ChE department

CHE AT YALE

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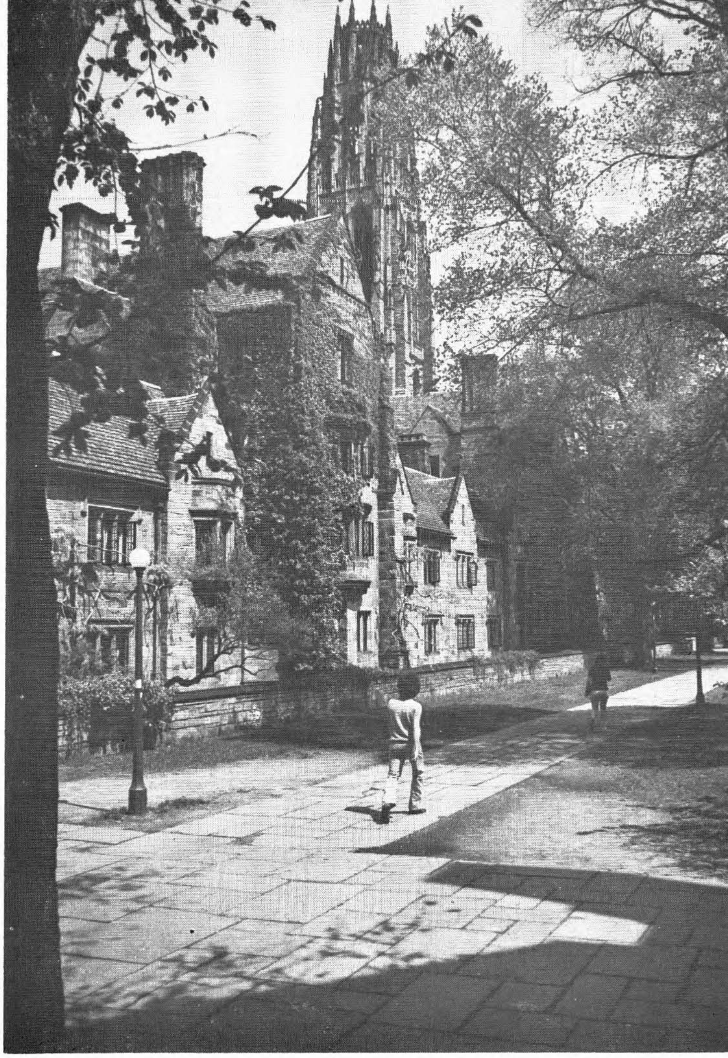

Photo by William K. Sacco

Although an undergraduate program in Industrial and Engineering Chemistry was offered in earlier years, a program in Chemical Engineering was first offered at Yale in 1922-23, and it was heralded as follows in the Report of the President for that year:

> **Professor Harry Alfred Curtis has been called to the chair of Chemical Engineering, for which we have provided admirable quarters in the new Sterling Chemistry Laboratory. . . . We shall look forward to the development of the new Department under his charge in the most hopeful spirit.**

Professor Curtis served as Chairman until 1931 and then left Yale to continue a distinguished career as director of research for a major oil company and later as Dean of Engineering at the University of Missouri and a member of the Board of Governors of the Tennessee Valley Authority. Before leaving, however, he had provided well for a successor in the person of Barnett F. Dodge, who came to Yale in 1925 and served as chairman from 1931 until his retirement in 1964. Professor Dodge's classic book on chemical engineering thermodynamics reflected his research interests in cryogenic engineering and phase equilibrium and chemical equilibrium at high pressures. Others who have served on the fulltime faculty in chemical engineering at Yale, in the order of the dates of their first appointments, and with the names of current faculty members in bold face type, are Clifford C. Furnas, Melvin C. Molstad, Roger H. Newton, Harold E. Graves, Winford B. Johnson, R. Harding Bliss, James A. Johnston, E. E. Lindsey, Jr., **Charles A. Walker**, Raymond W. Southworth, Homer F. Johnson, Dinwiddie C. Reams, Randolph H. Bretton, Shen-Wu Wan, John A. Tallmadge, Jr., Joshua Dranoff, John B. Butt, Colin McGreavy, Lawrence H. Shendalman, Reiji Mezaki, **John B. Fenn**, James B. Anderson, **Gary L. Haller**, **Daniel E. Rosner**, William N. Delgass, **Csaba Horvath**, **Paul C. Nordine**, Jimmie Q. Searcy, Constantinos G. Vayenas, **Bret L. Halpern**, and **Subbarao B. Ryali.** Comments on the contributions of each of the former faculty members are precluded by space considerations, but Harding Bliss's service as the first editor of *AIChE Journal* and the fact that the first course in computer programming at Yale was taught by a chemical engineer, Raymond W. Southworth, deserve to be mentioned. Research interests of current faculty members will be discussed later in this article.

