CEE chemical engineering education

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CHEMICAL ENGINEERING DIVISION OF AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Bill Baasel

of
Ohio University

AND ChE AT THE
UNIVERSITY OF TEXAS
AT AUSTIN

CEE

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THE UNIVERSITY OF

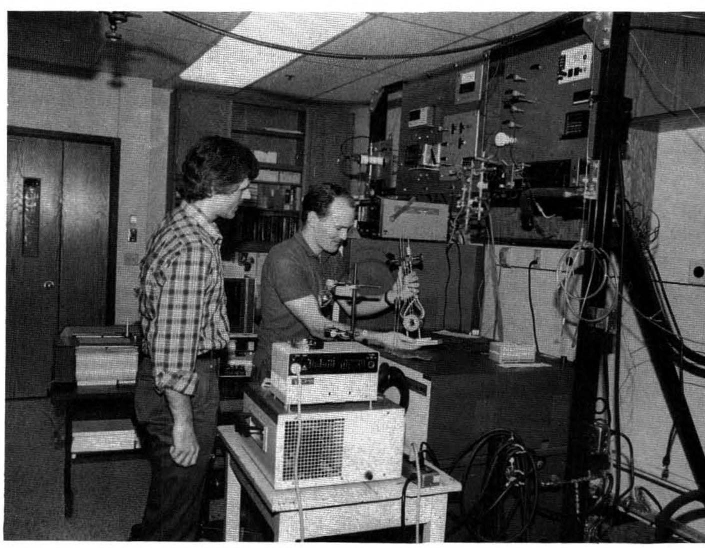
ChE FACULTY
University of Texas
Austin, TX 78712

The University of Texas at Austin, established in 1883, is a major research and teaching institution. It is the largest member of the University of Texas system, which consists of seven general academic institutions and six health science centers. It has grown from one building, two departments, eight faculty members, and 221 students on a forty-acre tract, to a campus of more than three hundred acres with more than 110 buildings. The enrollment is over forty-seven thousand.

The Gulf Coast is a major center of petrochemical activity and a large portion of the nation's chemicals and polymers are produced in this region. During the past fifty years the University of Texas at Austin has played a key role in training the chemical engineers who provide technical leadership in operation, research, and development of these industries.

A department of industrial chemistry was first established at the University of Texas in 1917 as a division of the Department of Chemistry. Chemical engineering degrees were first awarded in 1919. The chemical engineering program in its early years was embodied by the Bureau of Industrial Chemistry and was directed by Dr. E. P. Schoch, who served as its only permanent faculty member for almost twenty years. In 1938 chemical engineering was established as a full department in the College of Engineering. Since then dramatic changes have occurred in chemical engineering education, in the department, and in the profession. Throughout this period the University of Texas has taken a leadership position, graduating over 3000 BS, 700 MS, and 250 PhD's. Over 250 of our graduates have become president or vice-president of their respective companies, and UT-Austin ranks in the top ten chemical engineering departments in terms of number of graduates cited in *Who's Who in Engineering*.

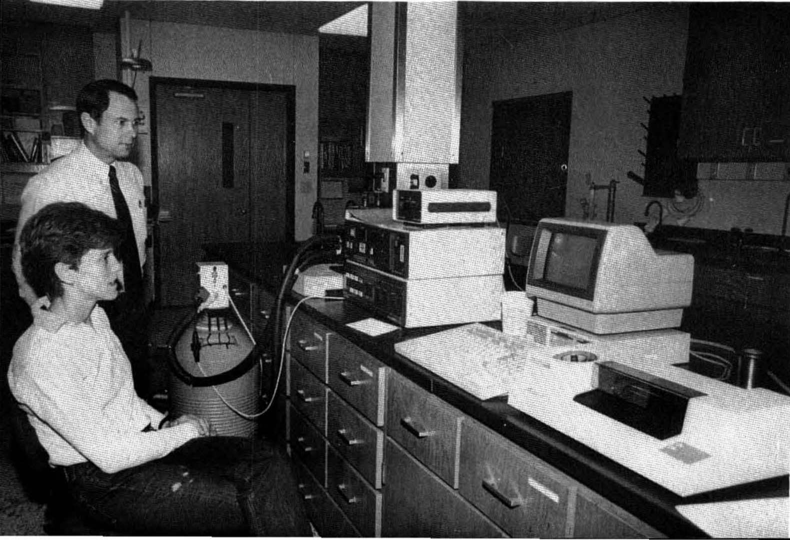
Our department has historically been strongly associated with the hydrocarbon processing industry. Retired faculty Cunningham, Hougen and McKetta made numerous contributions in this area. Beginning



John G. Ekerdt and Clark Williams prepare for an in situ infrared study of alkane activation catalysis.

in the 1960's, the department added faculty interested in polymers, biomedical engineering, materials, process control, and other diversified topics. Today the faculty have research expertise that represents the traditional as well as the emerging areas in chemical

Donald R. Paul and Pamela Tucker following an experiment on an automated thermal mechanical analyzer



TEXAS AT AUSTIN

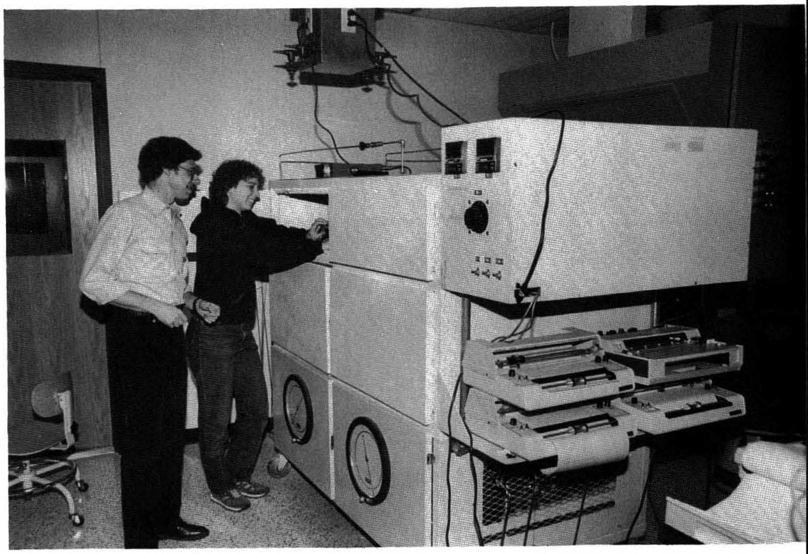
Chemical and Petroleum Engineering Building

engineering. The research program is currenly PhD-dominated, with more than 80% of its 120 graduate students pursuing the PhD.

As the engineering profession changes and adapts to the needs of the 1990's, so too must engineering education. We have continued to be a leader in curriculum development. Early in 1984, the department coordinated a zero-based study by a group of industrial leaders on the requirements for undergraduate chemical engineering education. The study resulted in a report by the Septenary Committee*, "Chemical Engineering Education for the Future," that was disseminated to chemical engineering educators and was later published by *Chemical Engineering Progress* [1]. This study proposed a framework for the future growth and development of chemical engineering education. Our department has adopted many of the proposals.

FACILITIES

We are fortunate to have outstanding physical facilities. In January, 1986, we moved into a new building with over 90,000 net ft^2 for the Chemical Engineering Department. Our half of this building includes fifty state-of-the-art graduate research laboratories with the latest safety devices and utility support, three large laboratories supporting our undergraduate teaching activities, a polymer processing laboratory, student study facilities, a large tutoring area, modern classrooms, a terminal and personal computer room for student use, a graduate student shop, and a student reference room. We also have research space available in the new Center for Energy Studies building at the Balcones Research Center, which was completed in 1985 and is located eight miles from the main campus. The larger scale equipment involving advanced separation science is located at the Balcones site. Over $6 million of new equipment for the two facilities has been obtained from various sources in the last two years.



William J. Koros and Susan Jordan mount a membrane for gas permeation testing

Our unit operation laboratory involves a computer controlled distillation system based around a Honeywell TDC 3000 computer control system. Other systems used for process control include a Fisher Controls PROVOX unit and several IBM PC's. A variety of other up-to-date experiments, such as a reverse osmosis membrane unit, provides the undergraduate student with an appreciation of current practices in

*This title was chosen because our department was in its seventh decade as a chemical engineering program.

. . . in 1984 the department coordinated a zero-based study by a group of industrial leaders on the requirements for undergraduate ChE education [which] resulted in a report by the Septenary Committee, "Chemical Engineering Education for the Future."

chemical engineering as carried out in modern industrial environments.

The polymer processing laboratory is used in supervised graduate and undergraduate teaching and in graduate research. This laboratory includes extruders with coextrusion capabilities, reaction and injection molding equipment, two roll mills, a Brabender system, and various supporting analytical equipment, all of which provide an excellent cross section of equipment currently used in polymer processing applications.

Support facilities on our campus are also quite impressive. The library system houses more than 5.5 million volumes, ranking it among the top seven academic libraries in the U.S. The University of Texas has always taken an aggressive position in making the latest computational facilities available for teaching and research. Such facilities include a Dual Cyber 170/750, IBM 3081 and 4341, VAX 780's, and a supercomputer (Cray X-MP/24). We also have over ninety microcomputers in the ChE building used for educational and research purposes; a substantial portion of these is connected to the main university computers via a network.

FACULTY

The faculty at UT-Austin have fostered high standards for scholarly activities as well as for professional leadership. Productivity is at an all-time high. Last year our faculty wrote over 100 journal articles and gave 80 oral presentations. Textbook and professional book writing continue to be important traditions for the department, with two major textbooks in press. Three journals are now edited in the department, the newest addition being *I&EC Research*, edited by D. R. Paul. We have three members of NAE, and UT faculty have held important offices and received numerous awards from AIChE, ACS, ASEE, and other professional organizations.

The faculty has a broad range of research interests covering essentially all of the traditional as well as the emerging areas in chemical engineering. These interests are reflected in the research projects undertaken by our graduate students and in the under-

TABLE 1
Faculty Research Interests

Joel W. Barlow (PhD, Wisconsin)
polymer properties, polymer thermodynamics, reaction injection molding

James R. Brock (PhD, Wisconsin)
aerosol physics and chemistry, air pollution science, multiphase systems

Thomas F. Edgar (PhD, Princeton)
mathematical modeling, process control, computer applications, coal combustion

John G. Ekerdt (PhD Cal-Berkeley)
catalysis, reaction mechanisms and kinetics, metallo-organic chemical vapor deposition

James R. Fair (PhD, Texas)
process design and development, separation processes, distillation

George Georgiou (PhD, Cornell)
protein engineering, fermentation, genetic engineering technology

David M. Himmelblau (PhD, Washington)
optimization, process simulation, fault detection and diagnosis

Jeffrey A. Hubbell (PhD, Rice)
thrombosis, biomedical and biochemical engineering

Keith P. Johnston (PhD, Illinois)
molecular thermodynamics, applied statistical mechanics, separation processes

William J. Koros (PhD, Texas)
membrane science, polymer thermodynamics

Douglas R. Lloyd (PhD, Waterloo)
membrane science, polymer properties

Donald R. Paul (PhD, Wisconsin)
transport in polymers, polymer blends, polymer properties, polymer processing, membranes

Robert P. Popovich (PhD, Washington)
artificial internal organs, biomedical engineering

Howard F. Rase (PhD, Wisconsin)
catalysis, reaction kinetics, enzyme catalysis, product development

James B. Rawlings (PhD, Wisconsin)
process control, process simulation, computer applications

Gary T. Rochelle (PhD, Cal-Berkeley)
separation processes, stack gas desulfurization, aqueous mass transfer, acid gas treatment

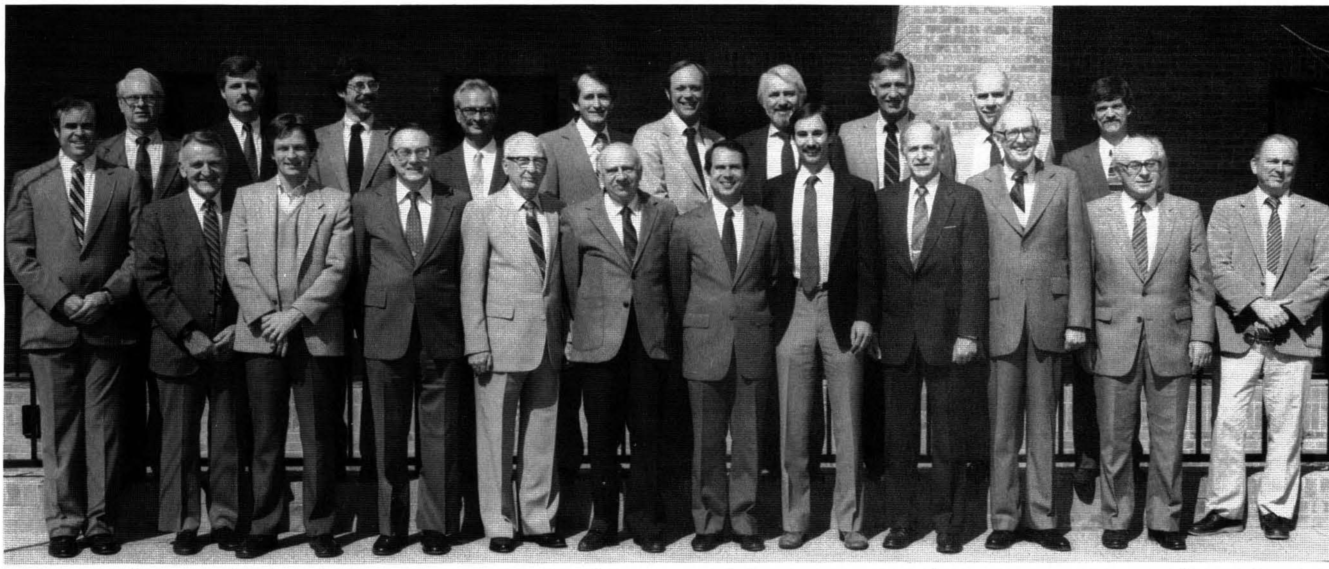
Robert S. Schechter (PhD, Minnesota)
colloid and surface science, enhanced oil recovery, adsorption, chromatography

Hugo Steinfink (PhD, Brooklyn Polytechnic)
crystal structure and properties, materials science, transition metal oxides and chalcogenides

James E. Stice (PhD, Illinois Inst. Technology)
chemical engineering education, process control

Isaac Trachtenberg (PhD, Louisiana State)
microelectronics processing, electrochemistry, materials science, renewable energy conversion

Eugene H. Wissler (PhD, Minnesota)
heat transfer, human performance under environmental stress, mathematical simulation



Front row, left to right; T. Edgar, J. McKetta. D. Lloyd, D. Himmelblau, W. Cunningham, H. Grove, D. Paul, K. Johnston, H. Rase, J. Fair, H. Steinfink, J. Brock. Back row, left right; 1. Trachtenberg, J. Ekerdt, W. Koros, N. McDuffie, G. Rochelle, J. Barlow, R. Popovich, H. Keskkula, E. Wissler, J. Rawlings.

graduate and graduate courses. There are presently twenty-three faculty on our teaching staff. The research interests of the faculty are summarized in Table 1. During the past two years the department has had a total of $7.6 million in research funding, much of it from the private sector. The research effort in emerging areas of chemical engineering has been strengthened by the "high-tech" environment of Austin, which has grown into a major city of over 400,000 residents. Faculty are interacting with companies on the subjects of electronic materials (IBM, Texas Instruments, Motorola, AMD, MCC), specialty materials (3M, IBM), process control (Fisher Controls), and a number of local biotechnology firms are now starting to appear.

In addition to individual research efforts, a number of collaborative efforts, both among chemical engineering faculty and faculty in other departments, have evolved in recent years to address new and complicated areas. The synergism that results from collaboration leads to an intellectually stimulating environment for the graduate students. Examples of such groups are:

Polymers and Advanced Materials • Professors **Barlow, Koros, Lloyd, Paul** and **Steinfink** supervise approximately forty graduate students, postdoctoral fellows, and other researchers who are associated with polymer research within the department. Cooperative programs in the areas of blends and transport phenomena in polymers (membranes and barriers) typify the activities of this group. Materials research also includes studies of synthesis and property evaluation of transition metal sulfides and oxysulfides.

Microelectronics Processing • This group includes Professors **Barlow, Brock, Edgar** (our current chairman), **Ekerdt** and **Trachtenberg** (on assignment from Texas Instruments). Research in this area was initiated within the past two years and already has seventeen graduate students and postdoctoral fellows associated with it. A variety of projects ranging from plasma and aerosol etching, metallo-organic chemical vapor deposition, control of etching processes, and microelectronics chip encapsulation using reaction injection molding are the focus of this group's interest.

Separation Processes • In 1984 the Center for Energy Studies and the Bureau of Engineering Research, with the support of the chemical engineering and chemistry departments established the Separations Research Program (SRP) to develop advanced approaches for current and evolving separation processes [2]. This cooperative industry-university program does fundamental research of interest to chemical, biotechnological, petroleum refining, gas processing, pharmaceutical, and food companies. The SRP involves six chemical engineering faculty: Professors **Fair, Johnston, Koros, Lloyd, Paul** and **Rochelle.** The program has achieved immense success with a total of thirty-seven industrial sponsors. Specific areas of technology now being studied by the program include distillation, adsorptive/chromatographic separations, liquid-liquid extraction, supercritical extraction, membrane separations, electric-based separations, and separations with chemical reactions.

Control and Optimization • Professors **Edgar, Himmelblau** and **Rawlings** work with over twenty graduate students and postdoctoral associates in this area. The group's interests include development of dynamic models for a variety of physical systems, algorithms for control of nonlinear multivariable systems, adaptive control strategies, expert systems, distributed parameter processes, multiple objective optimization, and fault diagnosis and detection in chemical plants.

Biochemical and Biomedical Engineering • Bioengineering research is presently being carried out by Professors **Georgiou, Hubbell, Popovich, Rase** and **Wissler** and represents our newest area of emphasis. Current projects include design and scale-up of enzyme production, detoxification of insecticide residues, synthesis of recombinant proteins, investigation of the interaction of blood cells with various natural and artificial materials, mammalian tissue culture processing, mass transfer in artificial kidneys and hemodialyzers, the development of continuous dialysis techniques, and mathematical simulation of biothermal systems.

In addition, we have ongoing research in surface science (Professor Schechter) and educational methods (Professor Stice).

THE UNDERGRADUATE PROGRAM

Our undergraduate program, like most, has changed considerably over the past fifty years in both content and total hours. Throughout this evolutionary process we have remained firmly committed to ensuring that our students are well-grounded in science and engineering fundamentals. The rapid explosion of information and the introduction of new technology areas into chemical engineering in recent years have strained curriculum content. We have recognized that we cannot teach, or expect our students to learn, everything. Science and engineering fundamentals remain unchanged; it is their application and the technologies to which they are applied that change. We have attempted to integrate computing and design throughout the curriculum, introducing students to flowsheeting programs as early as the junior year. A ChE computer applications course is taught in the second semester of the sophomore year to initiate the computational experience. The students are introduced to both mainframe and microcomputer usage.

We have recognized that we cannot teach . . . everything. Science and engineering fundamentals remain unchanged; it is their application and the technologies that change. We have attempted to integrate computing and design throughout the curriculum.

Because "change" is going to be the watchword of chemical engineering, we require a core set of courses in science, mathematics and engineering that teaches the fundamentals essential for all chemical engineering undergraduates. Students, through a block of "option area" courses, are then free to choose the best way to develop their talents or to specialize in an area they feel will offer the most career opportunities. This arrangement affords students considerable flexibility to adapt to new trends.

Each student must complete fifteen semester hours of option courses. The option courses include courses in chemical engineering as well as other departments. The eight option areas are: process analysis and control, polymer engineering, electronic materials engineering, environmental engineering, process engineering, product engineering, biomedical engineering and premedical/predental program, and biotechnology. In support of the option program we teach an unusually large number of undergraduate electives in chemical engineering, including process simulation, optimization, process analysis, polymer processing, polymer engineering, process economics, microelectronics processing, biochemical and biomedical engineering, industrial chemistry, and environmental protection.

