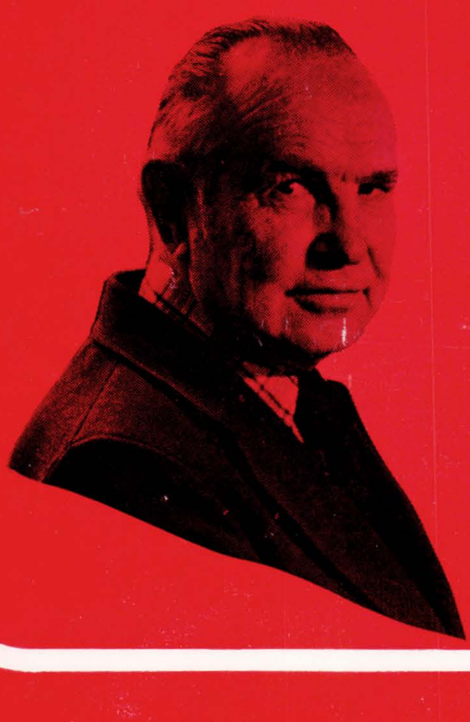
CEE

chemical engineering education

VOLUME XI • NUMBER 1 • WINTER 1977

CHEMICAL ENGINEERING DIVISION OF AMERICAN SOCIETY FOR ENGINEERING EDUCATION



Chemical Engineering Education

VOLUME XI NUMBER 1 WINTER 1977

FEATURES

DEPARTMENTS

ASEE Syposium

AIChE Report

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ChE book reviews

ENGINEERING CALCULATIONS IN RADIATIVE HEAT TRANSFER

by W. A. Gray and R. Muller
Pergamon Press, 1974.

Reviewed by Frank Kreith, University of Colorado

The authors of this work attempt to summarize engineering methods for calculating heat transfer by radiation and techniques for measuring radiation and temperature in a book of less than 150 pages. In view of the complexity of the field and the many recent advances in calculation methods, the authors selected topics and then attempted to integrate them into a book suitable for engineers with a general background in heat transfer and thermodynamics, but lacking detailed knowledge in radiation heat transfer. The topics selected are of general interest and would, therefore, make this book suitable as a supplementary text in some conventional courses, e.g. Unit Operations, as currently taught in many chemical engineering programs or Physical Climatology. Unfortunately, the authors have relied heavily for the material in their book on other texts in heat transfer, rather than on original sources. In their list of 47 references, 27 are to other textbooks and only 20 are to articles in the literature. Among the latter group, some, such as R. V. Dunkel's and A. K. Oppenheim's classical papers, are not referenced correctly, and only two articles published within the past five years are cited. Thus, the book cannot be considered an up-to-date reference text, but rather a compilation of well-known techniques, illustrated by a few examples. However, only two papers are devoted to the Monte Carlo Method which is capable of handling many complex problems in radiation and no worked out example is presented. Moreover, no mention is made of other numerical techniques suitable for computer processing. This appears a serious shortcoming in a book dealing with engineering calculations for technical people expecting to practice in the 1970's or 1980's.

On the positive side, the summary of measurements of radiation and temperature will be useful and the treatment of atmospheric radiation is well put together. However, also in these topics the material presented in this book does not contain recent findings and the bibliography will not help the reader to update his knowledge in the field.

In summary, the book will be useful for an engineer who lacks background in radiation heat transfer and wants to brush up without spending too much time doing so, but for an up-to-date treatment of engineering calculations in radiative heat transfer the reader will find the current literature a better source.

ACKNOWLEDGMENTS

The following companies donated funds for the support of

CHEMICAL ENGINEERING EDUCATION
DURING 1976:

MONSANTO COMPANY
3M COMPANY

We also thank the 134 Chemical Engineering Departments who contributed to the support of CEE in 1976!