. . . at Yale a unique aspect is the fact that chemical engineering students necessarily pursue their studies in close association with students and faculty members in many disciplines, including those in . . . social sciences and liberal arts.

Until 1962 chemical engineering activities at Yale were the responsibility of the Department of Chemical Engineering in the School of Engineering. In that year Yale embarked on an experiment in education by combining all engineering activities in a Department of Engineering and Applied Science in the Faculty of Arts and Sciences. While this experiment was successful in encouraging interdisciplinary teaching and research, the range of faculty interests was so broad as to make agreement on educational philosophy and faculty appointments difficult to achieve. In the spring of 1981 the faculty and administration judged that these difficulties were significant enough to justify a return to smaller, more homogeneous units, including a Department of Chemical Engineering.

During the years 1962-1981 chemical engineering activities continued under the direction of a faculty that varied in size from seven to ten members. During some of these years there were very few undergraduate students majoring in chemical engineering, and much of our effort was devoted to the graduate program and research. In more recent years undergraduate interest in chemical engineering has increased, as it has at other institutions, and the undergraduate program is again attracting reasonable numbers of students.

Thus, while we might appear to be a "new" department of chemical engineering, we are in fact a part of a continuing development of our discipline at Yale.

THE UNDERGRADUATE PROGRAM

THE UNDERGRADUATE CURRICULUM in chemical engineering at Yale is conventional in many respects and includes courses in the following subjects: introductory thermodynamics; conservation of mass and energy; chemical engineering thermodynamics; fluid mechanics; mass, energy, and momentum transport processes; chemical kinetics and chemical reactors; separation processes; chemical engineering laboratory; and chemical engineering process design, as well as options in biochemical engineering, environmental chemical engineering, and research projects.

The teaching of most of these subjects at Yale is not significantly different from the way they are taught in other universities and colleges. Each of us feels, of course, as do all educators worthy of the name, that he has developed an optimum method for teaching his subject or that at least he is now in position to teach it in optimum fashion *next year*. There seems to be little point, therefore, in outlining our approach to each of these courses, but two courses deserve special mention. Our course in chemical engineering process design is taught, quite successfully, by engineers from Olin Corporation. Dr. Herbert Grove, David Doonan, Joseph Levitzky, and Howard Martin have participated in teaching this course and have added significantly to the education of our students. We are grateful for their considerable efforts. Research projects can be taken for credit at any time in a student's undergraduate years. Each student is affiliated with one of several research groups and assigned a problem related to the ongoing research effort. Almost every chemical engineering student takes at least one semester of research, usually in the junior or senior year, and a few continue for two or more semesters and have their names appear on research publications.

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The general requirements for graduation from Yale College include a total of 36 term courses, 12 of which must be outside the area of the major. Thus chemical engineering students must take 12 term courses in disciplines other than mathematics, science, and engineering, a considerably heavier requirement of humanities courses than is typical for engineering students at other institutions. We observe that some of our students use these 12 courses to explore several disciplines, such as literature, history, economics, philosophy, and languages. Others satisfy a set of distributional guidelines and then use the remaining courses to concentrate in one discipline. One student, for example, was able to arrange her courses so that she satisfied requirements for majors in both chemical engineering and English literature. Another satisfied requirements for majors in chemical engineering and economics. The breadth of education that results from meeting this requirement is an important and desirable feature of the curriculum.