Our entering freshmen are academically better prepared than their predecessors; the top 30% (about forty to fifty students) have SAT scores averaging over 1350. In connection with UT-Austin's effort to attract National Merit Scholars (now second only to Harvard) the department initiated an Honors Program for talented students. We currently offer one honors section of about fifteen to twenty students for six core chemical engineering courses, which meshes with the already established Freshman Engineering Honors Program. The Honors Program has proven instrumental in challenging our best students and in retaining them in chemical engineering. It also serves as an effective way to channel these students into graduate programs. Because we offer required courses each semester, the average class size across the department is about twenty-five—quite a departure from the expected number at most large state-sponsored schools. Teaching effectiveness is an important concern in the department, and the fact that our department has won more than its proportional fraction of the College of Engineering teaching awards is testimony to that fact.

Graduates from the University of Texas program have traditionally been actively sought by petroleum and chemical companies. Recently, however, microelectronics companies have joined in the competition for our graduates. Roughly 25% of our graduates were hired in this fast-growing new area over the past few years. In the same period, nearly 20% of our graduates decided to pursue advanced degrees in either chemical engineering, medicine, or business.

GRADUATE PROGRAM

The University of Texas has an aggressive recruiting program to attract outstanding candidates for advanced study to Austin and our success is borne out by statistics that show the GPA of entering students is around 3.6/4.0. We have students from 27 states in our group of 120 graduate students (only 4% are from UT) and international students make up 25% of our current graduate student body. At least 75% of the incoming class specify that they want to study for a PhD; the remainder work for an MS, although some of these students later decide to go on for the PhD.

For either degree, independent scholarship is emphasized and presentations of research results at national technical meetings is stressed. Every graduate student gives an average of two formal oral presentations per year, many at industrial sponsor review meetings.

A Master's candidate is required to take eight courses, at least four of which must be in chemical engineering, in addition to completing the thesis research. Most students are able to complete the course work and submit a thesis within 15 to 18 months.

While the PhD program is intended to be flexible and has no specific course requirements, a typical PhD course of study would involve completion of approximately twelve courses, including core courses in the traditional thermodynamics, kinetics and transport phenomena areas. An active seminar program involving outside visitors supplements the scheduled courses. A prospective PhD student is not required to complete an MS degree first. A written qualifying exam on the traditional undergraduate topics must be passed along with demonstration of reading competency in a foreign language prior to acceptance into candidacy. A preliminary oral examination in the area selected for the dissertation research is also taken within the first two years in residency. Most students entering with a BS in chemical engineering take an average of 4.5 years to earn their PhD.

Doctoral student support can be either a fellowship or a research assistantship. Some students supplement their income by serving as teaching assistants beyond the one semester that is expected of all our PhD candidates. Supervisor selection is done within the first six weeks of the semester following presentations by all of our faculty and individual visits with those faculty who have projects of interest. Students select three possible supervisors/research projects; over 90% receive their first choice.

Over the last two years our department has ranked fourth in PhD production, with thirty-three degrees awarded. We expect to award fifteen to twenty PhD's annually for the foreseeable future. Our PhD's are finding employment in both academic and industrial positions.

REFERENCES

1. Septenary Committee, Univ. of Texas, *Chem. Eng. Prog.*, **81**, 9 (1985).
2. Fair, J. R., *Chem. Eng. Educ.*, Fall, 190 (1984). □

Editorial

A DEPARTMENT THAT SERVES

In previous editorials (*CEE* Winter 1986, page 3, and Spring 1986, page 100) we indicated that the goal of a chemical engineering department should not be to compete with other departments for high ratings or prestige, but instead should be to serve, in its own unique way, its students, the profession, the state, the nation, or in general, society as a whole. In our Fall issue we indicated that the goal of the individual professor likewise should not be to gain personal recognition but to serve society in his own unique way. We illustrated this with the life of Olaf Hougen of the University of Wisconsin. In this issue we feature the University of Texas, a prestigious department that exemplifies the ideal of service.

In 1984 the chemical engineering department at the University of Texas coordinated a zero-based study by a group of academic and industrial leaders on the requirements for undergraduate chemical engineering education. The study resulted in a report by the Septenary Committee: "Chemical Engineering Education for the Future."

The study proposed "a framework for the future role and development of chemical engineering education." Instead of an arbitrary, "How can we improve our rating?" the Texas department in effect asked: "How can we, as a department in a state university, better serve our students, our profession, and society as a whole?"

In trying to answer that question, the department did not merely adopt the program of the "average" department, or even that of other top-rated departments. Instead its Septenary Committee set out on its own to plan for the chemical engineering of the future—a future that is characterized by rapid change. As the committee, in fact, said, "Change appears to be the only certainty." They agreed that chemical engineering education must continue to prepare its graduates for change by emphasizing—even more than it has in the past—fundamental science and mathematics and "the ability to apply the fundamentals in diverse, complex, real world problem solving." They also called for "major improvement in teaching methods, including the extensive rewriting of textbooks."

Although one may not agree with all the conclusions of this committee, the department should be commended for its initiative, for its approach, and for its service to the profession.

Ray Fahien, Editor

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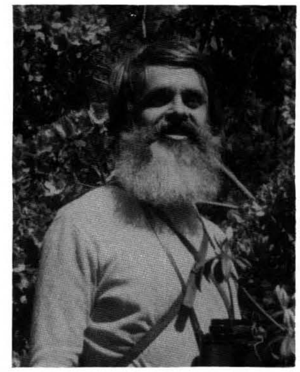

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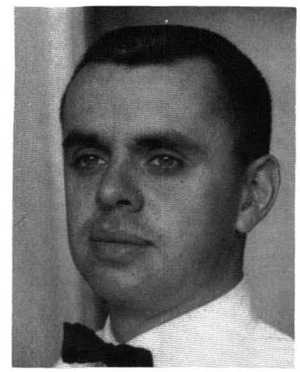

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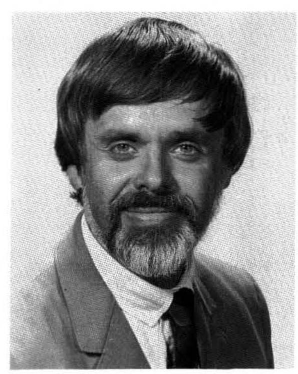

(and the medium)

of

Bill Baasel

THE FRATERNITY OF chemical engineering professors is not a very large one and many of us know, or have met, a sizable portion of the group. For those who have not met William Baasel, an article is a poor substitute but, short of stapling WDB clones into each issue of this journal, it will have to do until a real meeting can be made.

Bill has been at Ohio University since 1962, serving the students, the department and his profession in a variety of ways. As we will see, Bill's interests are eclectic (as is his taste in hats), and writing about him poses an interesting puzzle on exactly where to begin. So, following the White King's advice, let us begin at the beginning and proceed to the end, and then stop.

Bill was born (1932) and raised in Chicago, where he attended public schools through grammar school. He then went to North Park Academy for his high school years. After graduation from high school he went North, all the way to Evanston, where he did his BS and MS work at Northwestern University. His co-oping at Northwestern was at the Armour Union Stockyards. (Bill always points out that he worked at a pilot plant for amines and quaternary ammonium salts and vigorously denies he used a sledgehammer to kill cows.) From there he went to Cornell University, where he worked with J. C. Smith on a heat and mass transfer problem. While at Cornell he met Patricia Bradfield, whose father was chairman of Cornell's agronomy department and who was much involved in the "Green Revolution." While Pat clearly was the *main* attraction, her family's involvement in international affairs was a prelude of things to come. Pat was a student in child development and she and Bill were married in the summer of 1960. They spent their leisure time in the Outing Club, the Choral Union Club, and folk-dancing. (Bill still claims that the most perfect art-form is dance.)

. . . in 1965 he took advantage of . . . a Ford Foundation Residency in Engineering Practice at Dow Chemical. This experience convinced him that the teaching of design needed to be changed to better conform to industrial practice.

In 1959, still ABD, Bill went to Clemson, finishing his dissertation in the summers. In 1962 he came to Ohio University. The department at that time was about five years old, so Bill has had an opportunity to help establish its direction and character.

For the next three years, Bill taught the various required undergraduate and graduate courses (the

A little later on, Bill spent some time at MIT learning about self-paced learning (Keller) courses. His enthusiasm for the method led to the department committing the senior process control course to the technique with Bill as instructor. He taught the course for several years . . .

graduate work started a year later), but in 1965 he decided to take advantage of an opportunity to do a Ford Foundation Residency in Engineering Practice at Dow Chemical in Midland, Michigan. This experience convinced him that the teaching of design needed to be changed to better conform to industrial practice. He used his time at Dow to learn how to best change the design courses when he returned to Ohio. He found that his involvement with design people, and later his interaction with construction people, was most helpful to him in this respect.

His serious involvement with design led Bill into teaching the design courses in the curriculum and later, on a sabbatical in 1969, to use his industrial and academic experiences to create the shape of his book *Preliminary Plant Design*, published by Elsevier in 1976. (That book is now going into a revised second edition, and Bill says the manuscript is presently in the hands of the publisher.)

Meanwhile, back at the academic ranch, Bill became much involved with AAUP, ASEE, Sigma Xi and others, filling positions of leadership and office. The late 60's and early 70's were perilous times at OU, and the clash of competing ideologies both in the student body and in the academic structures led to very intense and emotional confrontations. Bill tried through all this to be an agent of constructive debate and peace and, his colleagues believe, he succeeded in that task. During that time, while Bill served as division chairman, an ASEE regional meeting was held at OU. Also during that time, OU's President held an extraordinary summer seminar (of which Bill was an important part) after student disturbances forced the premature closing of the University in 1970. Dealing simultaneously with professional matters, academic matters, and matters of governance made for busy times for Bill (and others). In the midst of this, Pat completed her PhD work in psychology and intensified her career work.

In the late 60's and early 70's, Bill wore an aggressive crewcut but his political and social views were more allied with the "long-hairs." The sight of Bill strolling around campus talking with agitated students, who at first sight had made assumptions (erroneous) about him, was interesting. In later years, Bill grew a lot of hair, including an "Old Man of the Mountains" beard. (As his colleagues, we are sometimes puzzled by his "out-of-phase" behavior. Maybe it comes from teaching too many control courses!)

Bill and one of his famous chapeaus, both on location in the Far East.

A little later on, Bill spent some time at MIT learning about self-paced learning (Keller) courses. His enthusiasm for the method led to the department committing the senior process control course to the technique with Bill as instructor. He taught the course for several years and found, as others have, that the method takes a lot of time. He carried on, however, until a new faculty member in the department took over the course, when it reverted to the more traditional form. The experience was good for all, although some colleagues were dubious of a process in which the predominate grade was an "A," even though Bill insisted that the grade was earned with sweat and tears. The students did say, as a matter of fact, that they had worked very hard and had learned a great deal in the course.

In 1978, Bill took a leave and spent the next two years with EPA in North Carolina. For some years he had been active in teaching campus-wide courses in environmental control, zero population growth, and other such things, and this seemed like a good opportunity to expand and intensify that knowledge. After his return to OU, he continued the relationship with EPA and finally wrote a book on environmental assessment, *Economic Methods for Multi-Pollutant Analysis and Evaluation*, published by Marcel Dekker in 1985.

The EPA experience also led to Bill's increasing involvement in Ohio's serious concern about acid rain and polycyclic organics. His computer experience (he had, among other things, taught the first FORTRAN course on campus and had served as acting director of the computer center many years ago) led him to create a program which computes costs and the implications of putting scrubbers on various plants and how these devices affect air quality and economics. Interestingly, some of Bill's studies caused him to form more cautious conclusions than would be expected from his long-standing social stance. He has continued this interest in modeling and, even though the EPA has not been able to implement his views, he still believes that the methodology is valid. The ability to predict environmental effects, even for substances for which no standards exist, would add to the rational planning process for industry and government.

In recent years, Bill has been an instructor in the college's freshman introductory courses. As these courses have evolved (or devolved, depending on one's point of view), Bill has been an active source of ideas. Thus, we see that over the years, and in any given year, Bill's teaching has ranged from entering freshmen to senior graduate students, a testimony to his deep concern for education and the academic life. This past year he took his "Flying Circus of Chemical Engineering" to Malaysia for a quarter, teaching FORTRAN and introduction to engineering at Petaling Jaya Community College, near Kuala Lumpur. He also made separate trips to the People's Republic of China, Singapore, Japan and Thailand. (You can imagine the sorts of hats he collected on these various trips!)

Again, for many years, teaching the senior design course has also led Bill to be official guide and tour operator for the senior plant trip. Generally, the university bus is rented for a few days and Bill takes the seniors on an intense visitation of a number of plants, including one operating plant of the type the students had to design that year. Sometimes the trip would include other components, as in 1985 when the entire senior class was taken to the national AIChE meeting in Chicago before launching into the plant trips proper. This year, the small senior class didn't need the massive bus, so Bill took them all in a large van and served as the driver as well. Over the years, this plant trip has been a good experience for students and, although other faculty members occasionally go along, Bill has had the major responsibility. He has become an expert at mediating incipient fistfights or modifying occasional raucous behavior at motels.

In their non-university life, Bill and Pat have retained their interest in folk-dancing and, in addition, have become ski enthusiasts, traveling wherever the snow is when they can. They have two adopted children, David and Nancy, and this has led to Pat's professional work in the psychology of adoption. Daniel, their younger son, is active in hockey, and that puts Bill at the rink as a spectator.

Bill's present task, in addition to teaching and all his other activities, is to look at the undergraduate curriculum and lead the discussion of what changes, substitutions, directions, and emphases should be implemented to keep us where we ought to be. His wide-ranging interests and professional involvements made him well-suited for this important work. (We have already made the laboratory hard hats come in green and white, the university colors, partly to keep up with Bill's sartorial eccentricities.) ☐

REQUEST FOR FALL ISSUE PAPERS

Each year CHEMICAL ENGINEERING EDUCATION publishes a special Fall issue devoted to graduate education. This issue consists 1) of articles on graduate courses and research, written by professors at various universities, and 2) of announcements placed by ChE departments describing their graduate programs. Anyone interested in contributing to the editorial content of the Fall 1987 issue should write the editor, indicating the subject of the contribution and the tentative date it can be submitted. Deadline is June 1st.

ChE book reviews

ENGINEERING PROPERTIES OF FOODS

M. A. Rao and S. S. H. Rizvi, Editors
Marcel Dekker, Inc., New York, 1986. 398 pages, $69.95

Reviewed by
C. Judson King
University of California, Berkeley

There is a general lack of compiled data on physical properties of food materials, as relates to various food-processing operations. Thus this book addresses an important need. The properties covered in chapters by different authors are rheological properties of fluid (M. A. Rao) and solid foods (V. N. M. Rao and G. E. Skinner), thermal (V. E. Sweat), mass-transfer (G. D. Saravacos), and electrical (R. E. Mudgett) properties, thermodynamic properties relating to dehydration (S. S. H. Rizvi), and properties relating to reverse osmosis and ultrafiltration (T. Matsuura and S. Sourirajan). The book represents a substantial effort on the part of the authors and is generally well edited.

As is characteristic of the food engineering field, the discussions do not presume or build upon prior knowledge of heat, mass, and momentum transfer and thermodynamics. Instead, an effort is made to start with the necessary basics and build forward. The difficulty of doing this is particularly evident in the chapter on mass-transfer properties where the forty-three pages treat diffusion, mass-transfer coefficients, phase equilibria, interphase mass transfer, operating diagrams, crystallization, and the various pertinent properties of foods. For the chemical engineer, the space occupied by the survey of basics in the various chapters could much more effectively have been devoted to the food properties themselves.

Given the title of the book, it is surprising that there are not more extensive tables and figures reporting actual food properties. Much more data exist at various places in the literature. In some cases (enthalpies, thermal conductivities) there are substantial listings of data, but in most other cases (*e.g.*, sorption isotherms) hardly any actual data or references to compilations of data are reported.

The chapter on membrane processes focuses less specifically on foods than do the other chapters and stands as a valuable general-purpose review of separation properties of membrane materials. □

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ChE lecture

THE INDUSTRIALIZATION OF A GRADUATE

METHODS FOR ENGINEERING EDUCATION

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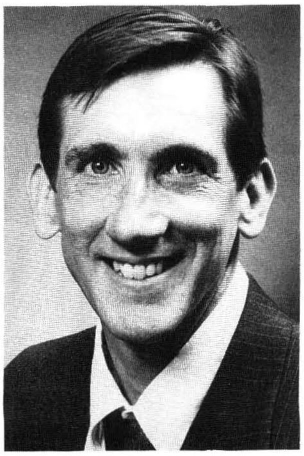
THIS IS THE SECOND of two articles* on the industrialization process. In the first article the industrialization process was defined as a required change in perspective as a person moves from student to producer. This change occurs during the first two years of an employee's career and has been called "learning the ropes." In recruiting interviews, industry looks for "fast starters" who will "hit the ground running"; by these terms they mean people who have the extra-technical awareness that will make them effective within the human environment and business priorities. In the traditional academic environment a student is not exposed to industrial experiences. Instead, he is programmed narrowly and technically to work in isolation and graduates with neither a make-it-happen attitude nor an appreciation for the complexity of life. In this article, I will discuss some teaching methods which I believe can broaden student awareness of the importance of, and skills required in, effective human interactions. The methods can also bring the typical open-ended, incompletely defined industrial problem scope into the classroom and, therefore, can accelerate the industrialization process and create faster starting, more marketable graduates.



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*See *Chemical Engineering Education*, Vol. 21, No. 1, (Winter 1987), page 18.

EXTRACURRICULAR ACTIVITIES

Each year, student professional organizations and senior seminars generally invite a few engineers from industry to present an industrial technical project. A speaker's reinforcement that academic skills are used in industry can inspire students to view classes with a more serious attitude. I would suggest that such speakers have at least five years of industrial experience and that they be asked to address the non-technical aspects of industrial projects as well as the technical aspects. Further, I would suggest that technical managers be invited to discuss requirements from their perspective of personal effectiveness. Such testimony could enhance the awareness of the business world, develop a student's perceptiveness for the extra-technical demands of employment, and perhaps accelerate the industrialization process.

Student organization activities also provide an opportunity for students to make-things-happen. Student leaders plan, work through details, interface with the university, relate to people, and take ownership of the project in order to move a conceptual idea to a happening. These experiences are important to their professional preparation, and a department's efforts to support such activities should be viewed as important to their service responsibility.

Co-op and summer technical employment can be an excellent awakening for previously book-bound people, and departments should work with industry to encourage these real-life experiences. Whether the job is that of a technician, or an operator, or at an engineering assistant level, the student's experiences with real equipment, business priorities, and people can be important [1].

CLASSROOM EXPERIENCES

Classroom assignments can be modified to simulate practical experience. I make some assignments which are incompletely specified, some which require open-ended design and self-critique, some which require a discussion of aspects (such as environmental impact, safety, labor, and controllability), and some which require students to use last semester's course notes. I am honest with the students and preview these aspects in an attempt to prevent frustration. Pedagogically, I recommend an openly "tricky" approach and even give erroneous or conflicting data and require the student to be critical of his own work and of the "givens." I occasionally give the students data which incorporate nonideal conditions and ask them to postulate causes for the unexpected result and to describe experiments to discriminate the cause. (For example, contrived shell-and-tube condenser performance data could indicate that the "U_oA_o" is 40% lower than expected. Causes might include condensate puddling, fouling, or plugged tubes, and each has telltale consequences.) Analysis of industrial operations are full of assumptions, and the answer is neither unique nor known. Students should be prepared for such situations throughout their education. Open-ended problems and critical thinking should not be reserved for a brief senior design experience. Assignments with such complications, however, can only be given after the student has practiced on idealized problems and understands the technology basics.

Student feedback to such realistic "trickery" in class assignments is mixed. On the one hand, they appreciate the additional perspectives gained from such an approach; but on the other hand, they would rather have the more directed and explicit traditional homework problem—it requires less time. A student's false starts associated with incomplete or conflicting specifications, the uncertainty in completing problem specifications, the formulation and testing of postulated causes, and the consideration of auxilliary aspects do take more time. It also requires more of the teacher's time. Although modification of the textbook problems to incorporate trickery is easy, grading requires close attention to the student's often inventive approach as well as a generous amount of subjectivity. As I interpret the feedback, students especially appreciate comments on their open-ended work, such as, "Yes, with its low thermal conductivity sulfur would make a great pipe insulator. However, wouldn't a fiberglass composite be safer and easier to install?"

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Logically organized, explicitly stated technical analysis, with assumptions acknowledged and defended, and answers whose reported digits and wording reflect the limits of the analysis, are important features toward establishing technical credibility. I require such features in all assignments. With requirements on assignment structure and presentation, the student practices submitting credible work; additionally, I believe that the student's technical grasp is heightened.

