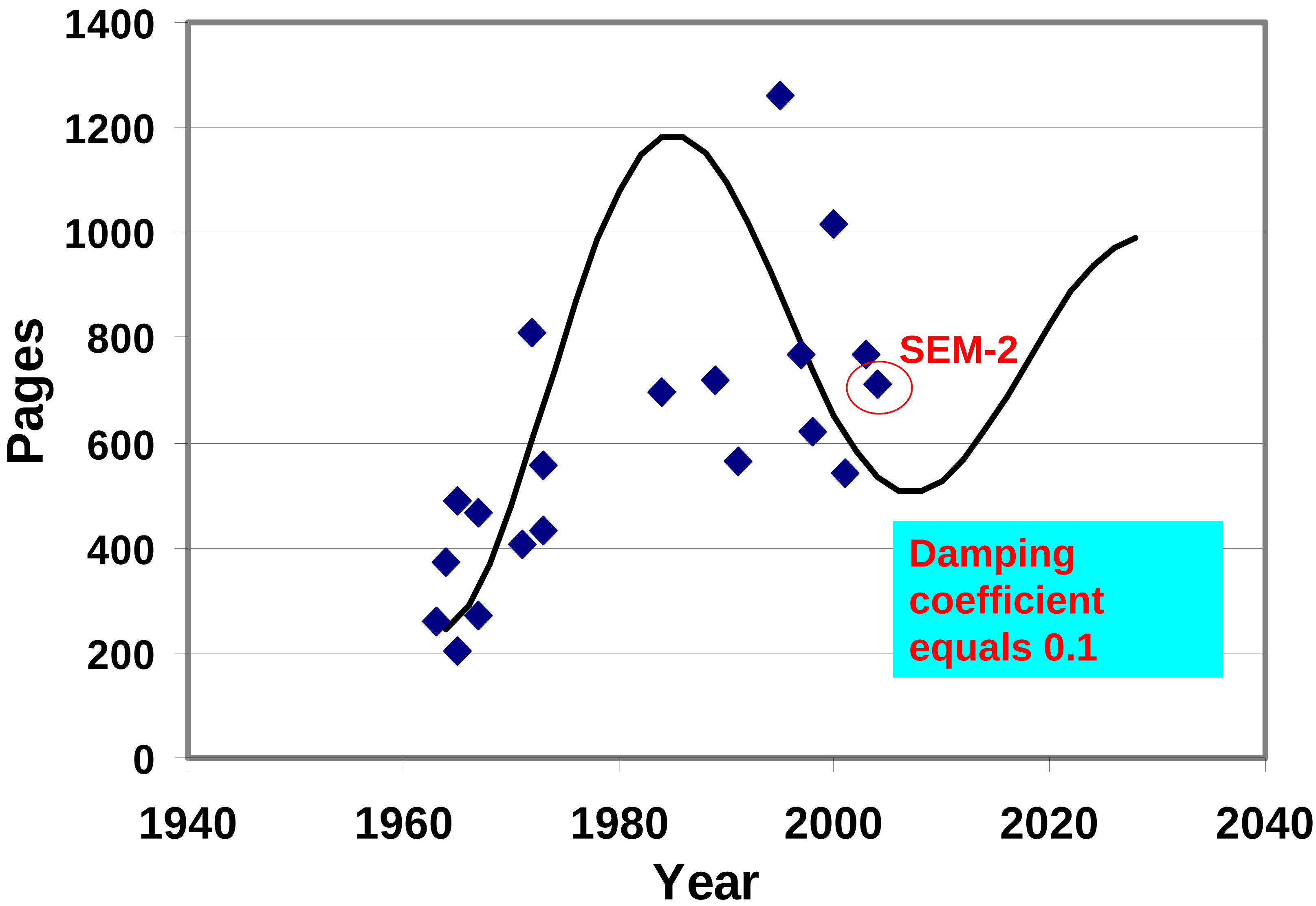




Second Generation Textbooks

1980's -	Deshpande and Ash (1981) Stephanopoulos (1984) Smith and Corripio (1985) Seborg, Edgar and Mellichamp (1989, 2004, & Doyle – 2009)
1990's -	Luyben (1990) Coughanowr (1991) and Leblanc (2008) Ogunnaike and Ray (1995) Marlin (1995, 2000) Luyben and Luyben (1997)
2000's -	Srvcek et al. (2000) Riggs and Karim (2001, 2007) Chau (2002) Bequette (2003) Romagnoli and Palazoglu (2006)