Recognizing the diversity of interests of students, we offer undergraduate degrees in chemical engineering at three levels of intensity. For those who plan to enter the profession, a B.S. in Chemical Engineering, requiring a total of 40 term courses and carefully structured courses in chemical engineering, is available. For those interested in chemical engineering but desiring to take more courses in other disciplines, a B.S. in Engineering Science (Chemical), requiring a total of 36 term courses and fewer courses in chemical engineering, is offered. For students planning on business school, law school, or medical school, a still less intensive B.A. in Engineering Sciences (Chemical) degree is offered. Most of our students take one of the B.S. programs and, after graduation, more than half go directly to industry and others go to graduate school in chemical engineering or to schools of business, law, or medicine. Class sizes are small but growing; in the past few years we have awarded 10-12 undergraduate degrees each year.

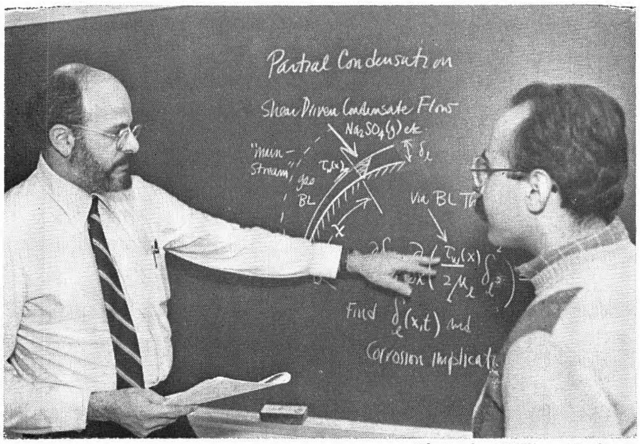

Photo by William K. Sacco

Dan Rosner at the blackboard with Suleyman Gokoglu.

In these *Chemical Engineering Education* articles about education at the variety of types of institutions that are the hallmark and the strength of higher education in the United States, readers deserve to learn what is unique about each institution as well as what they have in common. At the undergraduate level at Yale a unique aspect is the fact that chemical engineering students necessarily pursue their studies in close association with students and faculty members in many disciplines, including those in the natural sciences, the social sciences, and the liberal arts. This necessity is imposed in part by the fact that a large majority of undergraduates live on-campus in one of twelve residential colleges. These colleges are simply a basis for making dormitory life more attractive by providing a sense of belonging to well-identified units (Berkeley College, Silliman College, etc.) that are the centers of much of the social life of students, the intramural sports program, and numerous informal activities in the fine arts and the performing arts. The residential colleges are not organized by disciplines; in fact, considerable effort is expended in insuring that each college includes students with varied academic and extracurricular interests. Faculty members are also associated with these units, a few as residents, a few as occupants of offices in the colleges, a few as instructors in a limited number of general-interest seminars, and a larger number who take some of their meals in the college dining halls. The results of this system include a healthy mixing of students with varied interests and the encouragement of informal student-faculty interactions.

Thus chemical engineering students at Yale live in an atmosphere in which a majority of their classmates are majors in the humanities. This arrangement, the requirement of 12 term courses in the humanities, and the general educational value of studies in mathematics, science, and chemical engineering provide them with an opportunity to achieve a truly liberal education. As noted above, most of our graduates enter the chemical engineering profession, which we regard as among the most demanding and most satisfying of all professions. We are inclined to regard those students who go on to law, business, medicine, and other professions as tributes to the breadth of chemical engineering education rather than to bemoan the loss to our own profession.