R. M. Felder reports on a teaching device which he calls "The Generic Quiz." [2] We professors realize that constructing a final exam is an intensive learning process. Even in outlining the problem one reviews the technology, selects a portion, and incorporates all the necessary assumptions and restrictions into the problem statement. The problem creator must find the givens, not just accept and use them. Occasionally we express humor or relate interest stories in the problem statement. Why should the fun and learning process be reserved for the professor?

The problem statement in Felder's take-home "Generic Quiz" is essentially, "Prepare a final exam and its solution for this course." He previews for the student implicit/explicit, qualitative/quantative and derivation/application formulations. He reports his own pleasure with the results and an almost unanimous student response that the test was challenging, instructive, and enjoyable. I have used the generic homework approach: "Create and solve an original homework problem which incorporates three out of five [listed] skills." I, too, am pleased with student response and believe that the open-ended, often multidisciplinary, creative experience is good for their professional development.

LABORATORY APPROACHES

Opportunities for "trickery" naturally arise in the unit operations lab where data are already real. Fuzz and conflicts do not have to be contrived. A teacher can utilize that fact and not try to make lab data a perfect expression of the idealized classroom theory. Instead, students can be required to find sense among the statistical noise, external systematic effects, and nonidealities.

The unit operations lab also creates a special opportunity to practice the important task of communicating credibility through technical reporting. There are several classes of reports, including academic papers, oral presentations, internal business memos, and project technology summaries. Each report has its own purpose and style. The students would benefit if they were required to practice each style and understand where each would be most effective. A well written report is more credible than a poorly written one which offers the same conclusions.

Finally, the unit operations lab can be a key training ground in several other areas including the statistical treatment of real data, the student's design of the experiment, and his accountability for safety and hygiene. Robert M. Bethea and Elizabeth Orem [3] describe those various lab functions and the integration of technical and non-technical aspects at Texas Tech University. Such an integrated approach accustoms students to professional expectations.

I recommend assigning term papers in technical courses. The breadth of technology is such that only the tip of the iceberg is presented in the lecture and text. From one of twenty or thirty associated topics, small student groups can select and write a paper that could be used to teach their chosen subject.

REPORTS

I recommend assigning term papers in technical courses. The breadth of technology is such that only the tip of the iceberg is presented in the lecture and text. From one of twenty or thirty associated topics, small student groups can select and write a paper that could be used to teach their chosen subject. In such an exercise, the students would see the expanse of information and realize the limits of their own knowledge. They would practice what they will have to do to learn job-specific technology, and they would be required to communicate technology in a logical manner. I have been pleased with the results of this approach, both in my graduate education (Optimization of Engineering Processes, under R. M. Felder at North Carolina State) and in my teaching (Fluid Dynamics, at Texas Tech). Further, rising beyond a learning experience, the presentation of a polished, finished group work is a make-it-happen experience.

My industrial experience has taught me to view my final report as tentative. After being satisfied with organization, impact, and completeness, I'd give the draft to a few people in related departments along with the note, "Please review. Have I overlooked a concern that you might have?" With the frequency of project changes in a business career one is always a novice and can easily miss at least political sensitivities, if not technical aspects. Rather than training students that a report is finished when they are satisfied, I recommend grading it and then saying, "For your second grade, please explain how this impacts on . . .," and fill in some concern about safety, or equipment maintenance, or maybe plant flexibility. Or perhaps, with less structure, requiring students to seek and respond to two reviews of the draft prior to its completion. Where word processors are available to the student, report modification would be easy.

The passive academic reporting style, which emphasizes technology, considerably conflicts with the action-oriented economic-emphasis report desired by engineering supervisors. A caricaturized mind-set of management is, "What's happened?—What's it mean?—What do I have to do about it?—Move on to the next problem." Imagine, with that mind-set, the manager reading a technical report from a young engineer who was coached in the classic academic style of Title, Abstract, Introduction, Theory, . . . and finally Conclusions. Most engineering graduates have industrial careers. I believe that coaching them to write in a business/technical style as opposed to an academic/technical style will be instantly recognized and applauded by industry. Here are my ten rules, often given to new engineering employees, to aid their technical report writing:

1) Address the factors which are important to your audience (not necessarily to you), and do it in your first sentence.
2) Speak in your audience's language. Do not show off your command of jargon.
3) Still in the first sentence, address important associated issues, such as the effect on labor, the environment, startup control, plant flexibility, *etc.*
4) In that first sentence, either clearly direct an action or report on an activity.
5) In the second sentence elaborate, if necessary.
6) Still in the first paragraph, acknowledge assumptions and critique your work and recommendations.
7) Keep the first paragraph within fifty or so words.
8) In moderate detail, in subsequent paragraphs, set the background for the work, summarize the methods, *etc.*
9) For those who wish the delicious details, offer an appendix. If anyone ever reads your appendix it will be to judge your competence. Be sure that the appendix is structured so that your reader is

clearly guided through the calculational procedures. Be sure that assumptions are explicitly stated and defended. Be sure that the number of reported digits does not over or understate the justifiable precision. Be sure that your answer is labeled and contains units.

10) Before issuing your report, incorporate the comments of several reviewers.

The factors mentioned in the first rule, those which are important to a manager, are economics, or employee safety, or product quality, or system reliability or the like. If a professor invents, or allows each student to invent, a business scenario that requires the execution of some class project (a design or computer program), then the student can submit the project in the ten-rule format with an appendix containing the academic details. I believe such practice is good training for the student and require computer projects to be so reported. I am often surprised at how professional the students' reports are.

THE DIRECTION OF HUMANITIES

Students should be encouraged to take those sociology, psychology, history, and philosophy electives which give a perspective on normal adult behavior and an awareness of one's own needs. I emphasize normal adult behavior. Interpersonal relations with disparate personalities are a necessity in industry. A development engineer interacts with a maintenance foreman. A sales engineer wants the production engineer to run a trial. A young engineer wants an older manager to accept a recommendation. All players are normal adults, and the daily effectiveness of an organization depends on the effectiveness of their one-on-one interactions. Technical graduates learn to manipulate data, but they can be unaware and careless of important individual personal needs. Improved interpersonal effectiveness starts with awareness of oneself and includes recognition of other's needs. One can then temporarily adapt behavior to create an effective interaction, to establish credibility, or to make-it-happen.

PROFESSOR'S EXPERIENCE

Practicing engineers assemble technology and make something work, but they are largely taught by academic engineers who, by contrast, do science and publish elegant papers. We academics often admit our lack of industrial design experience and a weakness in providing relevant direction in the senior design course [4, 5]. But our lack of business experience is more extensive than that. One can imagine practicing engineering in the business environment, but without having lived through industrial experiences, a career academic usually cannot relate general business priorities, methods, and approaches to their students. Instead of being trained in the realities of the business environment, students are normally steered toward academic mind-sets. It is not necessary, however, for every professor to have industrial experience. In fact, I would say that it is very important for students to experience the direction, perspective, and skills of more theoretically oriented professors. However, I recommend a blend of each type on a faculty. Felder [4] mentions the benefits to the undergraduate laboratory, to the students' classroom experiences, and to department management of hiring a faculty member with no research interest but with thirty years of industrial experience. Departments which hire engineers to teach can balance the academic and practical perspectives. Grecco [5] suggests that practiced engineers can be hired as adjunct professors if not tenure-track.

CLOSING

In the first article, I described some key industry/academic differences which need to be internalized before a student becomes a fully effective engineer. This industrialization process, in which a new employee struggles to "get his feet on the ground" or to "learn the ropes," now lasts about two years. I believe, however, that a pedagogic style which incorporates industry-like experiences into the normal student assignments and activities can accelerate that process and produce "faster-starting" professionals.

I have not recommended curriculum subject revisions or additions. I claim we teach technology well. Instead, I have suggested blending make-it-happen and human awareness opportunities with the students' experiences. As a prior employer that would please me, and I would preferentially recruit from such schools.

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WHAT WILL WE REMOVE FROM THE CURRICULUM TO MAKE ROOM FOR X?*

Bite the Bullet—Throw Out Obsolete Material

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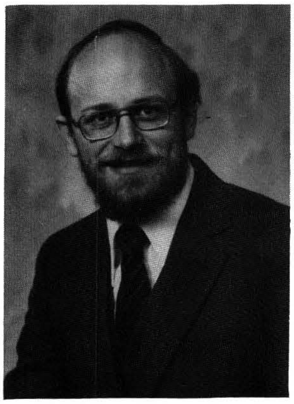
THE QUESTION IS: how do we get new material into the chemical engineering curriculum? The Septenary Committee on Chemical Engineering Education for the Future, sponsored by the Department of Chemical Engineering at the University of Texas [3] has done the profession a service by pointing out the need for change in the education of chemical engineers. This committee also suggested, in general terms, some ways that this can be done. In this paper I will first review some methods of making room for new material in the curriculum while retaining a four-year program. Then the question of which material has become obsolete will be considered in more detail. Finally, specific material in the area of separations which I think should be deleted or changed will be delineated.



Phil Wankat received his BSChE from Purdue and his PhD from Princeton. He is currently a professor of chemical engineering at Purdue. He is interested in teaching and counseling and has won several teaching awards. Phil's research interests are in the area of separation process with particular emphasis on cyclic separations, two-dimensional separations, preparative chromatography, and high gradient magnetic separation.

MAKING ROOM IN THE CURRICULUM

A variety of methods to make room for new material were mentioned by the Septenary Committee [3]. These will be briefly reviewed and expanded with some specific examples.

Avoid Duplication

Teach material once, and then use the material in other courses. There is an advantage to teaching material more than once and from different viewpoints; however, this seems to be a less effective use of the limited available time than covering important new areas. Plan the key course in the subject to explore the theory, the philosophy, and some applications of the subject. Then in later courses expect the students to use the material to solve problems. Perhaps the best example of teaching material more than once is thermodynamics. At many schools thermodynamics is taught in physical chemistry, in physics, and in chemical engineering. Reducing some of this duplication would make more time available for other subjects.

Purposely do not cover some of the material students will have to know for laboratory and design projects. One of the objectives of the laboratory or design project would be to require students to ferret out information on their own. This search for information and then using it could be guided at first and totally without help later.

Do less teaching of multiple ways to do the same thing. For example, learning ten different calculation methods for multicomponent distillation is probably not the optimum use of time.

*Presented at the AIChE annual meeting, Miami Beach, FL on November 4, 1986.

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Use Problems and Examples

Many students (and practicing engineers) have trouble generalizing. They cannot see that many of the methods they know can be applied in new areas. Practice in generalizing can often be done through examples and homework problems without teaching a lot of new material. For example, Michaelis-Menton kinetics for enzymes is Langmuir-Hinshelwood kinetics by another name. If Langmuir-Hinshelwood kinetics is covered in a course, Michaelis-Menton kinetics can easily be introduced either as an example or as a homework problem. This method for introducing new material can also help the student broaden his search for a job. For instance, the production of ultrapure water is important in electronics and can be done with standard chemical engineering unit operations. A problem on production of ultrapure water in an electronics plant would be a good homework assignment in a unit operations, separations, or design course.

REMOVE OR REPLACE OBSOLETE MATERIAL

Everyone agrees that obsolete material should be removed. The difficulty is in deciding what *is* obsolete. The modern practice of chemical engineering is becoming more and more computer and programmable calculator (which I will shorten to computer) oriented. Thus, we should teach in a *computer friendly form.* Teach material in a form which is easy to use with the computer. This will encourage students to use computers and prepare them for using the computer in their careers. A small fraction of our students will use the computer whenever possible and do not need any encouragement. Another small fraction of students treat the computer like it has AIDS—these students are hard to reach. The biggest fraction of students, however, use the computer when it is convenient, and we should encourage them by teaching material which is computer friendly. Computers *can* be over-stressed; however, I believe this is rarely done.

Using the desire to teach computer friendly material as a guide, I have selected the following material as prime candidates for removal from the curriculum.

- **Complex graphical calculation methods. The Ponchon-Savarit method is obsolete. The vast majority of students never learn the method well enough to use it to think, and the method does not appear to be used in industry. The McCabe-Thiele method is not obsolete since it is very useful as a tool to think about distillation problems even if a computer is used for the design.**
- **Mechanical drawing. The computer is doing drawing and graphing jobs. However, typing has replaced this as a useful skill. Pre-engineering students should be encouraged to take typing in high school.**
- **Graphical (count the squares) integration. Teach some of the simple numerical methods.**
- **Graphical correlations. An excellent way to show the fit of the correlation to data, but graphs are not computer friendly. Teach the equation form of the correlations in addition to the graphs.**
- **Nomographs.**
- **Trial-and-error methods devised for hand calculations.**
- **Flow sheets for obsolete processes. This can be a problem in design courses and requires industrial contacts to avoid.**

Why is it difficult to throw out material which is now dated? First, it may be difficult to identify which material is obsolete. Second, the material is probably included in all the books we teach from, and replacing it will be quite time-consuming. (This point is discussed in detail in the next section.) All our lectures and problems use the old material; again, replacing it will be time-consuming. Student access to computers may be limited (however, their access to calculators is not). Most professors learned to use computers when they were batch systems. Many professors have not adapted to modern computer work station engineering and are not prepared to teach computer friendly material. Finally, we learned this material and are very comfortable with it, and thus on some level feel that all chemical engineers should learn the same material.

SPECIFIC NON-COMPUTER FRIENDLY MATERIAL IN SEPARATIONS

I am not qualified to evaluate the entire chemical engineering curriculum. I do feel qualified to evaluate the areas of separations and the physical properties required to solve separations problems. I have extensively reviewed a number of modern (1980 and later) books which cover separations, and have identified where these books are teaching material in non-computer friendly ways. What I have found is that these books universally cover a lot of material in ways which are not computer friendly. Unfortunately, this means that most courses will be taught the same way.

Physical Properties

We will start with the physical properties required for many separation calculations. Almost universally

Continued on page 81.

ChE curriculum

THE FUTURE ChE CURRICULUM

MUST ONE SIZE FIT ALL?

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IN THE SOUL-SEARCHING about the future of chemical engineering currently being carried on at great length in journals, symposia, and the Exxon suite, the one point of agreement is that new material *must* be infused into the undergraduate curriculum. The shopping lists include, in no particular order, biotechnology, computer applications, microelectronics, industrial chemistry, quantum chemistry, rigorous mathematical analysis, economics, statistics, aerobics, pipe threading, pump sizing, stress tensors, social sciences, several dozen synonyms for "culture," oral communication skills, written communication skills, problem-solving skills, critical thinking skills, and countless things that involve the words "real world."

Can we do all that? Well, there's something to be said for the twelve-year chemical engineering curriculum—I can think of at least three of our students at N.C. State who seem to have made the case for it for themselves. However, there are practical arguments against stretching the program out beyond four years, mostly having to do with the large student population that would result and the critical shortage of available parking for them. So, the questions: (1) Which proposed additions to the curriculum are really all that essential for the preparation of well-trained and well-rounded students? (2) Which currently covered topics are we willing to scrap to make way for the essential replacements?

I would like to propose several axioms by way of introducing my ideas on the subject—axioms meaning I think we can all agree on them, even if they don't necessarily lead us to the same conclusions.

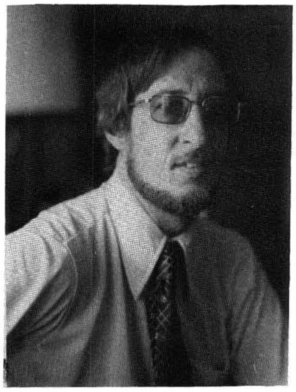
Axiom 1. No two of our students will be called on to solve an identical set of problems in their careers.

Our graduates will go into different industries, work on different products, provide different services. Some will go into petroleum-related industries, some into specialty chemicals, some into polymers, some into biotechnology, and some into microelectronics. Some will work in production, some in process design and development, some in product design and development, some in equipment design and construction, some in sales and service and computer-aided design and manufacturing and process control and quality control and project engineering and cost engineering, some in low-level management, some in high-level management. A few—5%, 10%—will go on to get PhD's and go into research or teaching. Which leads us to

Axiom 2. We can't possibly provide all the information our students will need to do all the things they will be called on to do in their careers.

We couldn't do it even if we did go to a twelve-year curriculum. Moreover, we have

Axiom 3. Our responsibility as educators is to try to meet the needs of the greatest possible number of our students. We should not short-change the many for



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*Modified version of paper presented at the AIChE annual meeting, Miami Beach, FL, on November 4, 1986.

For at least the past two decades we have hired as faculty members almost exclusively individuals whose background, training, and interests qualify them as research scientists, not as engineers or educators . . . the undergraduate curriculum has increasingly become a graduate school training program.

the benefit of the few.

This may seem to be a self-evident truth, consistent with the principles of the American democratic tradition. However, what it means to me is that if 10% of our students are going to go on to get PhD's and 90% of our curriculum is designed to meet the needs of this 10%, then something is wrong with the curriculum. I'm not claiming that our present imbalance is as serious as the 90% figure I just gave—at least not yet—but I do think an imbalance exists, that it has been growing steadily over the past two decades, and that in the correction of the imbalance lies at least part of the answer to the question, "What should we take out?"

The cause of the imbalance is not hard to deduce. For at least the past two decades we have hired as faculty members almost exclusively individuals whose background, training, and interests qualify them as research scientists, not as engineers or educators. Clearly, faculty members will focus on what they know best when they develop and teach courses. The result is that the undergraduate curriculum has increasingly become a graduate school training program. Those who in the past provided the balance—engineers with industrial experience, men and women whose principal interest is teaching—are reaching retirement age and leaving, and are being replaced with more research scientists. Occasionally an experienced engineer who happens to have a PhD will be hired to take care of the unit operations laboratory, but for the most part such individuals can't get through the door when vacancies arise.

One more proposition.

Axiom 4. Our graduates who go into industry don't necessarily agree with us about the usefulness of all we have taught them.

The September 19, 1983 issue of *Chemical Engineering* contained the results of a survey to which 4,759 readers responded, of whom 3,599 were U.S.-educated chemical engineers. Of all subjects studied in college, the one considered most useful was communication skills, which was cited by over 80% of the respondents. The standard chemical engineering subject most often cited was material and energy balances (78.9%), followed by engineering economics (77.7%) and unit operations (76.5%). The other subjects fell below 70%, with reactor design trailing the pack at a dismal 44.5%.

Although roughly 3/4 of the respondents to this survey thought they had been well-trained for their first job, many commented negatively on their training or the training of new engineers whom they supervised. To quote several of them:

- ***College prepared me almost not at all for my current work as a second-line supervisor of a chemical unit. Much of my engineering background was geared to how to create new plants, not how to keep 20-year-old plants on line in worsening economic times or how to manage the people who run them.***
- ***In general, I was totally ill-prepared to apply the theoretical knowledge gained from college to real world problems.***
- ***I know so little about fluid flow, material selection, equipment alternatives and cost estimating . . . which is what chemical engineering design is at my company.***
- ***Three years ago, I took a course titled "Intermediate Fluid Mechanics" . . . it should have been titled "Application of Second-Order Differential Equations." Navier-Stokes equations are fine in their place, but they're no help in finding friction factors in piping.***

And so on.

Now, what do we do with all this? Let's review the situation.

1. We have at least two populations to serve—industry-bound students and graduate-school bound students.
2. There are a number of specialty areas—biotechnology, microelectronics, computer-aided design, and so on—that we believe at least some of our students should be exposed to.
3. There is pressure from some quarters to give our students a more solid grounding in rigorous analysis in mathematics, chemistry, transport theory, *etc.*
4. There is equal pressure from other quarters to give our students less theoretical material and more background in industrial systems, economics, scaleup, communications, and so on.
5. You can't do everything for everybody in a four-year curriculum.

So what's the answer?

Flexibility!

We've all been exposed to a similar situation early in our academic careers—specifically, in high school. There are two populations there as well: college-bound and non-college bound. There is no way to put both groups through the identical curriculum in four years, and no one even tries. Through a system of electives and advising, each student winds up with a program tailored to his or her needs. Sometimes mistakes are made, but at least the odds are in the student's favor, whatever his or her post-high school plans.