ChE letters

MORE LETTERS ON GRISKEY RATINGS

Sir:

I'll be surprised if this is not one of a flood of letters you will get in reply to Gill's report, Carberry's response and Griskey's feature. The subject clearly matters to us all, yet becomes absurd when dissected too closely and publicized too much. In a hope that it may do more good than harm I offer the following observations:

1. Peer evaluations or perceptions may or may not relate to other relevant facts or substance but are of importance to us of and in themselves. The danger is positive feedback whereby the perception or reputation becomes an end in itself. I fear that Gill, Carberry, Griskey and perhaps all of us, are quickly caught in that cycle.
2. While some departments stand out as particularly excellent, and perhaps some as particularly poor I contend that with much fuzziness in what is being measured and large possible errors in measurement the rankings become rapidly meaningless apart from extremes. I am sure no department does or should accept a self image as second or third rate. This is not a pennant race whereby because someone is first it follows that there must be a number two, twenty and 115. It is not a zero sum game and Minnesota's or Buffalo's gain need not be MIT's or Notre Dame's loss unless we insist on making it so.
3. The Griskey feature displays data in some helpful ways making it possible to view and compare some operating characteristics. His GRPI may even be a useful lumped parameter for looking at some distribution of performance. Not surprisingly Griskey's Figure 5 shows that 50% of departments have GRPI's between 0.4 and 0.6 and GRPI makes no meaningful distinction among them. I doubt the validity of Griskey's conclusion and would fear its adoption. Means that are valid and helpful for characterizing a population are not necessarily useful or proper when applied individually to each unit of the population.

This is, properly, an emotional issue which pricks our departmental and thus our personal pride. We must compete and only one can be number one—for now.

David Hansen
Rensselaer Polytechnic Institute

Sir:

We are ambivalent about prolonging the debate in your pages on the ranking of chemical engineering departments, since titers of feeling, eloquence, numerical data and pages therein are already outdistancing more fundamental contributions to your journal. We are the more ambivalent because we share Carberry's view, to which he himself shows only partial adherence, that no single criterion and no particular combination of criteria has unique appeal and each will produce different results. Nonetheless we consider Griskey's recent article on this subject in your pages to demonstrate laudable objectivity and appeal to common sense in its formulation of *one* criterion. We want briefly to summarize a similar study we made last spring that produced similar but not identical results and then to offer some more general observations. Data from the last four Thesis Indexes of *Chemical Engineering Progress* and the last two ACS Directories of Graduate Research were used to calculate the average number of doctoral degrees per faculty member per year with the result shown in Table I.

The four-year averaging, approximately equal to a doctoral student's mean residence time, is desirable because many departments in these surveys produce only a few doctorates per year and are subject to fluctuating enrollments. Thus the "noise" of a single measurement channel in our study may be smoothed by a longer sample time so that the results may be of comparable quality to Griskey's shorter sample of multiple channels.

Gill, defending his study against Carberry's criticism, refers to the correlation among rankings. However, a close examination of the rankings which include the two American Council of Education ratings, the Gill and Griskey rankings and our own statistics showed that there was, in fact, very little correlation among them. The lack of correlation is most obvious on a plot using Griskey's results as the abscissa and the different ratings as the ordinate.

In offering our data set we suggest that each of these studies, ours included, establishes only a local truth and any implied catholicism must be regarded warily. Our survey was done to show our dean that our doctoral program was cost effective relative to those of other chemical engineering programs. Surveys that measure something close to a well-defined concept of goodness may have merit, but opinions report the feelings of those who opine, "efficiencies" measure against their own precise but narrow standard, and complex truth does not come cheap.

H. Y. Cheh
E. F. Leonard
Columbia University

Table I

The following table was taken from a recent survey concerning the productivity of doctoral degrees from various chemical engineering schools in both US and Canada. A total of 73 schools was included with data taken from Thesis Index, CEP and ACS Directory of Graduate Research. The first 10 schools are listed below:

	University	Average number of doctoral degrees granted per faculty per year (1971-75)
1	Stanford	0.979
2	UC Berkeley	0.913
3	Princeton	0.904
4	UCLA	0.863
5	Wisconsin	0.852
6	Northwestern	0.727
7	Columbia	0.694
8	Carnegie Mellon	0.683
9	Notre Dame	0.643
10	Colorado School of Mines	0.608

Average from 73 schools = 0.431
Standard deviation = 0.195

ChE department

CASE

JOHN C. ANGUS
Case Institute of Technology
Case Western Reserve University
Cleveland, Ohio 44106

IN 1884, THE CASE catalog announced the introduction of "Chemical Technology" as part of the chemistry curriculum. This was the first appearance of Chemical Engineering at Case. The first degree labelled Chemical Engineering was awarded by Case in 1909, but it appears that the curriculum itself was not called Chemical Engineering until 1913.