THE GRADUATE PROGRAM AND RESEARCH

OUR CURRENT graduate program emphasizes research and the PhD degree. This is a reasonable allocation of resources in view of the fact that current faculty members are research-oriented and few in number. Topics for graduate courses are selected in part on the basis of their suitability as a preparation for research and they are taught by research-oriented faculty members. Current regular course offerings include chemical engineering thermodynamics, chemical reaction engineering, transport processes, separation processes, spectroscopic surface analysis, and electrochemistry fundamentals and applications. Courses in combustion science and technology, aerosol science and technology, biochemical separation processes, chromatography, heterogeneous catalysis, and other topics are also offered periodically. Because some of our graduate students enter with undergraduate majors in subjects other than chemical engineering, some upper-level undergraduate chemical engineering courses are used as mezzanine courses, i.e., graduate students can take them for credit by satisfying requirements in addition to those imposed on undergraduates.

At this time about 20 graduate students are in residence, most of whom are studying for the PhD degree.

Most of the graduate courses contain subject matter relevant to development and design as well as research. They are therefore appropriate for students interested in a terminal M.S. degree and careers in development and design, and we have a few such students. In order to provide these students with the opportunities that should be available to them, however, we recognize that we need to add courses in materials, computer-aided design of separation processes, chemical process control and optimization, and advanced chemical process design. We are currently discussing such possibilities, realizing that offering these topics would require additional personnel, some of whom might well be adjunct faculty members from industry.

Yale's experiment with a Department of Engineering and Applied Science was successful at the graduate level, and we have retained the title Engineering and Applied Science for our graduate program in collaboration with the Sections of Applied Mechanics (later to be Mechanical Engineering), Applied Physics, and Electrical Engineering. This arrangement provides some significant benefits. Courses common to these disciplines, including applied mathematics and experimental methods, are readily available to our students, as are courses in electronics, control systems, fluid mechanics, and a variety of other topics. Students are provided with greater flexibility in their choices of research topics, and interdepartmental barriers to collaborative research programs simply do not exist.

Course requirements for the PhD degree depend on a student's background and interests. A committee of three faculty members works with each student to select courses that serve to advance the student's knowledge of chemical engineering and to prepare him or her for research. Sometime during the first year or early in the second year each student begins the process of developing a research topic by enrolling for research with particular faculty members. The student is then expected to collaborate with one or more faculty members in developing a proposal for research on a topic for which funding and equipment are available or can be obtained.

Chemical engineering laboratories in Mason Laboratory and Becton Center are lively with the activities of faculty members, graduate students, undergraduates, and postdoctoral research associates. Expenditures on research from grants and contracts amount to about $800,000 for the 1981-82 academic year. The varied research interests of current faculty members are described briefly below.

John Fenn applies molecular beam methods to the study of a variety of scientific and technological problems. His well-equipped laboratory provides the means for studying the distribution of translational, vibrational, and rotational energies of molecules during and after such events as free jet expansion, collisions in the gas phase, and collisions with surfaces. The results are of interest in analyzing energy distributions in heterogeneous catalysis processes, monitoring of pollutants from internal combustion engines, understanding the infrared radiation characteristics of rocket exhaust plumes at high altitudes, and elucidating structures and reactions in messy mixtures such as biological fluids and coal-conversion process streams.

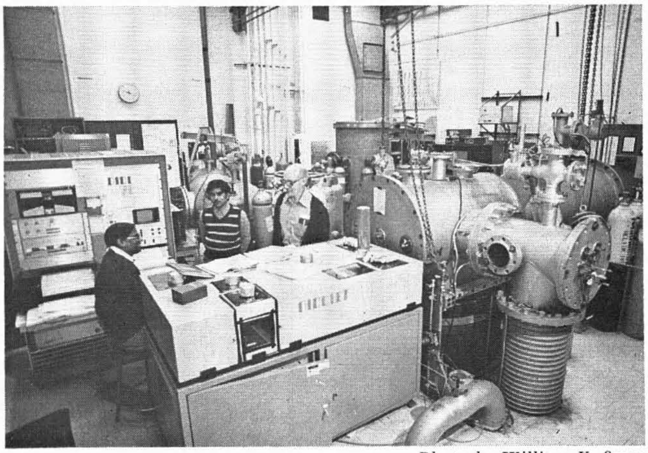

Photo by William K. Sacco

S. P. Venkatenshan, Subbarao Ryali, and John Fenn in the molecular beam laboratory.

Dan Rosner is engaged in research on mass and energy transfer at fluid-solid and fluid-fluid interfaces. His laboratories are equipped for studies of nonequilibrium multiphase systems under extreme conditions (high temperatures, partially dissociated gases, particle-laden gases). Current studies include the deposition of soot, ash, and inorganic salts from combustion gases to heat exchange surfaces and turbine blades, surface-catalysed combustion, and the role of thermal diffusion in high-temperature processes.