Process Control Textbook Trends



The Joy of Writing Books

Writing a book is an adventure. To begin with it is a toy, then amusement, then it becomes a mistress, then it becomes a master, and then it becomes a tyrant, and the last phase is that just as you are about to become reconciled to your servitude, you kill the monster and strew him about to the public.

Winston Churchill

1994-95 ABET Criteria in Chemical Engineering

"IV.C.3.g. Appropriate computer-based experience must be included in the program of each student. Students must demonstrate knowledge of the application and use of digital computation techniques for specific engineering problems. The program should include, for example, the use of computers for technical calculations, problem solving, data acquisition and processing, process control, computer-assisted design, computer graphics, and other functions and applications appropriate to the engineering discipline. Access to computational facilities must be sufficient to permit students and faculty to integrate computer work into course work whenever appropriate throughout the academic program."

How Should Modeling be Covered in the ChE Curriculum?

- Make the entire curriculum more model-based
- Dynamics should be introduced in more than the control course
- Design course should focus more on operations than steady-state design
- This could make the process control course more efficient and allow it to focus on relevant control issues

Reducing the Emphasis on Laplace Transforms and Frequency Response

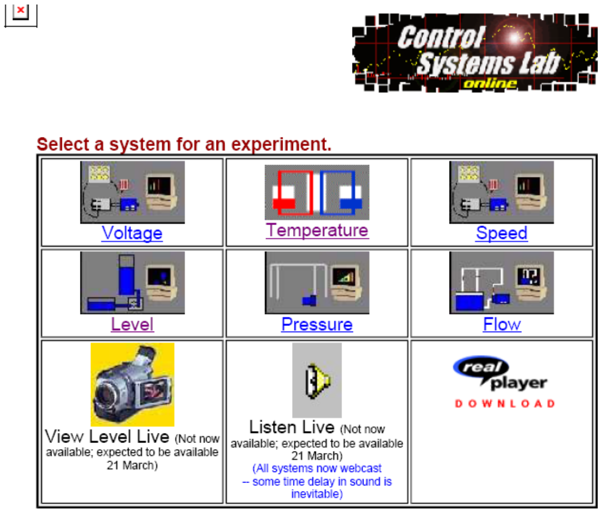
- Increase emphasis on Simulink for closed-loop control analysis
- Still cannot rely on Mathematics O.D.E. course to provide adequate preparation for process control
- Frequency response is suggested as a topic for reduced emphasis

Process Control Lab Experiments

- Very few dedicated control labs in existence
- Introducing students to unsteady state operation is very important
- Simple inexpensive experiments can be pedagogically effective
- How much is necessary (vs. simulation)?

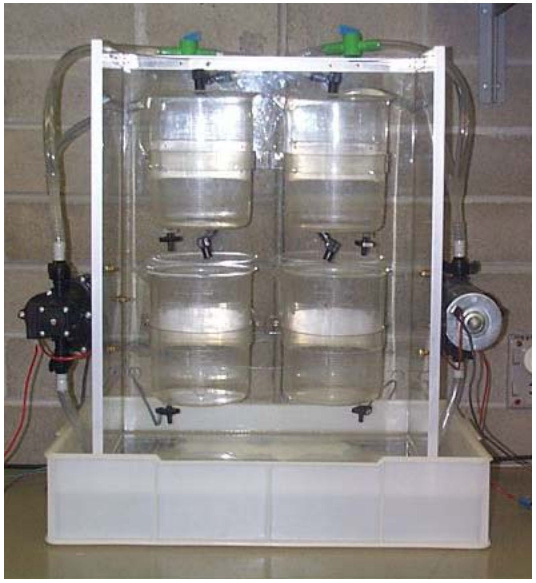
Recent Innovations

- Virtual Unit Operations Laboratory
  - Texas Tech, Control Station
- Remote Laboratory Experiments
  - MIT, EPFL, U. Tennessee – Chattanooga



Typical Control Experiments

Dynamic testing of various components
Valve characteristics
Heat exchanger dynamics and control
Level control of tanks in series
Thermal response of fixed bed
Thermocouple calibration and dynamic response
Control of tank pressure
pH control
Cascade control of a heated bar
Distillation column control
Impulse testing of a mixing tank
Feedback controller modes and tuning
Four tank system (dynamics and control)



More impact if part of control course?