We also have models to consider in our sister engineering curricula. Long ago, civil engineering departments decided that *all* of their graduates do not have to be experts in design and construction of bridges and dams, water treatment facilities, highways, and public transportation systems. Similarly, all electrical engineering graduates do not necessarily get training in communications, control theory, power systems, and artificial intelligence. Students in both disciplines take a few core courses and then branch out into diversified programs according to their interests and career goals.

Why not institute a series of options or tracks in the curriculum, and design the courses to meet the needs of those pursuing these tracks?

What would be wrong with doing something similar in the chemical engineering curriculum—abandoning the pretense that all of our students have the same needs and can therefore be served by the same curriculum, give or take a few electives? Why not institute a series of options or tracks in the curriculum, and design the courses to meet the needs of those pursuing these tracks? In structuring this flexible curriculum, we might proceed in something like the following manner.

1. *Decide what general subject areas and specific subject material are truly indispensable in the education of anyone who calls himself a chemical engineer.* As far as I am concerned, the basic freshman science, math, and English courses, the material and energy balance course, one thermodynamics course, one transport/separations course, and a minimal amount of social sciences and humanities are indispensable, and almost everything else—strength of materials, electrical circuit analysis, analytical chemistry, physical chemistry, the second semester of organic chemistry, process control, kinetics, the third course of the transport sequence, the second course of the transport sequence, any course involving the Navier-Stokes equations—is negotiable.

2. *Propose track titles.* Industrial chemical engineering? Pre-graduate school? Chemical engineering science? Biotechnology? Microelectronics? Computer-aided design and manufacture? Economics and management science? Material science? Aerobics?

The track titles will of course change with the times: the words energy and environment would have appeared on most lists of this sort a few years ago, the words nuclear and polymer would have been on earlier lists, and so it goes.

3. *List required and elective courses for each track.*

4. *Plan each course thoroughly,* deciding what really needs to be covered in lectures, what can be left for the students to learn in readings and homework, and what can profitably be left for graduate school or on-the-job training. Then cut down on the first category by a factor of two, and add the excised material to categories two and three.

5. *Plan a course schedule to minimize the number of offerings of elective courses.* One consequence of implementing this program—or any other program to accommodate demands for the inclusion of new material in the curriculum—is an inevitable increase in the number of courses being taught. To minimize the resulting teaching loads and/or need for additional faculty, offer courses that were formerly required but are now elective less often—*e.g.* once a year instead of once each semester or quarter.

6. *Consider cross-listing courses between departments, and eliminate duplicate offerings.* The usual practice is for each department to offer its own courses, regardless of redundancy. Thus, engineering thermodynamics and heat transfer are each taught in both chemical and mechanical engineering, and fluid mechanics is taught by the same two departments and civil engineering. Eliminating these duplications is another way to keep the addition of new curricular material from imposing excessive demands on department resources.

7. *Devise a mechanism for reasonably frequent review and updating of the system to accommodate changes in the industrial economy, national priorities, etc.*

8. *Implement the changes.*

In addition, we should explicitly acknowledge that a flexible curriculum designed to meet the needs of a diverse student body can only be implemented by a diverse faculty. If research science is not to constitute 100% of the curriculum, the faculty should not be composed of 100% research scientists. *If engineering practice is to be taught, some people who are, or have been, practicing engineers should be around to teach it.*

Now, all we have to do is designate someone to answer all the questions explicit and implicit in this plan. What's indispensable in our current curriculum? What tracks should be considered? What are the likely short-range and long-range demands for graduates from each of these tracks? In light of the answers to the previous question, what tracks should actually be instituted? What should the required and optional courses be in each track? What really needs to be taught in each course? Who's going to design and teach all those courses? How much is it going to cost to do all this? Who will bear the cost?

Who will come up with the answers? Certainly not me—I'm just one person, and I'm not getting paid for this. If history is a guide, designing and implementing a plan of this magnitude demands no less than a blue-ribbon panel with three or more corporate executives at the vice-president level and at least $500,000 support over a three-year period from the National Science Foundation.

However, I really believe that the details of implementation are of secondary importance at this time. We're all struggling to answer the focal question of this paper—what should we remove from the chemical engineering curriculum to make room for new material? Sometimes when you can't come up with a reasonable answer to a question no matter how hard you try, you should consider the possibility that you haven't asked the right question.

I think that's the case here. The premise that underlies the question is that there's such a thing as "The Chemical Engineering Curriculum"—one size fits all. If we back off that premise, and acknowledge that those coming to us have a spectrum of needs—most of which don't involve preparation for the PhD qualifying examination—then we find ourselves asking a different question: "How can we structure our program to best meet the needs of most of our students?" Since a single rigidly-structured curriculum presided over by a faculty composed exclusively of research scientists can't possibly meet those needs, we should be led to seek diversity and flexibility in both our curricula and our faculties. I believe that in this direction lie our answers. □

ChE book reviews

BASIC PROGRAMS FOR CHEMICAL ENGINEERS
by Dennis Wright
Van Norstrand Reinhold Company, 1986, 340 pages, $32.95.

Reviewed by
Jeffrey J. Siirola
Eastman Kodak Company

The title of this book is to be taken both ways: a collection of very elementary chemical engineering computer programs, all written in the BASIC computer language. The stated purpose of the book is to provide engineers who have access to personal computers with ready-to-be-copied listings to enable solutions to problems in thermodynamics, mass and heat transfer, design, economics, *etc*. Included with each listing is a brief explanation of the equations on which the program is based and an example of typical input and output. In addition, many of the routines include tables of properties data for selected compounds or situations.

With less than three dozen routines, the book covers only a small fraction of chemical engineering computation. Included, however, are data regression, Newton-Raphson and Runge-Kutta equation solving, shell-and-tube and double pipe heat exchange, Fenske-Underwood-Gilliland distillation, plate efficiency and hydraulics, stoichiometry, chemical and vapor-liquid equilibria, prediction of critical and other physical properties of pure components, the design and economics of packed towers, heat exchangers, cyclones, and orifices, and a few other miscellaneous topics. To facilitate transcription, most routines are very short, averaging just over 100 lines of code. As much of the BASIC code is often associated with input-output and data, such short routines are of necessity quite simplified.

This book is not highly recommended for students. For computational situations appropriate to the sophistication of routines contained here, the effort to understand and transcribe listings error-free probably exceeds that required to code the simplified equations from scratch. For more serious work, far more complete and robust routines are widely available in the form of both software packages and listing. □

ChE letters

HOUGEN TRIBUTE APPRECIATED

Editor:

It was gratifying, indeed, to read the tributes to my brother, Olaf, written both by you and Bob Bird. Thank you for these testimonials and your role in their publication.

Joel O. Hougen
University of Texas at Austin

ChE views and opinions

ENGINEERING SCHOOLS TRAIN SOCIAL REVOLUTIONARIES!

ISN'T IT TIME OUR STUDENTS WERE TOLD?

M. V. SUSSMAN
Tufts University
Medford, MA 02155

Most people, both in and out of the technical professions, realize that technology influences their lives, but few appreciate the breadth and the profundity of its effects on all human affairs.

Engineering educators, by and large, have no time and make little effort to study or become informed about the nature and extent of the cultural, political, social, and non-mathematical effects the practice of our profession produces. We seldom discuss these effects with our students and almost never teach them to non-engineering students.

At Tufts, since the early seventies, we have conducted a modest campaign to remedy what in our view is a serious educational oversight, by developing a course that shows that technology is a strong determinant of social structure and a *prime factor* in causing cultural and even political change. The course has ambitious objectives that are possibly unrealistic or immodest, but are, I believe, necessary and worthwhile.

- ***It attempts to build awareness among engineering students that in addition to being chemical, civil, electrical, mechanical** etc., **engineers, they are** cultural **engineers and fomentors of relatively bloodless revolutions.***
- ***It attempts to have them share and discuss this awareness with non-engineering, liberal arts students who usually are a majority in the class.***
- ***It attempts to show that technology is a characteristic or hallmark of all societies that are human and that even the most primitive society depends on technological skills that are passed from generation to generation as essential components of that society's culture.***
- ***It attempts to teach a chronology of technological and historical events.***
- ***It attempts to teach that technological gains are usually accompanied by social and cultural changes, and by cost.***

M. V. Sussman is professor of chemical engineering at Tufts University. His work in thermodynamics includes the books *Availability (Exergy) Analysis* (Mulliken House 1980) and *Elementary General Thermodynamics* (Addison-Wesley 1972). He has written numerous articles and has many patents.

Our course is called "Technology as Culture." It takes as a premise that we (*homo sapiens*) are too naked, too slow breeding, too small toothed, too puny, to get by on physique alone. We overcome our *under*-endowment by making things from the environment that facilitate living. Without this facilitation, called technology, humans cease to exist. With it, we threaten the Earth. The course has four parts, as shown in Table 1.

The first part is called (with no attempt at originality) "Man, The Tool-Making Animal." It presents a condensed history of technology with special lectures on the printing press and steam engine, after which students prepare a chronology of about 100 selected events (Table 2) ranging from the disappearance of the dinosaur to the communications satellite, and write a sentence or two on the cultural-historical repercussions of each event. This amounts to a jet-plane overflight of world and technological history, but it provides a historical perspective that most students have never had. One student commented that the worst anachronism in *The Flintstones* cartoon series was not the caveman's television or car, but his pet

. . . students prepare a chronology of about 100 selected events ranging from the disappearance of the dinosaur to the communications satellite, and write a sentence or two on the cultural-historical repercussions of each event. This amounts to a jet-plane overflight of world and technological history . . .

dinosaur. He realized, somewhat sadly and for the first time, that dinosaurs disappeared 65 million years ago, whereas Fred Flintstone or *homo sapiens* came on the scene only about 40 thousand years ago.

The second part of the course is called "Simple Technology Societies" and examines contemporary and historical societies with technologies less sophisticated than ours. The examination of simpler technological societies is a unique and valuable part of the course because it tells us where we have been and helps dispel the "noble savage" mythology that permeates the thinking of many students. Lectures cover the interaction of military technology and tactics in Athenian and Spartan societies, and an excerpt from the Hippocratic medicine opus that gives graphic instructions for cauterizing hemorrhoids without anesthesia. ("Your irons must be white hot.") There is a lot of seat squirming during this reading.

Contemporary societies are covered in readings and lectures on Eskimos and on Indian (Hindu) village life which illustrate that family structure, narrowly prescribed sex roles, *etc.*, are adaptations to the technological skills available in these societies.

The third part of the course, called "The Ascendency of Europe," explores the puzzling question of why Europe became dominant in technology when many essential aspects, like printing, textile manufacture, ship building, decimal number system, gunpowder, magnetic compass, *etc.*, originated in Asia. We also explore the eighteenth century European ambivalence toward mushrooming technology in a lecture on the philosopher Jean Jacque Rousseau whose creation, the "noble savage," lost nobility and virtue when he discovered the hammer.

The last part of the course deals with "The Advanced Technological Society." The evolution of the chemical industry is used as a paradigm for the growth of modern technological industry. Students learn of the essential role of the Haber process in permitting Germany to pursue World War I in spite of the British sea blockade that prevented Chilean nitrates, needed for munition manufacture, from reaching Germany.

TABLE 1
Lecture Schedule, Fall 1986

DATE	LECTURE	LECTURER
PART 1: Man:. The Tool-Making Animal		
9/2	Introduction	Sussman
9/5	Scope, purpose and conduct of the course; student responsibilities	Sussman
9/9	A capsule history of technology ΔTechnology = ΔCulture	Reuss/ Sussman
9/12	Prehistoric technology; tools as the signal of the emergence of man; the anthropologist's view; technology of wood, stone, pottery, agriculture, animal domestication	Bailey
9/16	The printing press revolutions	Solomon
9/19	Industrial revolution	Nelson
9/23	The evolution of the steam engine and social consequences	
PART. 2: Simple Technology Societies; Contemporary and Historical		
9/26	Life styles; leisure, work patterns and productivity; social structure; health, hygiene, food; individual aspirations	Sussman
9/30	Eskimo society	Carter
10/3	Same	
10/7	Military technology and its effects on the cities of ancient Greece	Hirsch
10/10	Greco-Roman medicine	Phillips
10/14	Same	
10/17	A village in India	Sussman
10/21	The ecological and social "steady-state"	Sussman
10/24	Early technology in China	Schaffer
PART 3: The Ascendency of Europe		
10/28	Aspects of Western culture that may have provided the foundations for the accelerated and systematic exploitation of technology	Sussman
10/31	Reactions: Rousseau and the "noble savage"	Simches
PART 4: The Advanced Technological Society		
11/4	The nature of modern technology as exemplified by the chemical industry; review of the history and structure of a modern industry and its social and political side effects	Sussman
11/7	Population and human ecology	Sussman
11/14	"Metropolis"; The conflict between man and machine	Gittleman
11/18	Same	
11/21	Energy and the ATS; Visit Seabrook or Plymouth	
11/25	Technology and law	Wells
12/2	Summing up	Sussman
12/5	Coda	Sussman

TABLE 2
Mid-Term Homework Assignment

NO.	EVENT	NO.	EVENT	NO.	EVENT
1.	Man becomes a commonplace species	35.	End East Roman Empire; Final Fall of Rome	69.	Jet aircraft
2.	Einstein Relativity Theory, $E = mc^2$	36.	Lateen sail	70.	Paul of Tarsus
3.	Man walks on moon	37.	Hinged rudder in West; in East	71.	Weaving
4.	Parthenon built	38.	Leonardo da Vinci	72.	Spectacles (eyeglasses)
5.	Watt steam engine	39.	Wheeled vehicles	73.	Artificial nitrates from air—Fritz Haber
6.	Commercial automobile	40.	Atomic pile	74.	Indo-Arabic numbers
7.	Galileo—"Epour si muove"	41.	Copper vessels	75.	Surgery for Appendicitis
8.	Potato introduced in Europe	42.	Pyramids built	76.	Meiji restoration, Japan
9.	Domesticated animals	43.	Paper making in West; in East	77.	Roman Capital moved East, Constantine I.
10.	Wood turning lathe	44.	Stirrup and improved horse collar	78.	Vasco de Gama in India
11.	Karl Marx	45.	Age of Arab scientific classics	79.	Empire of Ashoka
12.	Black Death in Europe	46.	Beginning of agriculture	80.	Synthetic dyes (Perkins)
13.	Hieroglyphic writing	47.	Benedict of Nursia/Labor as Prayer	81.	End of dinosaur era
14.	Use of fire	48.	Martin Luther	82.	Ether anesthesia
15.	Spinning Jenny	49.	Gothic cathedrals built	83.	Transistor
16.	Dog domesticated	50.	Copernicus—Heliocentric Universe	84.	Soap becomes a common place material
17.	Death of Aristotle	51.	Shakespeare	85.	Augustus Ceasar—Beginning of Roman Empire
18.	Chipped flint tools	52.	Elizabeth I of England	86.	Neanderthal man
19.	Atom bomb	53.	Queen Victoria	87.	House chimney & hearth
20.	Gunpowder cannon developed—Europe	54.	Distilled alcohol	88.	Air conditioning
21.	Iron implements	55.	Roger Bacon—Knowledge is power	89.	Commercial electric power, Edison
22.	Gautama Buddha	56.	Alternating current generator—Tesla	90.	Qing Dynasty, China, Boxer Rebellion
23.	Savery's "Miner's Friend"	57.	Computer—digital electronic	91.	First oil well drilled
24.	Moses, Ten Commandments	58.	Transatlantic radio	92.	Hegira—Mohammed
25.	First silk manufactured in Byzantium	59.	First artificial satellite	93.	Louis Pasteur—Germ theory of disease
26.	Bronze tools	60.	Isaac Newton	94.	Justinian—St. Sophia
27.	Alexander the Great	61.	Wright brothers' flight	95.	Euclid
28.	Australopithecus	62.	Coinage	96.	Aeolia Capitolina, Hadrian, Jerusalem obliterated
29.	Newcomen engine	63.	Luddites	97.	World War I
30.	Constructed fixed shelters	64.	Gutenberg's printing press	98.	World War II
31.	Death of Archimedes	65.	Commercial television	99.	Radar
32.	Flush toilet, internal plumbing	66.	Synthetic fibers—nylon		
33.	Brass tools	67.	Synthetic plastics—bakelite		
34.	Magnetic compass in Europe, in China	68.	Antibiotics—Penicillin manufacture		

They learn of an industrial chemical root of the present crisis in the Middle East (the Weizmann fermentation process). They visit a nuclear power plant. Lectures also cover high tech's interactions with population, law, energy needs, and such other aspects of human affairs as may be topical. The class gets to view *Metropolis*, a 1926 silent movie that addresses the topic of human domination by machines.

Students taking the course must read three books and about fifteen articles. This year's books were:

- J. Brunowski, *The Ascent of Man:* (based on the famous T.V. series)
- C. and W. Wiser, *Behind Mud Walls:* (a realistic sympathetic account of life in rural India)
- A. Huxley, *Brave New World:* (where technology achieves the ultimate in female liberation—freedom from the burden of reproduction—and establishes a caste system that can be measured against the Indian system described by the Wisers)

Students keep a journal on their readings, and in addition to the chronology previously mentioned they write a term paper on a topic related to the course's theme. The class meets twice a week for total of three hours.

About 60% of the course participants are liberal arts majors who can use the course to satisfy part of their science distribution requirement. Their reactions have been largely enthusiastic. One recently called the course "an epiphany"—which sent me to my dictionary. (An uplifting revelation; a sudden insight into reality.)

I always enjoy conducting the course, and as can be seen from the names on the Table 1 course outline, I impose shamelessly on my colleagues for help when we touch on their specialities. The course has taught me a little about history, anthropology, and technology, some of which may appear in a book one day—and some of which is handy in a game of "Non-Trivial Pursuits."

More information about the course can be obtained by contacting the author. □

WHAT WILL WE REMOVE

Continued from page 73.

the physical properties are listed in graphical correlations, nomographs or tables. This strongly encourages the student to do hand calculations.

1. K values. Simple determination of K values is done with the dePriester charts. Usually these monographs are presented without any equations in correlation form [4, 8, 9, 10]. The presentation of both the dePriester charts plus correlations in equation form would be preferable. Faust *et al* [4], present equations in terms of temperature at different selected pressures, and do not present the dePriester charts.

More detailed analysis of K values often includes description of various computer friendly methods [4, 6, 7, 9], but some books present the convergence pressure charts which are not computer friendly [5, 9].

2. Physical properties: viscosity, specific heat and enthalpies. Both viscosity [1, 5, 8, 9, 10] and specific heat [1, 8, 9, 10] use a nomograph form which is difficult to use and provides no physical insight. Correlations in equation form are readily available [*e.g.* 11] but have not permeated into the separations literature. The steam tables remain in tabular form. Accurate equations to correlate this data would be very useful to encourage computer problem solving.

Separation Method Calculations

There are several examples of presentations of non-computer friendly material in teaching separations. This list is not inclusive.

1. Ponchon-Savarit Diagrams. As was mentioned earlier I think that the Ponchon-Savarit analysis of distillation is now obsolete. McCabe *et al* [8], and Perry and Green [9] apparently agree since this material was removed from the latest editions. However, it is difficult to obtain agreement on what is obsolete. Other authors [1, 2, 4, 5, 6, 10] apparently disagree since they have included this material. The use of the Ponchon-Savarit or triangular diagram in extraction calculations appears to me to be more justified. This method is included in most books which discuss extraction.

2. Graphical solution of Kremser or Colburn equations. Back in slide rule days these equations could be difficult to solve and graphical plots of the solutions were justified. With the ready availability of powerful calculators this justification is no longer valid. The continued use of these graphs in many books [1, 4, 5, 6, 9, 10] is a good indication of the inertia involved in producing chemical engineering textbooks.

3. Gilliland Correlation. The Gilliland correlation is a useful short-cut technique which was originally done in graphical form, but has also been correlated by equations. Inclusion of both a figure to show the fit to data and an equation appears to be the best way to present this material. This has been done in Henley and Seader [4], King [6] and Perry and Green [9]. Only the graphical correlation is presented in other books [5, 7, 8].

4. Graphical integration. Graphical or numerical integration is required for batch distillation and for the HTU-NTU analysis of packed columns. Methods such as the trapezoidal rule which is easy to computerize are preferred over count-the-squares graphical integration. The trapezoidal rule is used by Faust *et al.* [2], Hines and Maddox [5], and McCabe *et al* [8], although Faust *et al* show a count-the-squares graphical integration in batch distillation. Only count-the-squares type of graphical integration are shown in other books [4, 7]. King [6] and Treybal [10] state that graphical integration is done, but do not illustrate it; thus, the instructor can do what he wishes.