Gary Haller's research interests are in surface chemistry and heterogeneous catalysis. Current studies include reactions of olefins on chromium oxide catalysts, analysis of binary alloy catalysts using X-ray, photoelectron, chemisorption, and reaction kinetics methods, and Fourier transform internal reflection infrared spectroscopy applied to metal-support interactions.

Csaba Horvath's research interests are in biotechnology with particular regard to biochemical separation processes and enzyme reactors. With Wayne R. Melander, Research Associate and Lecturer in the Department, he studies the fundamentals of chromatography and the thermodynamics of adsorption on non-polar surfaces. High performance liquid chromatography is used in fundamental studies of the interaction of biological substances with surfaces and the development of linear free energy relationships of technological significance. In collaboration with physicians at Yale and at Roswell Park Memorial Institute in Buffalo he is investigating the use of hollow fiber enzyme reactors in extracorporeal shunts in clinical applications. Other applications of enzyme reactors are in the production of precious biochemical substances and in food processing. He is also studying the design and optimization of high performance displacement chromatography, a potential industrial process.

Paul Nordine's research interests are in high-temperature heterogeneous reaction kinetics. He has developed techniques for jet levitation of solids and laser heating and applied them to studies of the preparation of crystals, reductive chlorination of metal oxides, and fluorine-resistant refractory materials.

Bret Halpern is also interested in the dynamics of chemical reactions catalyzed by solid surfaces. His studies on partitioning of chemical reaction energy within product molecules and energy dissipation in catalysts, monitoring of the deposition of hydrocarbons and carbon on metals, and oxidation of carbon at high temperatures complement John Fenn's interests. He is now engaged in expanding his interest in research on electrochemical processes.

Charles Walker has collaborated with social scientists during the past few years in studies of social and political aspects of problems in environment and energy. He has worked with the Department of Energy on technology assessment and is currently working with colleagues on a book about social and political problems in radioactive waste management.

COURSE REQUIREMENTS
B.S. IN CHEMICAL ENGINEERING,
YALE UNIVERSITY

	SEMESTERS
Calculus	3
Ordinary Differential Equations with Applications	1
Partial Differential Equations with Applications	1
Comprehensive General Chemistry (with laboratory)	2
Organic Chemistry	2
Physical Chemistry	2
Advanced General Physics (with laboratory)	2
Computer Science	1
Introductory Thermodynamics	1
Introduction to Chemical Engineering	1
Chemical Engineering Thermodynamics	1
Fluid Mechanics	1
Energy, Mass, and Momentum Transport Processes	1
Chemical Kinetics and Chemical Reactors	1
Separation Processes	1
Chemical Engineering Laboratory	1
Chemical Engineering Process Design	1
Chemical Engineering Projects	1
Technical electives in Engineering	2
Humanities courses	12

Subbarao Ryali uses molecular beam techniques to study energy exchange (translational, rotational, and vibrational relaxation processes) and energy transfer (translation to rotation and vibration) in gas-gas encounters under well-defined conditions. Other research interests include gas-surface interactions, nucleation and condensation, heat transfer, and combustion.

CLOSING COMMENT

THE COURSE of chemical engineering education is influenced by the institutional setting in which it occurs as well as by professional societies and the needs of employers of chemical engineers. There is, of course, a need for some degree of uniformity in the teaching of this discipline, but chemical engineering education can and should reflect the variety that is, as noted above, the hallmark and the strength of higher education in this country. As do other educators, we at Yale seek to develop courses, curricula, and research programs that are compatible with the long-range interests of the chemical engineering profession in its service to society and compatible with our own institutional setting. □