Importance of Control to Industry

- Control training is valued, but emphasis may depend on industry where student is employed and nature of job responsibilities
- Job openings in manufacturing (“process engineer”) often request skills in simulation, computing, and control
- Commodity and energy enterprises will still need new engineers
- Are B.S. graduates unprepared for industrial assignments related to control?

Industrial Survey: Ranking of Key Control Concepts (10 = highest priority)

1. (8.6) Optimization of a process or operation
2. (7.2) Statistical analysis of data and design of experiments
3. (7.0) Physical dynamic process models
4. (6.9) Statistical/Empirical dynamic process models
5. (6.6) Multivariable interactions and system analysis
6. (5.3) Statistical process control and process monitoring
7. (5.1) Design and tuning of PID loops
8. (3.9) Nonlinear systems dynamics and analysis
9. (2.4) Frequency domain analysis
10. (1.9) Expert systems and artificial intelligence

Changing Other Courses Can Strengthen Process Control Education

- Emphasize more dynamic modeling/operations in reactor and plant design course
- Exposure to optimization tools (open-ended problem solving), perhaps in numerical analysis course
- Influence content of mathematics courses (Laplace transforms, matrix algebra), probability and statistics
- Digital control/data acquisition in junior/senior laboratories
- Statistics background for process monitoring/diagnosis, statistical process control

Faculty Have Changed

- Less than 40% of ChE Departments (U.S.) have one faculty member with primary research interest in systems area
- Government funding for control research relatively hard to obtain
- Recent faculty hiring has emphasized bio, nano, enviro with few systems hires
- Some departments have eliminated a separate control course (coincides with ABET 2000 criteria change)

PSE Faculty in Chemical Engineering Departments in U.S. (2004)

	Assistant	Associate	Full
Berkeley	-	-	-
Caltech	-	-	-
Carnegie Mellon	1	-	4
Cornell	-	-	-
Delaware	-	-	1
Georgia Tech	-	2	1
Illinois	-	-	1
Michigan	-	-	-
Minnesota	-	1	-
MIT	-	1	2
Northwestern	-	-	-
North Carolina State	-	-	-
Pennsylvania	-	-	1
Penn State	-	1	-
Princeton	-	-	2
Purdue	-	-	4
Stanford	-	-	-
Texas Austin	-	1	1
Texas A&M	1	-	1
UCLA	-	1	1
UCSB	-	-	3
Wisconsin	-	1	1
	2	**8**	**23**