5. Design correlations. A number of graphical design correlations are routinely used in separations. For example, the two O'Connell correlations are often used to estimate the overall efficiencies of distillation and absorption columns. This is invariably shown graphically [4, 5, 6, 7, 9]. Unfortunately, I am not aware of an equation form of this correlation although generating such an equation is straight-forward. As a second example, the Sherwood correlation (often as modified by Eckert) is used for both flooding and pressure drop of packed columns. Equations for the pressure drop curves are available for different packings [9], but an equation for the flooding curve does not appear to be available. Most books which cover this material give the graph only without any equations [1, 4, 5, 6, 7, 8]. Many other examples in this area could be shown.

Obviously, book authors could be much more careful to try and cover material in computer friendly forms. This would greatly aid professors in teaching the material in computer friendly forms. Unfortunately, if the goal is to make room for other material, only large changes, such as not teaching the Ponchon-Savarit analysis, have a significant impact. The other changes will update the course, but they don't make room for other material.

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CHEMICAL ENGINEERING DIVISION ACTIVITIES

SUMMER SCHOOL '87

The Summer School for Chemical Engineering Faculty is organized by the Chemical Engineering Division of the American Society for Engineering Education and is held every five years. The 1987 Summer School will be the tenth in the series begun in 1931 and will be held at Southeastern Massachusetts University, North Dartmouth, Massachusetts, on August 9-14, 1987. New developments in chemical engineering education will be discussed, and opportunities will be provided for interaction between faculty members and representatives from industrial firms concerned with the education process. Cochairmen for the 1987 Summer School are Glenn L. Schrader and Maurice A. Larson of Iowa State University, Ames, Iowa 50011.

In January, 1987, a Prelimiary Announcement was mailed to all chairpersons of chemical engineering departments in the United States and Canada. Attendance at the Summer School is limited because of constraints on class sizes and accommodations, and the Chemical Engineering Division has elected to have each chairperson select the departmental representative. Based on this response, program and registration material was mailed beginning February 28, 1987. The due date for receipt from the designated representatives of the 1) Program Enrollment Form, 2) Housing and Food Service Reservation and Registration Form, and 3) Poster Session Proposal-to-Present Form was April 15, 1987. Final information regarding the Summer School will be mailed to registrants on June 1, 1987.

The theme of the Summer School will be the revitalization of the chemical engineering curriculum in response to the changing technological needs of modern society. A series of Plenary Sessions and Workshop Blocks have been organized:

• PLENARY SESSIONS •

Future Curriculum Directions in Chemical Engineering
Industrial Needs in Biotechnology
Industrial Needs in Electronic Materials Processing
Industrial Needs in Advanced Materials and Composites
Computers in Chemical Engineering Education

• WORKSHOPS •

BLOCK #1

Emerging Technology (G. L. Schrader, Chariman)

- ***Electronic Materials Processing I, II, III***
- ***Biomedical Engineering I, II***
- ***Biochemical Engineering I, II, III***

BLOCK #2

Computers and Computation in Chemical Engineering Education (H. S. Fogler, Chairman)

- ***CACH Projects***
- ***Microcomputers***
- ***Batch Processes***
- ***Process Design***
- ***Artificial Intelligence I, II***
- ***Process Control***
- ***Optimization***

BLOCK #3

Applied Chemistry in ChE (J. W. Schwank, Chairman)

- ***Applied Thermodynamics I, II***
- ***Surface Chemistry I, II, III***
- ***Advanced Materials***
- ***Electrochemistry I, II***

BLOCK #4

Curricula, Courses and Laboratories (J. C. Friedly, Chairman)

- ***Chemical Engineering Curriculum***
- ***Safety I, II***
- ***Introductory Courses***
- ***Design***
- ***Scaleup***
- ***Undergraduate Laboratories***
- ***International Programs***

• THE PLENARY SESSION SPEAKERS AND WORKSHOP LEADERS INCLUDE •

Timothy J. Anderson	*Mark A. Kramer*
Jay B. Benzinger	*Costas Kravaris*
Lorenz T. Biegler	*Maurice A. Larson*
Theodore W. Cadman	*Douglas A. Lauffenburger*
Brice Carnahan	*Frank P. Lees*
Thomas W. Chapman	*Richard S. H. Mah*
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Thomas F. Edgar	*Edward C. Roche, Jr.*
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Richard H. Heist	*J. D. Seader*
Dennis W. Hess	*James C. Seferis*
Bradley R. Holt	*Warren D. Seider*
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Robert L. Kabel	*William H. Smyrl*
Jeffrey C. Kantor	*Lyle H. Ungar*
Iftekhar Karimi	*James Wei*
T. A. Kletz	*Eduardo. E. Wolf*

The annual 3M Award Lecture will be presented at the Summer School on Wednesday, August 12, 1987. A special banquet will also be held that evening. A poster session will also be held to provide participants the opportunity to present additional topics on teaching chemical engineering. Additional special sessions are also being planned. Visits to a variety of special cultural attractions have been arranged.

The Summer School is supported by industrial sponsors. The following companies have made contributions as of April 8, 1987:

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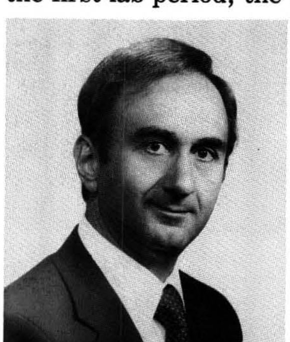
Manhattan College
Riverdale, NY 10471

THE COMPUTER-CONTROLLED heat exchange experiment is one of several experiments utilizing microcomputers in the senior chemical engineering laboratory course at Manhattan College. The objectives of the experiment are as follows:

- **To become acquainted with the components present in a digital control system and the application of computers for data acquisition, data analysis, and control.**
- **To investigate instability in a feedback control system from open-loop frequency response experiments and closed-loop continuous cycling experiments.**
- **To evaluate system performance with Ziegler-Nichols [1, 2, 3] settings of the parameters in a PID controller.**
- **To demonstrate the use of an error-squared integral objective function in achieving optimum control.**

In the first part of the experiment, conducted in the first lab period, the open-loop frequency response of the system is examined by introducing a sinusoidal variation in the inlet cold stream flow rate and plotting the cyclic variation of the exit hot stream temperature. Bode plots are constructed to obtain the maximum controller gain, $K_{c,max}$, and the ultimate period, P_u, of the system.



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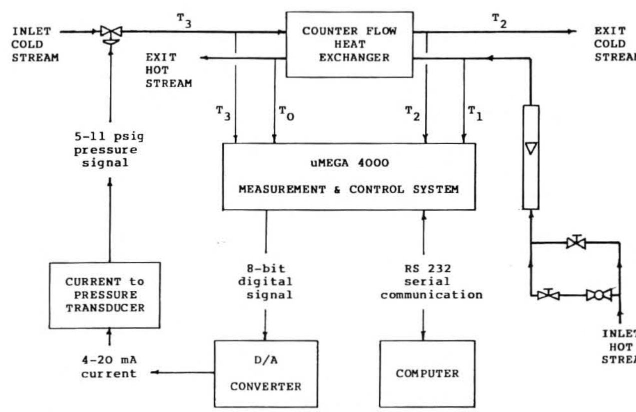

FIGURE 1. Schematic diagram of heat exchanger control system.

In the second part of the experiment, conducted in the second lab period, new values of $K_{c,max}$ and P_u are determined by the continuous cycling method. The values of $K_{c,max}$ and P_u obtained from both methods are used to determine Ziegler-Nichols control parameters. Performance of the control system with these parameters is examined by introducing a step disturbance in hot stream flow rate. After completing the Ziegler-Nichols runs, exploratory runs at different settings are conducted with the objective of minimizing an error-squared integral objective function.

EXPERIMENTAL PROCEDURE

A schematic diagram of the experimental system is shown in Figure 1. A description of system components and details of the experimental procedure are given by Famularo [4]. The controlled variable is the exit hot stream temperature and the manipulated

*This paper is based on a paper that has been previously published in the ASEE 1986 Annual Conference Proceedings.

variable is the cold stream flow rate. Water is the process fluid for both streams. Step disturbances in the hot stream flow rate are produced with a quick-opening ball valve in the piping system upstream from the rotameter. Inlet and exit stream temperatures are monitored; however, only the exit hot stream temperature is employed in the control system.

The experiment is conducted in two laboratory periods, and involves the completion of the following tasks:

Period 1

1. Determination of the effluent hot water temperature corresponding to different control valve settings.
2. Determination of $K_{c,max}$ and P_u from open-loop frequency response data.

Period 2

1. Determination of $K_{c,max}$ and P_u by the continuous cycling method.
2. Evaluation of control system performance using Ziegler-Nichols settings.
3. Determination of optimum controller settings.

Steady-state runs are conducted to determine the effluent hot water temperature at several cold water flow rates. Runs are conducted at Q/Q_{max} equal to 0.2, 0.5, and 0.8, with an inlet hot water temperature of 70°C and a hot water flow rate of 60% of the full rotameter capacity. The effluent hot water temperature from the steady-state run at Q/Q_{max} equal to 0.5 serves as the reference temperature in automatic control runs.

In open-loop operation of the heat exchanger control system, the loop is broken after the control algorithm is executed in the computer, as shown in Figure 2. Q/Q_{max} is controlled to follow the sinusoidal equation

$$q = q^\circ + A*\sin(360*f*t) \quad (1)$$

where $q = Q/Q_{max}$, $q^\circ = q$ at the midpoint of the sine wave, A = amplitude, f = frequency in cycles per minute, and t = time in minutes. Runs are conducted with $q^\circ = 0.5$ and $A = 0.3$, producing sine waves ranging from 0.2 to 0.8.

During the execution of a frequency response run, the time, cold water flow rate, and temperatures are displayed at the terminal and are written to a disk file. This file is accessed at a later time to produce a graph of the run in which the controlled variable, T_0, is presented as the dimensionless temperature,

$$TAU = (T_{max} - T_0)/(T_{max} - T_{min}) \quad (2)$$

In the first part of the experiment . . . the open-loop frequency response of the system is examined by introducing sinusoidal variation in the inlet cold stream flow rate and plotting the cyclic variation of the exit hot stream temperature.

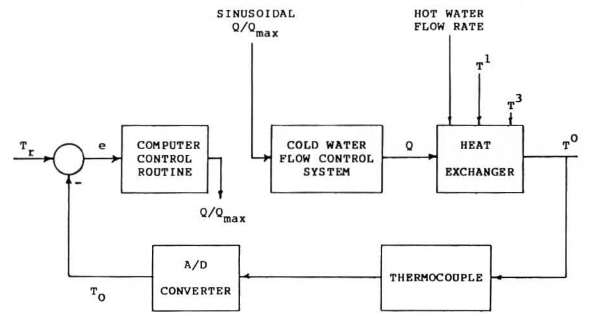

FIGURE 2. Block diagram for open-loop frequency response runs.

where T_{max} is larger than the greatest value of T_0 and T_{min} is smaller than the smallest value of T_0 observed during the run.

Although the response of TAU to the sinusoidal variation of Q/Q_{max} is cyclic and of the same frequency as the input, TAU does not follow a sine wave. This fact is illustrated in the graph in Figure 3. The time lag during the portion of the cycle in which the cold water flow rate reaches its maximum value of 0.8 is less than the time lag when the cold water flow rate is at its minimum value of 0.2. This is explained by the fact that the film heat transfer coefficient on the cold water side of the exchanger increases as the flow rate increases, causing the effluent hot water temper-

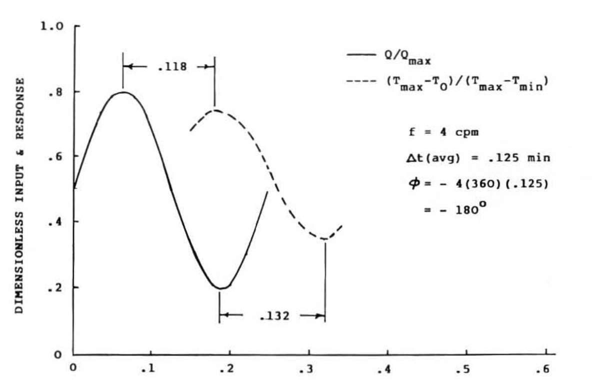

FIGURE 3. Determination of frequency response phase angle.

ature to respond more rapidly. A Bode plot analysis of the frequency response data can be made by calculating the phase angle from the average time lag of the response of TAU, as shown in Figure 3.

Students conduct a Bode analysis of the frequency response data prior to the second laboratory period. The objective of this analysis is to determine the gain corresponding to marginal stability, $K_{c,max}$, and the ultimate period, P_u, of the system. Figure 4 and Figure 5 are Bode plots from a series of frequency response runs conducted on the system. The parameters deduced from the plots are as follows: $K_{c,max} = 1/7 = 0.14°C^{-1}$, $P_u = 1/4 = 0.25$ min.

PERIOD 2 PROCEDURE

All experimentation in the second lab period is conducted with the heat exchanger operating under closed-loop automatic control. A control algorithm is included in the software which approximates the following proportional-integral-derivative (PID) action

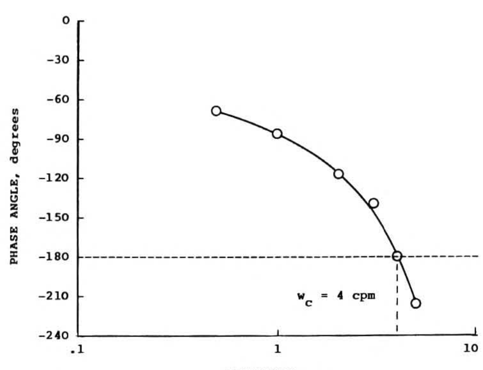

FIGURE 4. Phase angle vs *frequency Bode plots.*

$$q = -K_c\left(e + \frac{1}{t_i}\int e\,dt + t_d\frac{de}{dt}\right) + q° \qquad (3)$$

where q = fractional flow rate of cold water, q° = flow rate with zero control action, e = error in °C, K_c = controller gain in $°C^{-1}$, t_i = integral time in minutes, and t_d = derivative time in minutes.

Operation of the system has revealed that T_0 can experience random changes in temperature by as much as 0.2 C°. These fluctuations are due to "noise" in the system and do not represent actual changes in water temperature. The presence of a random temperature error influences the manner in which the error and error derivative are calculated for use in the control algorithm. First, with respect to e, instead of using a single set point temperature, T_r, the error is defined in terms of distance from a set point band.

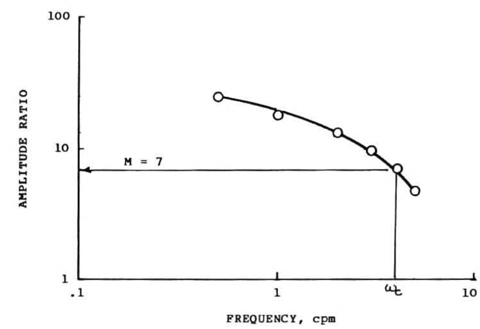

FIGURE 5. Amplitude ratio vs *frequency Bode plot.*

The upper boundary of the set point band, T^*, is defined as $T_r + E_t$, where E_t is the absolute value of the temperature error. The lower boundary is $T_* = T_r - E_t$, and the error in the control equation is calculated as follows

$$\text{If } T_* < T_0 < T^*, \quad \text{then } e = 0$$
$$\text{If } T_0 < T_*, \quad \text{then } e = T_* - T_0$$
$$\text{If } T_0 > T^*, \quad \text{then } e = T^* - T_0$$

Since "noise" in T_0 can cause erratic changes in de/dt, this derivative can not be calculated using only two consecutive temperature scans. In the control software the derivative at a specific time is calculated using the current scan and two preceding scans. A least-squares line is determined for these three points and de/dt is calculated from the slope of the line.

Determination of $K_{c,max}$ and P_u by the Continuous-Cycling Method

A discussion of the continuous-cycling method of determining $K_{c,max}$ and P_u may be found in Harriott [2]. It is an experimental procedure that involves operation of the system under closed-loop automatic control with only proportional action. Successive runs are conducted at increased values of K_c until a step disturbance causes cycling at a constant amplitude. The cor-

TABLE 1
Marginal Stability Parameters

$K_{c,max}$ ($°C^{-1}$)	P_u (min)	Footnote
0.14	0.25	§
0.18	0.28	†

§ Obtained from open-loop frequency response
† Obtained from continuous-cycling

responding value of K_c is $K_{c,max}$ and the period of cycling at the maximum gain is the ultimate period, P_u.

Operation under only proportional control is achieved by setting the derivative time and the reciprocal of the integral time equal to zero. Each run is conducted in the same fashion. The system is operated for one-half minute with the ball valve open and 80% hot water flow rate. The time is recorded and the ball valve is closed to produce a step change in hot water flow rate from 80 to 40% of the rotameter range. The response of the system is observed at the computer terminal, and if it appears that the oscillations are decaying in amplitude, the run is stopped and a new run is started at a higher value of K_c. This process is continued until the system is clearly unstable, as evidenced by cycling in the cold water flow rate from Q/Q_{max} = 0 to 1. At this point, K_c is reduced in magnitude in small increments with the objective of finding the smallest value of K_c that produces cycling without decay. The period in minutes of the corresponding cycling in T_0 is P_u.

TABLE 2
Ziegler-Nichols Controller Settings

K_c (°C^{-1})	t_i (min)	t_d (min)	Footnote
.063	.208	0	§
.084	.125	.0312	§
.081	.233	0	†
.108	.140	.0350	†

§ Based on open-loop frequency response
† Based on continuous cycling

The values of $K_{c,max}$ and P_u obtained by the continuous-cycling method compare quite well with the same parameters obtained from frequency response experiments, as revealed in Table 1.

● Closed-Loop Operation using Z-N Settings

Ziegler-Nichols (Z-N) controller settings are related to the marginal stability parameters through the following equations:

Proportional-Integral (PI)

$$K_c = 0.45\, K_{c,max}, \qquad t_i = P_u/1.2 \tag{4}$$

Proportional-Integral-Derivative (PID)

$$K_c = 0.6\, K_{c,max}, \qquad t_i = P_u/2, \qquad t_d = P_u/8 \tag{5}$$

The Z-N setting corresponding to the marginal stability parameters in Table 1 are listed in Table 2.

In all automatic control runs the input disturbance is a step change in hot water flow rate from 80% to 40% of full flow. A record of the response of the system is available in tabular and graphical form. The tabular output includes the cold water flow rate, the error integral, the error derivative, the objective function, and the system temperatures. The graphical output contains the error and objective function versus time.

The particular objective function employed in the computer software integrates the square of the error over time, as indicated below

$$F = \int e^2\, dt \tag{6}$$

Figures 6 and 7 show the response of the system with three of the sets of Z-N parameters listed in

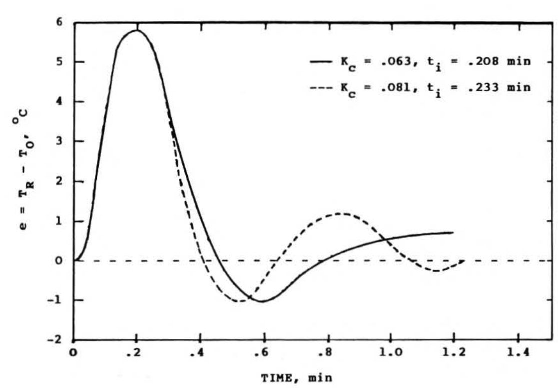

FIGURE 6. Closed-loop response to a step change in hot water flow rate using PI control with Ziegler-Nichols settings.

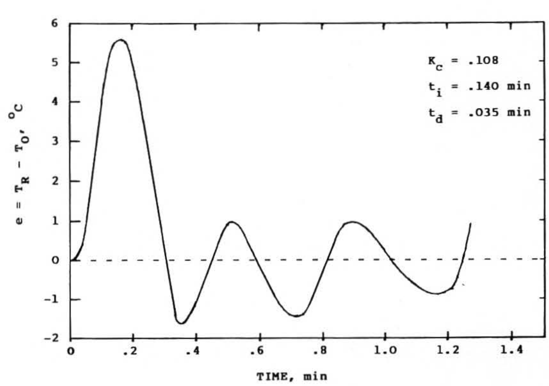

FIGURE 7. Closed-loop response to a step change in hot water flow rate using PID control with Ziegler-Nichols settings.

Table 2. An examination of the two PI runs in Figure 6 reveals that the best control is achieved using K_c = 0.063 and t_i = 0.208, the parameters based on the open-loop frequency response. The gain of K_c = 0.081 derived from continuous cycling experimentation is too large and caused excessive cycling.

The PID run with Z-N settings shown in Figure 7 represents poor control. However, this should be expected because derivative action is relatively ineffective in systems containing a large effective time delay. The heat exchanger control system contains time delays associated with flow from inlet to exit, and also time delays associated with the functioning of electronic components such as the A/D and D/A converters. In fact, an analysis of the Bode plots in Figures 4 and 5 leads to the following approximate open-loop transfer function

$$\frac{E(s)}{Q(s)} = \frac{37\, e^{-0.042s}}{(0.176s+1)(0.037s+1)} \tag{7}$$

As can be seen from the above transfer function, the loop contains an effective time delay of 0.042 minutes (2.52 seconds). This time delay is roughly 25% of the major time constant of 0.176 minutes. At the critical frequency, the effective time delay accounts for 60 degrees of the total phase lag of 180 degrees and causes crossover to occur before the smaller time constant is able to reduce the amplitude ratio. Since the resultant amplitude ratio curve is not steep in the vicinity of the critical frequency, the phase lead contributed by derivative action does not justify increasing K_c very much above the value of K_c used in PI control. This fact is apparent from the poor system response using Z-N settings with PID control.

● Optimization of Controller Setting

After completing the Z-N runs, students are required to conduct several exploratory runs to improve upon the best of the Z-N runs. The goal is to find the combination of parameters that results in the smallest error-squared integral objective function, as defined in Eq. (6). The lower limit of integration is the time of upset and the upper limit of integration is the time required for the error to drop to, and remain below, an absolute value of 0.5°C.

A partial optimization of PI control parameters has revealed that the best parameters are K_c = 0.06, and t_i = 0.208. The corresponding objective function was found to be F = 6.97. It should be noted that these optimal parameters are almost identical to the Z-N settings in Table 2, derived from the open-loop frequency response data. Optimization runs were not conducted with PID control. Therefore, it is possible that some derivative action might produce a smaller objective function than 6.97; however the optimal PID parameters for this control system are not the Ziegler-Nichols recomendations.

REPORT

The lab report for the experiment includes all calculations and/or analyses associated with the determination of $K_{c,max}$ and P_u. Students are also asked to construct an open-loop transfer function from their Bode diagrams and to discuss the relative merits of PI and PID control for the heat exchange control system.

ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance of two Manhattan College students, Elizabeth Schaub and Thomas Meloro, for their part in the preparation of software for this experiment. Ms. Schaub wrote the routines controlling the display of data at the computer monitor, and Mr. Meloro wrote the programs which graph the frequency response and automatic control runs on the dot-matrix printer.

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ChE book reviews

FUNDAMENTALS OF HEAT EXCHANGER AND PRESSURE VESSEL TECHNOLOGY

by J. P. Gupta
Hemisphere Publishing Corporation,
Washington, DC (1986),
607 pages, $45.00

Reviewed by
Stuart W. Churchill
University of Pennsylvania

This book is entirely in the form of over 1200 questions and answers. It provides descriptions of various types of heat exchangers and pressure vessels, and also a discussion of the factors which favor the choice of one form over another for reasons of economics, safety, maintenance, *etc.* Both of these aspects are of direct interest in process design and operation. The book is said to be intended for newcomers in practice and for senior-level students. However, it will surely prove to be a standard reference even for experienced engineers.

Preliminary drafts of the various chapters were reviewed by individual experts. The list of these reviewers is virtually an honor-roll of the leaders in process heat transfer. Their participation gives this book an aura of authority over a very broad range, while at the same time the singular authorship provides a greater consistency than is ordinarily accomplished in a compilation of contributions by many authors.

The book is profusely and well illustrated, which is essential for descriptive purposes. Attention in the questions and answers is focused on the choice of various types of equipment for different applications. Although some quantitative information is given in connection with such choices, procedures of design for specific equipment are not included. Such procedures of course provide the primary content of conventional books on heat transfer and process design.

Quantities are given in English units with the SI equivalent in parentheses, or vice versa, depending on the original source. A detailed table of contents and a very complete index are essential for a book of this type in which the reader will be searching for information on a few special matters rather than reading from cover to cover. Spot tests indicate that both the table of contents and the index meet this standard, although omissions were noted in the latter. For example, the "effectiveness factor" and the "correction factor" do not appear as primary items.

Fluidized beds, direct-fired boilers, cooling towers and regenerators were arbitrarily excluded, but otherwise the book is very comprehensive. Individual topics are necessarily limited in scope and thereby incomplete. For example, the discussion of spiral heat exchangers does not mention the inapplicability of the log-mean temperature difference owing to two-way heat exchange at each point of each passage.

Despite the minor omissions noted above, this book is remarkably complete and generally sound. The format of questions and answers proves to be surprisingly successful and convenient. Students in process design will find this volume to be an essential resource, and practicing engineers will find it an invaluable reference.

The author and the publisher are to be commended for producing an imaginative and useful contribution in a mature field.

Despite the overly generous statement in the acknowledgement, my contribution to the concept was only in terms of encouragement, and to the content only as a reader. Hence, I offer the above remarks objectively as a potential user. □

PRINCIPLES AND PRACTICE OF AUTOMATIC PROCESS CONTROL

by Carlos A. Smith and Armando B. Corripio, John Wiley and Sons, $43.95, 1985

Reviewed by
Glenn A. Atwood
University of Akron

This text is designed to present classical control theory and practice to senior level students and industrial practitioners. The text focuses on single variable control loop design for continuous processes using examples from the chemical process industries. The topics covered are the same as have been included in popular chemical engineering control texts for over twenty years.

The authors have prepared a text comparable to the classic by Coughanowr and Koppel. They have succeeded in their goal of preparing a text with both principles and practice. However, with the recent advances in control theory and practice, the text should include coverage of batch process control, programable controllers, adaptive control, discrete control, distributed and computer control. Many of the above topics have been included in texts for other fields since the early to mid '70's. It is imperative that chemical engineering control texts include the more modern topics and that these be included in the curriculum. The field cannot continue to cover the same topics as were covered in the past and meet the needs of our graduating engineers or the industrial users.

The text can be divided into six major sections: mathematical basics, process dynamics, control system components, single loop control system design, and additional control techniques. The section on mathematical basics covers Laplace transforms, linearization, and complex variables. The Laplace transform and linearization sections are well-written and should provide the reader with the mathematical foundation to use the techniques in controls and other areas. The linearization section includes both single and multi-variable methods with applications to typical control problems. The section on complex numbers is very short and probably should be expanded to give students an adequate background.

Chapters 3 and 4 introduce the development of transfer functions for typical first order systems along with the system response to input disturbances.
Continued on page 97.

ChE classroom

A MEANINGFUL UNDERGRADUATE DESIGN EXPERIENCE

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Frank Manning is a professor of chemical engineering at the University of Tulsa. He holds a BEng from McGill University and a MSE, AM, and PhD from Princeton University. His academic experience includes ten years at Carnegie Tech and nineteen years at Tulsa University. His current interest is field processing of petroleum—a topic he has presented worldwide.

CHANGE IS THE way of life for engineering curricula. There are many obvious reasons: emergence of calculators and computers to replace slide rules; technology advances; faculty research interests; and the genuine faculty desire to improve education.

The present discussion of a meaningful design experience addresses three topics. First, the question "What is design?"; second, current and proposed ABET design requirements; and third, criteria to define a minimum design competence.

DESIGN

Let us start by comparing Webster's (1973) definitions of engineering and science:

> ***Engineering:*** . . . the application of science and mathematics by which the properties of matter and sources of energy in nature are made useful to man in structures, machines, products, systems, and processes.
>
> ***Science:*** . . . knowledge attained through study and practice.

Simplistically, and perhaps overly so, the key difference between engineers and scientists is that engineers apply what scientists discover. And the importance of economics is epitomized by the adage, "A good engineer can do for $1 what any fool can do for $2 or more."

In other words, "Scientists tackle those problems which can be solved; engineers are faced with problems which must be solved." [8]

The original Encyclopedia Britannica definition, "Engineering is the art and science of weaving technology into the fabric of society," is worth discussing [4]. Webster [9] defines technology as: (1) technical language, (2a) applied science, (2b) a technical method of achieving a practical purpose, and (3) the totality of means employed to provide objects for human subsistence and comfort.

The present discussion . . . addresses three topics. First, the question "What is design?"; second, current and proposed ABET design requirements; and third, criteria to define a minimum design competence.

Hugh Guthrie [4] observed that coupling the Britannica definition of engineering with Webster's definition of technology generates an all-encompassing description of engineering. For (1) weaving "technical language" into the fabric of society implies the need for public understanding and approval; (2a) "applied science" reinforces the previously stated key difference between engineers and scientists; (2b) emphasizes the importance of combining theory (science) with practice (art); and (3) is equivalent to the Webster definition of engineering.

Now let us examine what is meant by design. Not surprisingly this is a prime example of "*Quot homines, tot sententiae.*" However, a safe start is the ABET definition [1]:

> **Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-**

making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, and detailed system descriptions. Further, it is desirable to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

Because this all-inclusive ABET definition is open to many interpretations, let us remember AIChE's Program Criteria statement:

> The various elements of curriculum must be brought together in one or more capstone engineering design courses built around comprehensive, open-ended problems having a variety of acceptable solutions and requiring some economic analysis.

Peters [5] extends the above definitions of design to capstone courses "where principles previously learned are put to use in situations with real-life aspects of economic evaluation, social consequences, communication, and other directly practical considerations."

Traditional though it may be, Peters' definition of design is not universally accepted. Denn [3] correctly observes that "design" is not restricted to "process design." Denn also eloquently states that design can be taught in open-ended problems and that computing technology can be a great help in solving such open-ended problems. However the statement that design is an open-ended problem is necessary but not sufficient criterion. Playing chess is certainly an open-ended challenge but who will claim design credit for a win? While design is unquestionably open-ended, it is also "real world" complete with stated or implied constraints such as economics, codes, insurance requirements, government permits, safety, environmental regulations, *etc.* Again simplistically, "Design fulfills a need while science satisfies a curiosity." [10] In design the objective is finite and includes a productive purpose. Design involves judgement which frequently includes selection from an apparently overabundant and sometimes contradictory supply of data, methods, "laws," and equations.

Successful design implies innovation and entrepreneurship. In fact, design is the *sine qua non* that differentiates engineers from scientists. Faculty who attribute omnipotence to "a strong grasp of the fundamental sciences," or "to teaching students how to think," overlook the truism—practice makes perfect, or you learn by doing. Motive also separates design from engineering science. Studying the stress tensor is engineering science but how to increase crude oil flow from an offshore platform through an existing pipeline to the onshore treating facility is a design challenge.

The recently initiated NSF funding of university-industry-government partnerships is a welcome new contribution to the challenge of adding a practice-base or industrial know-how to the existing science base.

Can anyone imagine training doctors without hospitals? Shouldn't industry play a comparable role in engineering education? The recently initiated NSF funding of university-industry-government partnerships is a welcome new contribution to the challenge of adding a practice-base or industrial know-how to the existing science base.

ACCREDITATION CRITERIA

Current accreditation practices (especially those involving design) have been subjected to much criticism. Invectives such as "mess at accreditation," "stylized charade," "bean counting," "fraud," "mindless exercises in mediocrity," have been used. Why this assault? Is it a sincere desire to improve the engineering design stem? Or is it a clever ruse to decrease the design content and thus make room for favorite research topics disguised as fundamentals? As usual, the truth lies somewhere between these two points of view.

ABET has suggested that the current curricular requirements of one year of engineering science and one half-year of engineering design be replaced with a single criterion:

> One and one-half years of an appropriate combination of engineering sciences and engineering design, with a distribution of design throughout the curriculum, that culminates in a meaningful design experience in the final year of the program.

This proposed change is very similar to the recently adopted change which combined the old criteria of one half-year of mathematics and one half-year of basic sciences into one criterion: one year of mathematics and basic sciences. Has this change improved the mathematics and/or basic science stems? Or has it merely permitted more mathematics at the expense of physics and chemistry?

The proposed one and one-half years of combined engineering science and design will, it is claimed, reduce the problem of "bean counting." And, if adopted, program evaluators may no longer be required to undergo the alleged "stylized charade" or "fraud" of seeking partial design content in many engineering courses. While trying to detect design content in engineering science courses, this ABET program evaluator has developed sympathy for Supreme Court justices. Theirs is the no-win task of distinguishing between "redeeming artistic content" and "pornography." Who pleads more fervently—professors or proprietors of adult bookstores? And who receives more criticism—ABET or the Supreme Court?

Before we rush to climb on the bandwagon and adopt this proposed panacea, we would do well to ponder three questions recently posed by Saperstein [7]:

1. **Do the criteria lead engineering programs into sufficient depth in the design experience?**
2. **Do the criteria allow the programs to instill sufficient independence and creativity?**
3. **Will the criteria prevent programs from offering a single, isolated course as their response to the design requirement?**

The last question is frightening. Will 45 credit hours of engineering science and 3 credit hours of design produce engineers or scientists?

RECOMMENDATIONS

Saperstein has stated the challenges facing ABET (and AIChE) very well and succinctly:

1) **Can we write criteria in such a way that program evaluators can judge the sufficiency of a design experience?**
2) **Within our review process, can evaluators be assured that the students have acquired the intangible understanding of the design process while they have produced the tangible product seen by the evaluator? The ultimate question for all of us is**
   - **Can all of the above be reduced into a few, mutually understood words that can be easily enforced?**

While Saperstein's challenge appears monumental, I respectfully suggest that AIChE define meaningful design experience as:

1. *A year-long sequence of two or more, senior-level capstone design courses comprising one quarter of an academic year (*e.g. *two four-credit hour semester-long courses).*
2. *These capstone design courses shall include the three "ingredients" recommended by Peters [5] (see Table 1).*
3. *We should encourage departments to include the AIChE Design contest in their senior capstone design experience.*
4. *We should encourage variety in the design projects and discourage an endless sequence of traditional chemical process projects. By all means let us include biochemical engineering, microchip manufacture,* etc.
5. *Students should be exposed to open-ended, real world problems prior to the senior-level capstone design experience. AIChE could solicit such problems and make them available (with solutions) to interested faculty.*

TABLE 1
"Ingredients" Recommended by Peters

1. **Economic Evaluation**
   - A. **cost estimation**
   - B. **concepts of cash flow and interest**
   - C. **measures of profitability**
   - D. **choice among alternative investments**
2. **Engineering Design**
   - A. **from preliminary estimates to firm process designs**
   - B. **strategy of design including shortcut methods**
   - C. **areas of practical significance such as plant location, plant layout, safety, pollution, etc.**
   - D. **equipment and component design**
3. **Real Industrial Processes**
   - A. **The course should be organized so that the students work in groups as well as individually, [on problems of varying length]**
   - B. **Computers should routinely be used where appropriate**
   - C. **Examples of real-life events should be given**
   - D. **When the course is finished, the students should complain about all the hard work they had to do, but they should also say that they finally found out where all the material they had studied previously can be put to use.**

My reasons for the above recommendations are:

Recommendation 1

Open-ended, incompletely specified design problems often constitute a "culture shock" for students accustomed to "one-right-answer" mathematical problems. A "soak time" of one year is required to wean would-be engineers from the one-correct-answer viewpoint. Adequate practice, individually and in groups, on problems of increasing length and complexity easily requires eight semester credit hours.

Recommendation 2

Max Peters' excellent summary should be interpreted broadly—surely "process" is not restricted to "traditional chemical processing," but rather is "the manufacture of any product." The design stem should include the widest spectrum of real world events: incomplete, incorrect, or contradictory data; the overriding necessity of economic viability; the practical consequences and ethics of specifying "too big" or "too small" equipment; troubleshooting; improving existing processes; *etc.* Allowing students to exercise and to develop judgement is more important than learning specific methodologies. Feedback and open-ended problems are essential.

Recommendation 3

The AIChE design contest problems are prepared very thoughtfully by outstanding design engineers. These industry experts make sure that the design problems are realistic and contain "traps" for the naive and unwary. In the 1986 contest, forty-four student solutions were submitted but only five did not commit some fatal mistake, such as extrapolating a vapor pressure curve below the freezing point [6]. Surely the place for learning such facts of life is in the classroom and not on the job. AIChE devotes a session at the annual meeting to the design contest, and the contest problem, the first-prize solution, and the judges' comments are published (*e.g.* AIChE, 1985). However, expansion of the judges' comments and publication in a more widely-circulated journal such as *Chemical Engineering Education* would be very helpful.

Recommendation 4

In the past chemical engineering has "missed the boat" in aerospace, process metallurgy, pollution control, *etc.* We must not let current and future opportunities such as biochemical and electronic-component manufacture slip away.

Recommendation 5

Senior students with three full years of fundamentals (mathematics, basic sciences, engineering sciences, computer programming) will not automatically start designing and innovating the moment the first capstone design course begins. Nor will graduates with four years of fundamentals magically become design engineers their first day on the job. Early and repeated exposures to the "engineering facts of life" are essential.

We must never forget that far, far more BS graduates work in design, manufacturing, sales, technical services, operations, and troubleshooting than in research. Let us put student welfare first and make sure that all accredited undergraduate programs contain a truly meaningful design experience.

ACKNOWLEDGEMENTS

The author thanks all those colleagues who so kindly and generously provided their inputs. However the opinions expressed herein represent the views of the author and do not, at this time, reflect any official position of AIChE's Education and Accreditation Committee.

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ChE book reviews

ENGINES, ENERGY AND ENTROPY

by John B. Fenn
W. H. Freeman and Company, 1982,
288 pages, $12.95 paper

Reviewed by
John P. O'Connell
University of Florida

"Thermodynamics is a state of mind," one of my colleagues has said, referring to the fact that the desired approach to and understanding of this noble human construct depends on one's personal taste as much as anything else. Thus, the plethora of available beginning treatments range from the mathematical and abstract, such as the impressive work of C. Truesdell, to the historical and physical, such as this charming book by Fenn, and all have at least a few champions.

Fenn's apparent objective is to make plausible and understandable the needs and uses of thermodynamic properties and analysis in two ways. One is his direct connections to the reader's everyday experience, and the other is his incisive descriptions of the evolution of thought from the rudimentary observations of cavemen, represented by Charlie (who is shown in comic

Continued on page 100.

The object of this column is to enhance our readers' collection of interesting and novel problems in chemical engineering. Problems of the type that can be used to motivate the student by presenting a particular principle in class, or in a new light, or that can be assigned as a novel home problem, are requested as well as those that are more traditional in nature, which elucidate difficult concepts. Please submit them to Professor H. Scott Fogler, ChE Department, University of Michigan, Ann Arbor, MI 48109.

A CONTRIBUTION TO THE TEACHING OF THERMODYNAMICS

A PROBLEM BASED ON THE GIBBS-DUHEM EQUATION

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PROBLEM

A question can be set up in the form of a paradox, based on a commonly-used form of the Gibbs-Duhem equation. I have used this problem in an advanced thermodynamics class and as a question in an oral examination for admission to candidacy for the degree of PhD.

Consider a system consisting of two phases, α and β, and two components, 1 and 2. The condition for chemical equilibrium with respect to mass distribution is

$$\mu_i^\alpha = \mu_i^\beta = \mu_i \tag{1}$$

where μ_i is chemical potential. Differentiating Eq. (1), we obtain

$$d\mu_i^\alpha = d\mu_i^\beta = d\mu_i \tag{2}$$

We write the Gibbs-Duhem equation in the form

$$x_1^\alpha d\mu_1^\alpha + x_2^\alpha d\mu_2^\alpha = 0 \tag{3a}$$

$$x_1^\beta d\mu_1^\beta + x_2^\beta d\mu_2^\beta = 0 \tag{3b}$$

where x is mole fraction.