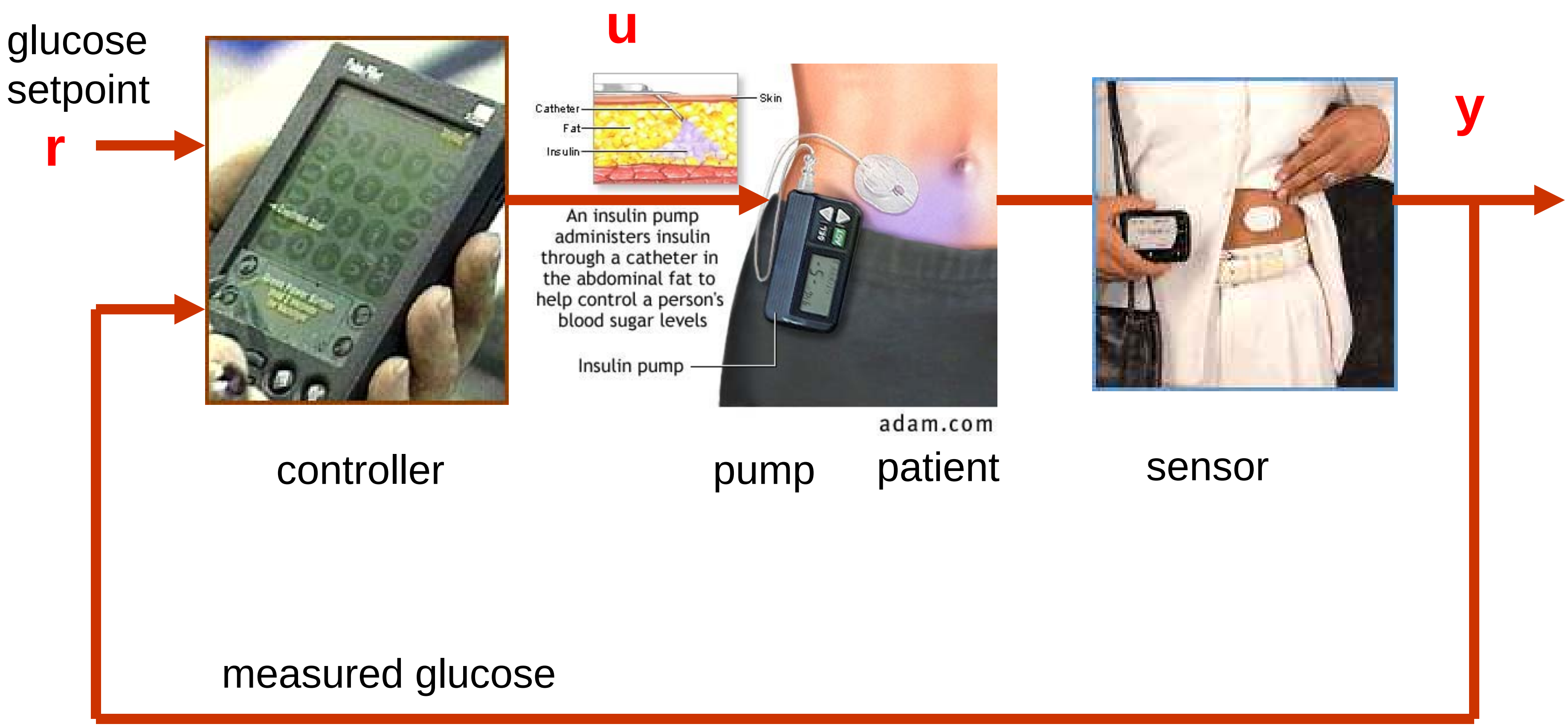
70% have at
Least one PSE faculty

Source: Ignacio Grossman

Incorporation of Biological Content in Process Control

- Modest amount of biological examples in latest control textbooks
- Already occurring in control courses at various universities
- State space emphasis (vs. Laplace transforms)
- Some topics in traditional process control course not covered
- Prototypical examples: yeast fermentor, insulin-dependent diabetic patient

Closed-loop Artificial Pancreas



New ABET Criteria(2007) state that graduates must have

- Thorough grounding in the basic sciences including chemistry, physics and biology, appropriate to the objectives of the program, and
- Sufficient knowledge in the application of these basic sciences to enable graduates to design, analyze, and control complex physical, chemical and biological processes, *as appropriate to the objectives of the program*

Students Have Changed: The New Digital Generation

- Lives with pervasive microprocessors and telecommunications (e.g., cell phones)
- Napster, Playstation, Pokemon, Facebook
- Demands computer interaction, plug and play
- Learns through experimentation, group interaction, intuition
- Focuses on future practical goals