We now use Eq. (2) to eliminate $d\mu_1$ from Eqs. (3a) and (3b). Thus

$$d\mu_1 = -\frac{x_2^\alpha}{x_1^\alpha} d\mu_2 \tag{4a}$$

$$= -\frac{x_2^\beta}{x_1^\beta} d\mu_2 \tag{4b}$$

Equating the coefficients of $d\mu_2$, and rearranging, we obtain

$$\frac{x_2^\alpha}{x_2^\beta} = \frac{x_1^\alpha}{x_1^\beta} \tag{5}$$

This can be true only if the compositions of the two phases are the same. A little algebraic manipulation yields

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$$x_2^{\alpha} = x_2^{\beta} \tag{6a}$$

$$x_1^{\alpha} = x_1^{\beta} \tag{6b}$$

Hence the phases have the same composition, and there can be only one phase. But we had postulated that there are two phases.

The question is, "Where did we go wrong?"

It is worth noting, before giving the solution to this problem, that less than half the teachers of thermodynamics to whom this problem has been posed have given the correct answer at once. Also, at least one very eminent thermodynamicist (now deceased) has made precisely the mistake that is the basis for the problem, and persisted in repeating it in several editions of his book on thermodynamics.

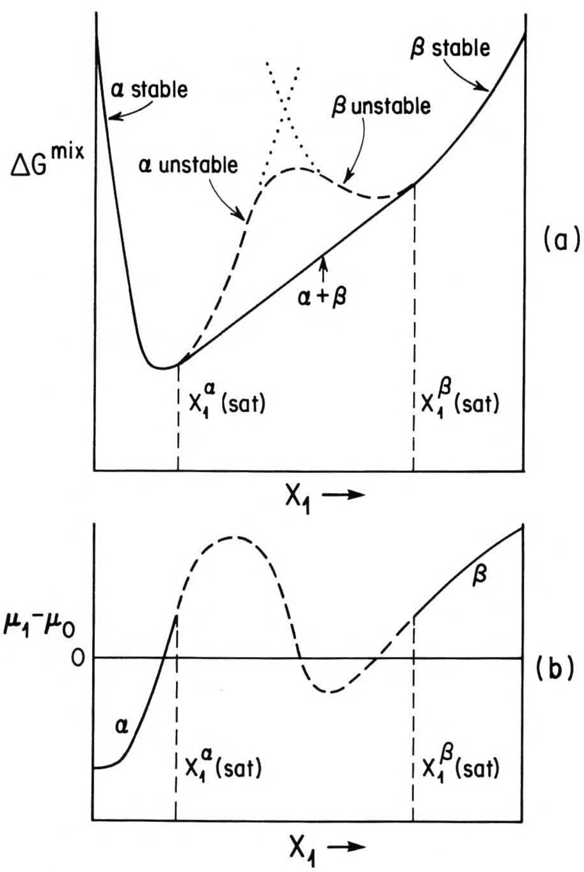

FIGURE 1a. Free energy of mixing vs mole fraction, for a two-component system with a miscibility gap: ————, free energy in unstable region; . . . ., free energy in central region of gap, for two crystalline solids having unlike crystal structures.

FIGURE 1b. Chemical potential of component 1 in system described by Fig. (1a).

. . . less than half the teachers of thermodynamics to whom this problem has been posed have given the correct answer at once. Also, at least one very eminent thermodynamicist (now deceased) has made precisely the mistake that is the basis for the problem, and persisted in repeating it . . .

SOLUTION

The problem has a solution which can be drawn from a paper by Ibl and Dodge [1].

The Gibbs-Duhem equation, in the form that was employed in the posing of the problem, namely Eq. (3a) and Eq. (3b), was written for constant temperature and pressure. But a binary, 2-phase system at constant temperature and pressure is invariant, according to the Phase Rule. So, although the condition of equal chemical potentials holds, for each component in all phases, *e.g.*, Eq. (1), this equation is mathematically "pathological." It cannot be differentiated with respect to composition, for a binary system. Such a differentiation would mean, physically, that the concentration of a component was being varied. But that would be impossible in view of the zero variance of the system.

So, the differential form, Eq. (2), is not valid when $d\mu_i$ is not identically zero. The term, $d\mu_i$ (if not equal to zero) has more than an exclusively mathematical existence only when there is but one phase. Hence the "x" terms on the left in Eq. (3) have zero as their multipliers, and this limits Eq. (3) to the trivial case of $0 = 0$.

We can demonstrate the invalidity of Eq. (2) by an alternative method. Consider the functional dependence of the free energy of the *equilibrium* system on composition. This function is a smooth curve when only one phase is present. When there are two phases in equilibrium, the free energy in the two phase region is a linear function of mole fraction in the overall composition.

Figure 1 shows schematically (a) the dependence of free energy on composition at fixed temperature and pressure, and (b) the dependence of chemical potential of component 1 upon composition. Compare Ref. [2], p. 278. In Figure 1a, the dashed line that crosses the central region smoothly, describes the nonequilibrium condition for systems in which the phases are fluid. Systems in which both phases are crystalline may have miscibility gaps caused by influences such as differences in crystal structure. For these, the extrapolated free energy curves for the phases α and β in the unstable region will not join smoothly. (This argument is the basis for one of the Hume-Rothery rules regarding the existence of solid solutions in alloys [3].)

In general, the regions around the minima in the free energy curves for phases α and β, Figure 1a, will not have exactly the same shape. So while

$$\mu_1(x_1^\alpha \text{ sat}) = \mu_1(x_1^\beta \text{ sat}) \tag{7}$$

the slopes at the saturation compositions

$$\left(\frac{\partial \mu_1^\alpha}{\partial x_1}\right)_{x_1^\alpha \text{sat}} \quad \text{and} \quad \left(\frac{\partial \mu_1^\beta}{\partial x_1}\right)_{x_1^\beta \text{sat}} \tag{8}$$

will, in general, have two different values.

Therefore, in general

$$d\mu_1^\alpha(x_1^\alpha \text{ sat}) \neq d\mu_1^\beta(x_1^\beta \text{ sat}) \tag{9}$$

Thus, if the values of the differentials $d\mu_i$ and $d\mu_j$, in Eq. (2), are not zero, their values are not unique. Hence Eq. (3) is not a physically relevant set of equations.

Removing the constraint of constant T and P, we write the valid, general form

$$x_1^\alpha d\mu_1 + x_2^\alpha d\mu_2 = V_m^\alpha dP - S_m^\alpha dT \tag{10a}$$

$$x_1^\beta d\mu_1 + x_2^\beta d\mu_2 = V_m^\beta dP - S_m^\beta dT \tag{10b}$$

where the subscript, m, denotes, per mole of (1 + 2).

Ibl and Dodge have discussed how the Gibbs-Duhem equation may be applied correctly to a binary liquid-vapor system. Their result, at constant temperature and with neglect of gas imperfections, can be put in the form

$$x_1^\alpha d\mu_1 + \left(1 - x_1^\alpha\right) d\mu_2 \cong -\frac{V_m^\alpha}{V_m^\beta} RTd\,\ell n\,P \tag{11}$$

where α refers to the liquid and β to the gas phase. The right side of Eq. (11) is approximately zero if

$$V_m^\alpha << V_m^\beta \tag{12}$$

which is generally true at ordinary pressures, though not at high pressure.

For the gas phase

$$x_1^\beta d\mu_1 + \left(1 - x_1^\beta\right) d\mu_2 = -V_m^\beta\, dP \cong -RTd\,\ell n\,P \tag{13}$$

At constant pressure, the result given in Ref. (1) can easily be put in the form

$$x_1^\alpha d\mu_1 + \left(1 - x_1^\alpha\right) d\mu_2 = \frac{\Delta H}{RT^2}\, dT \tag{14}$$

where ΔH is the enthalpy of the phase change. The term on the right cannot be neglected.

If we include the constraint on the number of components for the constant-temperature-constant-pressure form for a 2-phase system to be valid, we may write

$$\sum_{i=1}^{n} x_i^\alpha\, d\mu_i = 0, \qquad n > 2 \tag{15a}$$

$$\sum_{i=1}^{n} x_i^\beta\, d\mu_i = 0, \qquad n > 2 \tag{15b}$$

A corresponding form can be written for a system with three phases, with the constraint that $n > 3$. If the number of phases is ν, the constraint is $n > \nu$. If the constraint condition in Eq. (15) is not met, then the general form, *i.e.* Eq. (10), must of course be used.

DISCUSSION

The precise form of the constraints on the form of the Gibbs-Duhem equation, given above, is directly implicit in the complete Gibbs-Duhem equation itself, and in the Phase Rule. The rigorous Gibbs-Duhem form is presented in practically all modern chemical engineering thermodynamics textbooks. But I have not seen the constraints (as in Eq. (15)) spelled out explicitly. Indeed, authors of some textbooks apply the Gibbs-Duhem equation to a single-phase, *e.g.* using Eq. (3a) by itself, without pointing out that this form is useable *only* in single-phase systems.

E. A. Guggenheim fell into this trap some 30 years ago, and he persisted in using the form, Eq. (3), for binary, two-phase systems, through five editions [4]. Thus, he wrote

$$\left(1 - x^\alpha\right) \frac{\partial \mu_1^\alpha}{\partial x^\alpha} + x^\alpha \frac{\partial \mu_2^\alpha}{\partial x^\alpha} = 0$$

$$\left(1 - x^\beta\right) \frac{\partial \mu_1^\beta}{\partial x^\beta} + x^\beta \frac{\partial \mu_2^\beta}{\partial x^\beta} = 0$$

This is a verbatim transcription of Guggenheim's Eqs. 5.60.6 and 6.60.7.

Guggenheim's explicit purpose in his Section 5.60 was to derive rigorous, general formulae in regard to the effect of pressure and temperature on interfacial tension, in two-phase systems, that were "applicable to any interface in any system of two components." He noted, however, "We warn the reader that these formulae are too complicated to be of any use." Compare Ref. [5], for a rigorous treatment of the pressure coefficient of interfacial tension.

In view of the adoption of the error that I have noted, by so eminent a thermodynamicist as Guggenheim, surely a student who, un-warned, makes this mistake should not be cast into outer darkness. Thus, there is an obligation for teachers of chemical thermodynamics to caution against this error. And it would be, to say the least, desirable for workers in phase equilibria to be reminded of the Ibl and Dodge treatment in connection with testing vapor pressure data for self-consistency, via the Duhem-Margules equation.

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REVIEW: Automatic Process Control

Continued from page 89.

Example problems are typical of the chemical process industries. Chapter 3 contains an excellent comprehensive introduction to block diagrams. However, this section seems out of place and disrupts the dynamic response presentation. Chapter 4 is primarily limited to non-interacting and interacting series of first order systems with just a brief mention of other higher order systems.

Chapter 5 is a discussion of control system components including the sensors and transmitters, the control valve, and the controller. The section on control valves includes design and selection procedures from two major valve manufacturers, a discussion of the control valve types, and the importance of including both the valve and piping system characteristics when selecting control valves. Appendix C provides a discussion of specific equipment and is a welcome addition to the text. The section on controllers includes a discussion of the major control modes along with pictures of different classical controllers. A major omission in this section is the absence of a discussion about programmable controllers.

Chapter 6 introduces the reader to closed loop control system response, control system stability, control system tuning, and control system synthesis. This section will be especially valuable to those practicing in plants with standard analog controllers.

Chapter 7 contains the classical single loop feedback control design procedures, including both the root locus and frequency response techniques. The root locus procedures are presented through the use of examples. The open loop frequency response techniques at times were confusing because of the symbology which is different than that often used in the literature. Closed loop response from the open loop response and the Nyquist procedures are briefly discussed. The chapter contains a section on pulse testing which should be expanded if it is to be of use to the reader. A rearrangement of material in Chapters 6 and 7 would improve readability of this major section.

Chapter 8 covers additional topics in control including ratio control, cascade control, a brief introduction to multivariable control and de-coupling, and an introduction to feed forward control. The coverage is sufficient to introduce the reader to the topic but is not sufficient for design purposes. A further limitation is the few references provided for further reading.

Chapter 9 is a brief introduction to the modeling of complex processes. It provides an overview of procedures to develop and solve the model and provides simple examples. As with Chapter 8, additional background will be required for use in design.

Appendix A contains the standard control sheet notation. Appendix B contains a series of case studies in control which are valuable for the student. Appendix D contains root finding programs written in FORTRAN. These are a valuable addition to the text.

The text contains numerous solved examples and has abundant problems at the end of each chapter. The problems are closely related to the topics presented.

The use of the first person was at times distracting to this reader. There were sections which could have benefitted significantly from a tightening of the presentation. Additional references for each chapter would be valuable for those wishing a more comprehensive discussion in specific areas. □

ChE classroom

A SIMPLE MOLECULAR INTERPRETATION OF ENTROPY

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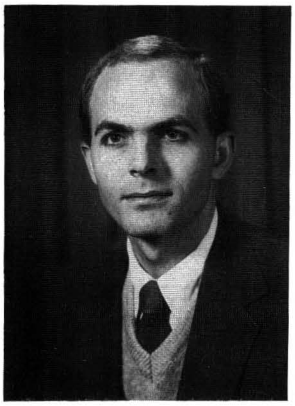
A CHALLENGE OF MODERN physical science and engineering is to satisfy students as to the connection between fundamental microscopic theories (*e.g.*, gas kinetic theory or quantum mechanics) and macroscopic measurements (*e.g.*, free energy or entropy changes). An approach based on simple notions from gas kinetic theory (thus avoiding the relatively inaccessible approach provided by statistical thermodynamics [1]) has recently been proposed [2] for explaining such macroscopic concepts as heat and work, with specific applications to simple thermodynamic processes. The purpose of this paper is to extend this simple approach so as to provide easily assimilated molecular explanations of entropy changes for such processes.

INTERNAL ENERGY, HEAT, AND WORK

The most direct link between the microscopic theories and macroscopic measurements is the internal energy E. For a system of molecules, the total energy is essentially the sum of the individual molecular energies measured relative to some arbitrarily established reference configuration. It can be easily shown [3] that all other macroscopic thermodynamic quantities (*e.g.*, free energy, enthalpy, *etc.*) are simple mathematical extensions of this internal energy which are in some way convenient for the understanding of thermodynamic processes.

A given system of molecules (at thermodyamic equilibrium) is characterized by a temperature T. It is easy to show [4] that such a system of molecules exists in a set of distributions of energy (translational, vibrational, rotational, electronic) centered around the Boltzmann distribution. This equilibrium distribution of the energy among the molecules is, in a sense, a naturally random arrangement of energy within the physical constraints of fixed particle number and fixed total internal energy. It is the naturally occurring distribution which arises from the most random arrangement possible.



Boyd A. Waite has been an assistant professor in the Chemistry Department of the United States Naval Academy since 1982. He received his BS from Brigham Young University in 1978 and his PhD from the University of California, Berkeley, in 1982. His primary research interests are in molecular reaction dynamics and the physical chemical aspects of biological phenomena.

It has been shown [5] that an additional input of internal energy into a system already in Boltzmann equilibrium results in a rapid "randomization" of the energy among the particles so that a new Boltzmann distribution is formed, characterized by a higher temperature T. Energy can be added to such a system in two distinct ways, giving rise to the phenomena commonly referred to as heat and work.

As described previously [2], heat and work are mechanisms for energy transfer processes involving contact between molecules set within unique distributions. Heat is the mechanism for energy transfer between two systems, both of which are in naturally random distributions. Work, on the other hand, is the mechanism of energy transfer between two systems, at least one of which presents itself in some sort of organized distribution (non-Boltzmann).

ENTROPY

One of the most crucial and least understood of all macroscopic quantities is entropy. Accepting the simple definition of entropy as the measure of the randomness inherent to a system (with reference to a completely non-random condition), it appears that a molecular understanding of entropy change lies not in the energy characteristics of individual molecules, but in the nature of distributions of energy among systems of molecules. A single molecule may possess internal energy, but it cannot be described as possessing an inherent amount of randomness. Randomness must be measured by the number of different ways in which the internal energy can be distributed among a system of particles. For example, if the total internal energy available is zero, there is only one unique way of distributing it among the particles. More internal energy (corresponding to higher temperatures) results in more possible distributions. Of course, it can be shown [4] that the Boltzmann distribution consists of a very large number of *identical-looking* distributions.

For a gas phase system of molecules, one of the important measurables relating to entropy is the volume. The larger the volume, the more translational energy levels become available for occupation by individual molecules, resulting in more alternatives for constructing distributions. A larger volume, therefore, leads to a higher number of identical-looking naturally random distributions, *i.e.*, a larger entropy.

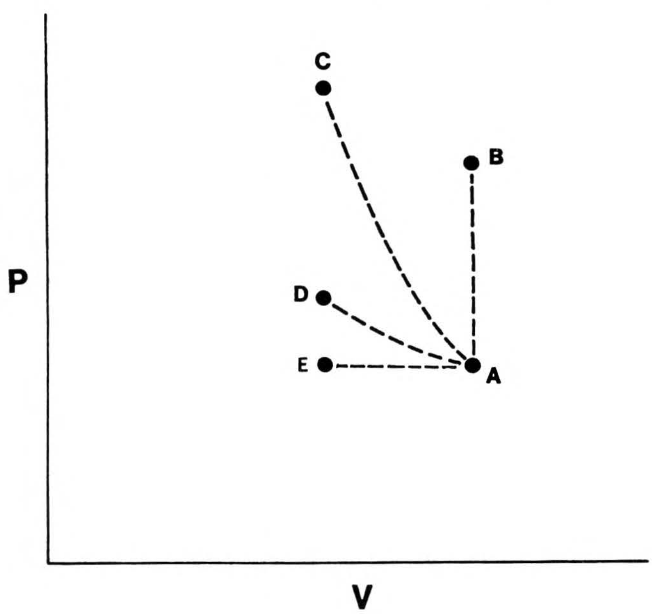


FIGURE 1. A PV diagram depicting four typical gas processes. A-B is a constant volume process resulting in an increase of entropy ($\Delta T>0$, $\Delta V=0$; $\Delta S>0$). A-C is an adiabatic compression resulting in no change in entropy ($\Delta T>0$, $\Delta V<0$; $\Delta S=0$). A-D is an isothermal compression resulting in a decrease in entropy ($\Delta T=0$, $\Delta V<0$; $\Delta S<0$). A-E is an isobaric compression resulting in a larger decrease in entropy than the isothermal case ($\Delta T<0$, $\Delta V<0$; $\Delta S<0$).

Another important factor in changing entropy is the temperature. Raising the temperature is a result of increasing the total amount of internal energy available for distribution, leading to an increase in the number of identical-looking arrangements available to the system of particles. Thus, as with the volume, increase in temperature results in an increase in entropy.

ANALYSIS OF SOME SIMPLE THERMODYNAMIC PROCESSES

The four simple gas processes shown in Figure 1 will each be considered separately in order to illustrate the concepts of molecularity relating to heat, work, and entropy as developed above. These processes can be considered as reversible so long as the distributions of energy for the systems are maintained as equilibrium distributions at each infinitesimal step of the process. Othewise, this constraint need not be invoked.

The constant volume process A-B results when a gas confined to a rigid container with diathermal walls is brought into contact with a bath at a higher temperature. Heat transfer occurs through the walls via the random-random mechanism described above. Notice that there is a "flow" of "randomness" in the direction of the gas. Since the walls are rigid, there is never an organized energy transfer. The internal energy of the gas increases, leading to a new Boltzmann distribution corresponding to a higher temperature T. Entropy has increased due to the temperature increase (although the volume is constant).

The adiabatic process A-C results when a gas confined to a container with adiabatic walls is compressed. There is no contact with any external randomly distributed system. The compression results in a completely organized energy transfer, *i.e.*, it corresponds to work and results in an increase of internal energy of the system. Upon redistribution of this added energy, the gas achieves a new Boltzmann distribution with higher temperature T, resulting in a contribution of increased entropy. However, since the volume has decreased, there is an equal contribution of decreased entropy yielding a net result of no change in entropy of the system. This can be seen clearly by noting that since there has been no contact with external random distributions, there can be no change in randomness of the system. Hence the entropy change for this adiabatic process is precisely zero.

The isothermal process A-D results when a gas confined to a container with diathermal walls is compressed. The compression of the box results in organized energy transfer (work) and would result in a temperature increase except for the fact that the diathermal walls allow for contact between two randomly distributed systems. Since the work transfer tends to push the temperature up, the natural "flow" of "randomness" will be away from the gas towards the external bath. Hence, as far as the system of gas in concerned, the isothermal compression has resulted in a net decrease of randomness, hence a decrease of entropy. This is also evident since the temperature has stayed constant while the volume has decreased.