Observations by a Faculty Curmudgeon

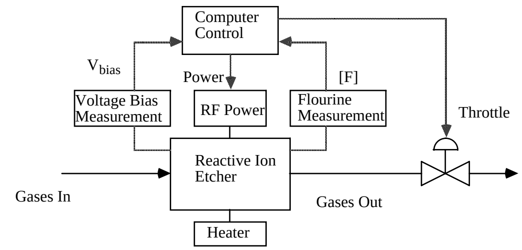
Today's students

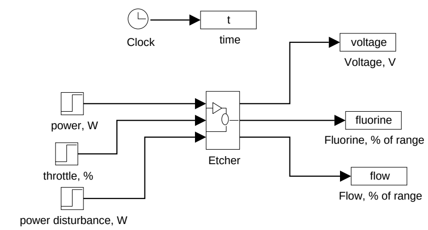
- Are an impatient culture
- Prefer sound-bite answers
- Do not want to engage in a methodical analysis
- Do not enjoy deriving equations
- Say "don't tell me why, tell me how"

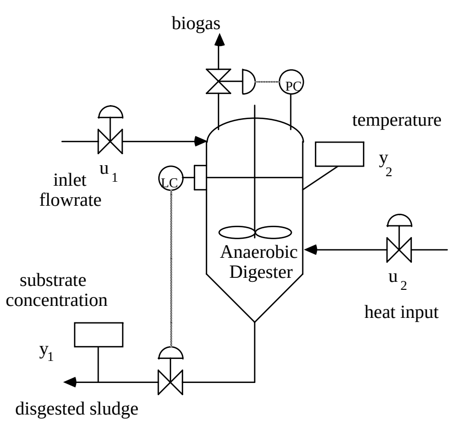
Case Study Projects

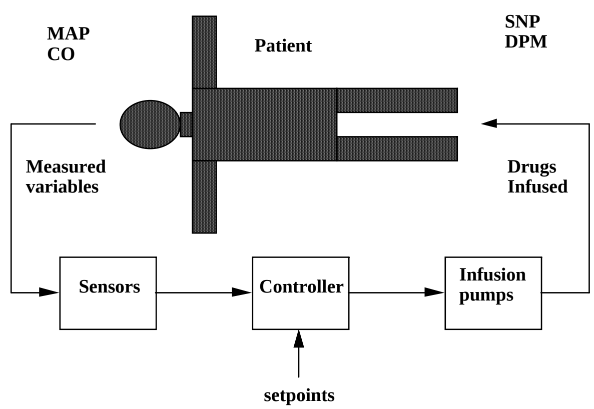
MIMO Control

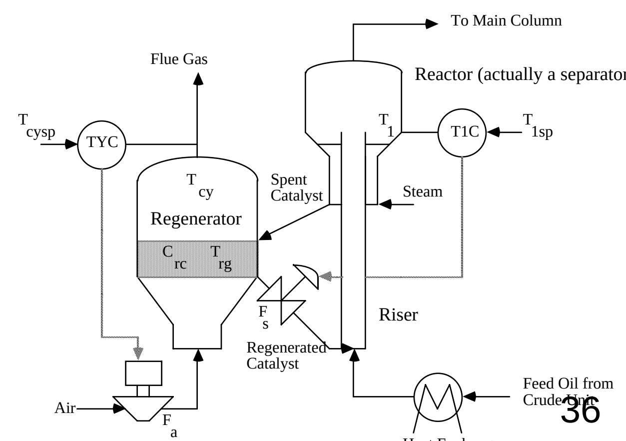
- Final 1/3 of Course
- Choice of Projects
  - Reactive Ion Etcher
  - Lime Kiln
  - Fluidized Catalytic Cracking (FCCU)
  - Anaerobic Sludge Digester
  - Drug Infusion Control (Critical Care)
- Different Advisor (Instructor/TA/RA) for Each Project
- Lit. Review, Model Develop, SISO, MIMO, Written Reports & Final Pres.











Conclusions and Recommendations

1. De-emphasize frequency response but keep Laplace transforms
2. Reduce coverage of multiple approaches for PID controller tuning
3. Increase use of simulation in sophomore and junior chemical engineering courses, so students are well-prepared for dynamic simulation when they take the control course. Use more dynamic simulation in the capstone design and operations course

4. Introduce a number of short laboratory experiences that allow students to collect actual dynamic data, analyze the data, and use a controller to influence the behavior (as part of the process control course)
5. Use case studies to show how process control can be employed to solve real engineering problems. This will help in introducing non-traditional area such as biotechnology and nanotechnology into the control course