Finally, the isobaric process A-E results when a gas confined to a container with diathermal walls is compressed and also immersed in a variable temperature bath which is adjusted so as to keep the internal pressure of the gas constant. Again, the compression results in an organized transfer of internal energy (work) tending to increase the temperature. In order for the system to retain constant pressure, however, it is necessary for the increased internal energy to escape via the only route available to it, *i.e.*, the random distribution contact with the external bath. Not only must there be such a contact, but the bath must be adjusted so that the temperature actually decreases. This results in a doubly intense outward "flow" of internal energy via the random distribution mechanism (heat). Hence, the entropy of the system actually decreases more than in the isothermal case. Also, since both the volume *and* temperature decrease for this process, it is clear that the entropy decrease is greater than for the previous case.

Of course, all of these examples have been previously described [2] in terms of pressure effects. The purpose of this set of descriptions has been to extend the gas kinetic ideas to the very difficult concept of entropy.

CONCLUSION

Definitions of internal energy allow for direct connection to the macroscopic thermodynamic quantities commonly sought by scientists and engineers. The aim of this work has been to demonstrate a simple connection between molecularity (as contained in gas kinetic theory of distributions) and macroscopic quantities such as entropy. It has been shown that entropy, defined as a measure of randomness relative to some reference condition, can be easily interpreted in terms of the distributions and how they change. "Flow" of "randomness" due to different interactions betweeen systems clearly helps to explain entropy changes. While this approach may not simplify the actual calculations required in applications of thermodynamics, it is hoped that it provides a satisfying semi-quantitative explanation of the inherent connection between molecular mechanics and macroscopic thermodynamic quantities.

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REVIEW: Engines, Energy, Entropy

Continued from page 93.

drawings with clever poems on most pages), to the ideas and results of the great thermodynamicists of the 19th Century. Further, everything is given to accomplish the essential calculations for thermal processes of all types. Thus, anyone with college level experience and intelligence can calculate the efficiencies of the various automotive engine and heat pump cycles without knowing either logarithms or integration beforehand—even their basics are included.

This is not to say that the book is superficial or incomplete (except that it is restricted to constant-composition systems). The order of contents is ancient observations, temperature, systems and states, work, heat, cycles (including Carnot's), energy, heat engines, entropy, and followed by appendices on mechanical properties, logarithms, entropy as a property, atomic weights and symbols. Each chapter has useful and enjoyable worked examples and problems whose answers are given in the back. I found the introduction of entropy quite nice since energy had previously been revealed as a quantity we use merely for keeping track of observations in a special way, and the distinction of heat and work had been carefully established. Then the desirability for having another state property of the special form $\delta q/T$ could be easily justified by several rigorous, but simple and novel, physical processes and mathematical relationships. Unlike the discussions of some others, I found the portions devoted here to the treatments of temperature scales, pure component phase behavior and thermodynamic cycles to be interesting and in excellent balance with the more intriguing historical, mathematical and molecular discussions. I would expect the book to be challenging to students, but also not expect to hear any complaints about obscurity or loftiness.

While the book could not serve as the only text for an engineering course, I recommend that all instructors of beginning engineering thermodynamics have a copy in their library and consider it for either a supplementary required book or a reference for their students to access. Teachers will find it a valuable resource for correct citations of thermodynamic history, for good concepts, developments and problems for beginners and for enhancing their own appreciation of the wondrous breadth of possibilities that thermodynamics allows in pedagogy and application. It may also be the best way to help that not-so-small set of students whose understanding depends on concrete physical examples and straightforward discussion in a text they can hold in their hands as much as, if not more than the sophistication and beauty of the logic described by their instructor. □

INTEGRAL METHODS IN SCIENCE AND ENGINEERING
Edited by F. R. Payne, C. C. Corduneanu, A. Haji-Sheikh and T. Huang
Hemisphere Publishing Company, 1986, 653 pages, $95.50

Reviewed by
Anthony G. Dixon
Worcester Polytechnic Institute

This is a proceedings volume of the first international conference on global techniques, held at the University of Texas at Arlington in March, 1985. The main emphasis of the conference and its proceedings was and is global solution methods, such as the finite element method (FEM), boundary elements (BEM) and integral transforms, to name a few. A second emphasis is the application of such methods to a wide variety of physical problems, of which those in the fluid mechanics and thermal sciences areas are probably of most interest to chemical engineers.

The book contains fifty papers and two synopses, arranged into six topic areas: mathematical physics, mathematical analysis, fluid mechanics, solid mechanics, thermal sciences and finally optimization and population dynamics. Some unity with areas is attempted by means of a summary by one of the editors, before the papers for each area. Given the aim of diversified applications, however, this is not very successful.

The volume itself is attractively bound and well-presented. The papers are not in a standard type, being reproduced from camera-ready copy, but apart from one or two cases they are clearly laid out and easy on the eye. The writing styles vary widely, from introductory (as in Payne's advocacy of direct formal integration [DFI] methods) to the very abstruse "theorem-proof" layout of one or two contributions in the mathematical analysis section.

I do not believe this book would be suitable as a main text for any chemical engineering or applied mathematics course, due to its diversified nature. It is unlikely that there is *enough* of interest to any one reader to warrant the $95 purchase price. On the other hand, there will be *something* of interest to anyone using mathematical methods in engineering. A copy should be available in the library of any educational institution, from which judicious selections could well enhance graduate courses in applied mathematics, fluid mechanics or heat transfer. □

ChE books received

Seventh Symposium of Biotechnology for Fuels and Chemicals, edited by Charles D. Scott; Wiley Interscience, Somerset, NJ 08873; 741 pages, $84.95 (1986).

Design of Devices and Systems, by William H. Middendorf; Marcel Dekker, New York, NY 10016; 456 pages, $35 (1986).

Selected Papers of Turner Alfrey, edited by Raymond F. Boyer and Herman F. Mark; Marcel Dekker, 270 Madison Ave., New York 10016; 592 pages, $95 (1986).

Handbook of Aqueous Electrolyte Solutions: Physical Properties, Estimation and Correlation Methods, by A. L. Horvath; John Wiley & Sons, Halsted, Somerset, NJ 08873; 631 pages (1985).

Dioxins in the Environment, by Michael A. Kamrin and Paul W. Rogers; Hemisphere Publishing, 79 Madison Ave., New York 10016; 328 Pages, $49.95 (1985).

Process Plant Layout, Edited by J. C. Mecklenburgh; Halstead Press, Wiley & Sons, Somerset, NY 08873; 625 pages (1985).

Fabric Filtration for Combustion Sources, R. P. Donovan; Marcel Dekker, New York, NY 10016; 448 pages, $75 (1985).

Economic Analysis and Investment Decisions, Chi U. Ikoku; John Wiley & Sons, Somerset, NJ 08873; 277 pages, $34.95 (1985).

Quality Assurance in Process PlantManufacture, by J. H. Rogerson; Elsevier Publishing Company, 52 Vanderbilt Ave., New York, NY 10017; 159 pages, $41.25.

High Temperature Heat Exchangers, by Mori, Sheindlin and Afgan, published by Hemisphere Publishing, 79 Madison Ave., New York, NY 10016; 606 pages, $95.00.

Heat Exchanger Sourcebook, edited by J. W. Palen, published by Hemisphere Publishing, 79 Madison Ave., New York, NY 10016; 805 pages, $59.95.

Managing Steam: An Engineering Guide to Commercial, Industrial and Utility Systems, edited by Jason Makansi, published by Hemisphere Publishing, 79 Madison Ave., New York, NY 10016; 224 pages, $37.95.

ChE international

THE DEVELOPMENT OF APPROPRIATE CHEMICAL ENGINEERING EDUCATION FOR NIGERIA

O. C. OKORAFOR
University of Port Harcourt
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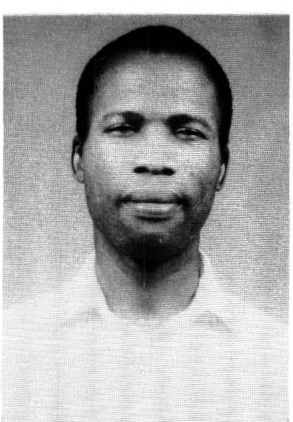
THE CULTURAL ENVIRONMENT of a young Nigerian engineer is different from that which is experienced by a young man in an industrialized country. Our students do not grow up surrounded by the familiar products of technology. They do not have the casual confidence in technology that North Americans have. Technical knowledge comes from books, but unfamiliarity with technology in daily life makes the transition from book or theory into reality more difficult.

The work environment is also different. A young graduate in an industrially developed country starts work in a department where there are many skilled and knowledgeable people available, and in his first two years he learns. He could do nothing, and the job would still be done by others in the organization. In Nigeria a graduate engineer entering industry is immediately given an important, high-level position where he is expected to get things done. Yet, the more pressing the need for the engineer to perform, the lower the probability is that there will be trained personnel to support him or routines to guide his ac-



Ogbonnaya Charles Okorafor graduated with BSc (1977) in chemical engineering at the University of Lagos. After graduation he worked for two years as a research engineer with the Federal Institute of Industrial Research, Oshodi Lagos. He received his MASc (1980) and his PhD (1982) from the University of British Columbia, Vancouver, and returned to Nigeria as a Lecturer at the department of chemical engineering, University of Port Harcourt. His present research interests include crystallization and process engineering.

TABLE 1
Existing Curriculum, Bachelor of Engineering

CREDIT/COURSE *First Semester*	CREDIT/COURSE *Second Semester*
YEAR I	
3 Communication Skills, English	3 Science, Technology & Society
3 Chemistry (Matter/Energy I)	3 Chemistry (Matter & Energy II)
3 Physics (Mechanics/Properties of Matter)	3 Physics (Introduction to Electricity and Magnetism)
3 Preparatory Mathematics	3 Calculus with Analytic Geometry I
2 Engineering Drawing I	3 Engineering Drawing II
1 Workshop Practice I	1 Workshop Practice II
YEAR II	
3 Physical Chemistry	3 Inorganic Chemistry
3 Physics (Vibration/Waves)	3 Computer Programming
3 Calculus/Analytic Geometry II	3 Calculus/Analytic Geometry III
3 Engineering Statics	3 Engineering Dynamics
3 Organic Chemistry	3 ChE Process-Analysis
Summer Industrial Attachment	
YEAR III	
3 Probability/Statistics	3 Mass Transfer Processes
3 Fluid Mechanics	3 Differential Equations
3 Engineering Thermodynamics	3 Heat Transfer
3 Strength of Materials	3 Engineering Economics
1 Workshop Practice III	3 Particulate Systems
Summer Industrial Attachment	
YEAR IV	
3 ChE Kinetics and Catalysis	3 Electrical Technology
3 Industrial Chemistry	3 Chemical Reaction Engineering
3 ChE Lab I	3 ChE Lab II
3 Polymer Science and Technology	3 Numerical Methods
	3 Principles of ChE Design
Summer Industrial Attachment	
YEAR V	
3 Process Dynamics/Control	3 Chem Process Design Project*
3 Process Modeling/Optimization	6 ChE Research Project*
3 ChE Analysis	1 Technical Seminar
3 Intro: Biochemical Engineering	
3 Chem Technology of Polymers	*Any Two Courses From*
	3 Petroleum Production Eng.
	3 Food Processing Engineering
	3 Physico-Chemical Methods in water Pollution Control
	3 Pulp/Paper Technology
	3 Energy Resources/Production

*Actually started in the first semester.

tions or decisions. In this organizational context, it is not surprising to find even the most competent engineer alarmed by the size of the job and by his inability to perform.

It seems obvious that given these differences, variations would exist in the chemical engineering education offered to our students and those offered to North American students. This paper addresses the question of what chemical engineering education in Nigeria should strive for.

. . . variations exist in the chemical engineering education offered to our students and those offered to North American students. This paper addresses the question of what chemical engineering education in Nigeria should strive for.

EXISTING CONDITIONS

As educators, our degree of freedom for improving engineering practice in Nigeria is largely restricted to manipulating the curriculum to satisfy goals which we set. These goals depend on what we perceive chemical engineering to be, as well as a consideration of the country's needs.

With many diversified areas of activity for chemical engineers, a fundamental emphasis on teaching principles rather than specific industrial applications has been employed in the teaching of chemical engineering all over the world. The success of this approach (even in countries such as Nigeria) can be attested to by the fact that no one has complained of a lack of chemical engineering *knowledge* by developing nations' engineers. The problem has always been an inability to apply this knowledge in practice. To remedy this, I suggest a different approach in the research and design courses rather than a radical change in curriculum.

TABLE 2
Proposed Curriculum, Bachelor of Engineering

CREDIT/COURSE *First Semester*	CREDIT/COURSE *Second Semester*
YEAR I	
(No change from existing curriculum)	
YEAR II	
3 Calculus/Analytic Geometry II	3 Inorganic Chemistry
3 Engineering Statics	3 Computer Programming
3 Physics (Vibration/Waves)	3 Calculus/Analytic Geometry
3 Physical Chemistry	3 Engineering Dynamics
3 Organic Chemistry	3 Differential Equations
3 ChE Process Analysis	3 Fluid Mechanics
Summer Industrial Attachment	
YEAR III	
3 Probability/Statistics	3 Particulate Systems
3 Engineering Thermodynamics	3 ChE Lab I
3 Strength of Materials	3 ChE Kinetics/Catalysis
3 Engineering Economics	3 Separation Process
3 Heat Transfer	3 Industrial Chemistry
3 Mass Transfer	
Summer Industrial Attachment	
YEAR IV	
3 ChE Lab. II	3 Process Modeling/Optimization
3 Polymer Science/Technology	3 ChE Analysis
3 Electrical Technology	2 Intro to Biochemical Eng.
3 Engineering Economics	2 Technical Seminar
3 Chem Reaction Engineering	3 Chem Technology of Polymers
3 Electrical Technology	*Any two courses from courses in the existing 5th year program*
	3 Electives
Summer Industrial Attachment	
YEAR V	
9 ChE Research	18 ChE Design Practice
9 ChE Design	

PROPOSED INNOVATION

The Nigerian chemical engineering curriculum should still be a five-year program, but with the modification that the courses and industrial training requirements be satisfied in four years. The fifth year would then serve as an internship period for the students. A similar pattern is found in the preparation for careers in medicine or law, and it is characteristic for development of professional competence. The internship year would be devoted to research, design, and fabrication. Table 1 lists the existing curriculum of a Nigerian University (University of Port-Harcourt), and the proposed revision is given in Table 2.

Most industries in Nigeria are "import-substitution" ventures that depend on foreign sources for raw materials and equipment. The flaw in this policy has manifested itself during our austerity period, and numerous calls have been made for alternative sources of indigenous raw materials. The satisfaction of this need depends on research. If progress is to be made, Nigeria needs people who know and can apply research methodology.

Teaching research methodology to engineering graduates is imperative. Presently, most students are not willing to pursue a graduate program because there are limited employment opportunities for doctorate degree holders in Nigeria. With a background in research, it would be easier for a fresh graduate to handle problems where there are little or no data available. Research topics should extend from the search for alternative raw materials to other issues peculiar to Nigeria, such as political factors where North-South balancing could dictate a plant location.

The remaining part of the internship year could be devoted to design and construction of equipment, either for pilot-plant or industrial plant scale. Efforts should be geared toward helping the student translate theory and calculation into engineering drawings, and from this to actual hardware. This aspect of the program would require help from outside Nigeria, perhaps in the form of fellowship awards to one or two chemical engineering lecturers to work with a major design-contracting company for a specific period every year.

The design portion of the internship year must deal with the following key topics:

- **Chemical Engineering Systems Analysis: definition of needs and goals, evolution/innovation, chemical engineering systems and environment interaction, effect of socio-techno-economic criteria.**
- **Chemical Engineering Design Analysis: a) principles of authentic design, b) creativity-innovation-reliability in design which should include group dynamics, brainstorming, definition and types of failure, and reliability parameters in design, c) chemical engineering design project, d) feasibility study involving physical realizability, economic worthwhileness, and financial feasibility, e) preliminary design including design concept, mathematical modeling, and sensitivity compatibility and stability analysis, f) synthesis of solutions involving methods of optimization, linear, nonlinear and dynamic programming, and general simulation techniques, and g) evaluation and decision including value/worth transformations, estimates of system utility/worth, the decision matrix, decision under risk/certainty/uncertainty, expected values—probabilities, competitive decisions, and mixed stategies.**
- **Chemical Engineering Application Analysis: a)network planning techniques with general network methods, critical path analysis, time-cost effectiveness studies, and control of the system in action, b) matching of the design to the environment, c) modifications, d) implementation, and e) trouble shooting.**

The design course should not be a theoretical one. The implementation part should require the actual construction of a plant (or some units of it) by the student-lecturer group. In situations where there is not enough information for design, the group should use research methods to fill the gap. In this way students would learn to appreciate the value of research in an industrial concern. This value is not recognized by graduate engineers in Nigeria and other developing countries. To assist this program, Nigerian government policy should make it possible to award part or all of plant design contracts to chemical engineering departments at various universities in the country. Some of the benefits of such a policy would be an increase in revenue for the institution, a faster rate of technology acquisition, and more confident and capable graduates. It is assumed that a solid understanding of design and construction would help the graduate to adapt to any type of engineering function. In this proposal, I have also assumed that the principles of design for the component units of a plant would be covered in various areas of chemical engineering fundamental courses.

Implementation of such a program should reduce the inability of Nigerian engineers to apply the knowledge they possess. The argument for the use of university facilities for the internship training is that there are few industries in Nigeria. Chemical plants that do exist have been built under turnkey contract and students cannot learn much since their role would be primarily one of operator, a role they have already learned during their long vacation (summer) industrial attachment. □

ChE books received

Project Evaluation: A Unified Approach for the Analysis of Capital Investments, J. Morley English; MacMillan Publishing Company, 866 Third Ave., New York 10022; 401 pages, $29.85,(1984).

Potential Flows: Computer Graphic Solutions, Robert H. Kirchhoff; Marcel Dekker, 270 Madison Ave., New York 10016; 200 pages, $54 (1985).

Principles of Turbomachinery, R. K. Turton; Methuen Inc., 733 Third Ave., New York 10017; 199 pages, $37 HB, $17.95 PB, (1984).

Mathematics for Chemists. P. G. Francis; Methuen, Inc., 733 Third Ave., New York, 10017; 193 pages, $33 HB, $15.95 PB (1984).

Designing for Reliability and Safety Control, Ernest J. Henley, Hiromitsu Kumamoto; Prentice-Hall Inc., Englewood Cliffs, NJ 07632; 527 pages, $49.95 (1985).

Mineral Impurities in Coal Combustion:C Behavior, Problems, and Remedial Measures, Erich Raask; Hemisphere Publishing Corp., 79 Madison Ave., New York 10016; 484 pages, $69.50 (1985).

Measurement Techniques in Power Engineering, Naim H. Afgan; Hemisphere Publishing Corporation, 79 Madison Ave., New York 10016; 569 pages, $84.50 (1985).

Measurement Techniques in Heat and Mass Transfer, R. I. Soloukhin, N. H. Afgan; Hemisphere Publishing Corp., 79 Madison Ave., New York 10016; 569 pages, $84.50 (1985).

Corrosion and Deposits from Combustion Gases: Abstracts and Index, Jerrold E. Radway; Hemisphere Publishing Corp., 79 Madison Ave., New York 10016; 575 pages, $95 (1985).

Flow Visualization III, W. J. Yang, Hemisphere Publishing Corp., 79 Madison Ave., New York 10016; 889 pages, $95.00 (1985).

High Temperature Equipment, edited by A. E. Sheindlin, Hemisphere Publishing Corp., 79 Madison Ave., New York 10016; 402 pages $74.95.

Water Treatment Principles & Design, James M. Montgomery, Wiley-Interscience, New York, NY 10158; 696 pages, $49.95 (1985).

Salts, Evaporites, and Brines: An Annotated Bibliography, Oryx Press, Phoenix, AZ 85004-1483; 216 pages, $87.50 (1984).

Laser Processing and Analysis of Materials, W. W. Duley; Plenum Publishing, New York, NY 10013; 463 pages, $59.50 (1983).

Moisture Sensors in Process Control, K. Carr-Brion; Elsevier Science Publishing, New York 10017; 122 pages, $39.75 (1986).

Heat Transfer in High Technology and Power Engineering, Wen-Jei Yang and Yasuo Mori. Hemisphere Publishing, New York, 10016; 602 pages, $95.00 (1987).

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