The Case ChE program was one of the very first in the country. Similar developments took place throughout the 1880's and 1890's at Tulane, University of Illinois, University of Pennsylvania, Massachusetts Institute of Technology and the University of Michigan. It was not until 1922 that the American Institute of Chemical Engineers could even agree on a definition of what Chemical Engineering was. When the AIChE instituted accreditation in 1925, the Case program was one of only fourteen to be approved.

The men responsible for the founding of ChE at Case were Professors Charles Mabery and Albert W. Smith. Mabery, an early leader in petroleum research, was department head from 1883 to 1911. Smith, department head from 1911 to 1927, was a key figure in the early history of the Dow Chemical Company. It was under his leadership that ChE emerged as a separate course of study.

For many years the department was integrated with Chemistry in a Department of Chemistry and Chemical Engineering. In 1962, the ChE activities were severed from Chemistry and became the Chemical Engineering Science Division of the School of Engineering. In 1972, we became the Department of Chemical Engineering.

The completion of the $2,500,000 renovation of the Albert W. Smith Building in January, 1976 signals the beginning of a new period of growth of ChE at Case.

TRADITION OF ACCOMPLISHMENT

THE DEPARTMENT HAS had many well known and influential ChE's associated with it over the years. Herbert H. Dow, a Case Tech graduate of 1888, founded the Dow Chemical Company, which has become one of the world's largest chemical enterprises. Dr. Albert W. Smith worked closely with Dow and made many contributions which were crucial to the survival and growth of the company. Among these were the first American production of carbon tetrachloride and the synthesis from this of chloroform. Professor Smiths' sons, Kent H. Smith, and A. Kelvin Smith, and F. Alex Nason, were co-founders of the Lubrizol Corporation, the world's leading manufacturer of lubricant additives. They are Case ChE graduates from 1917, 1922 and 1922 respectively.

Throughout the years 1927 to 1956, the chairmen of the department were Professors William R. Veazey, Carl F. Prutton '20 and William Von Fischer. All were very active within the U.S. chemical industry.

This tradition of accomplishment has continued to the present time. Today, Case graduates are found in responsible positions throughout the American and world chemical industry and in academia. A very few examples of the many that could be cited follow. Dr. Durga Ambwani, who received his Ph.D. in 1968, is the cofounder of the Asia Development Corporation. Dr. Paul Friedl, a Case B.S. and Ph.D. Chemical Engineering graduate, developed the new IBM 5100 table top computer. Dr. Glenn Brown, Ph.D. 1958, is Vice President for R. and D. of SOHIO. Shunji Kumazawa, M.S. 1965, is General Manager of Technical Development for Toray Industries, one of Japan's leading corporations. Richard Knazek, a Case B.S. Chemical Engineering graduate of 1962, was chosen as "One of the Ten Most Outstanding Young Men in the U.S." by the U.S. Jaycees in January, 1976 for his medical research.

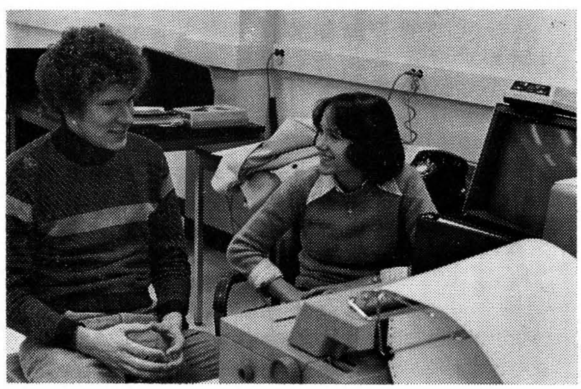
Our most recent graduates are also doing well. Two members of our 1976 senior class, Mr. Donald Feke and Mr. Max Gorensek, won National Science Foundation Graduate Fellowships. (Only fourteen were awarded to ChE's in the entire U.S.). Mr. Feke also won one of the three Electrochemical Society summer fellowships in 1976.

A total of 1686 B.S., 280 M.S., and 117 Ph.D. degrees have been awarded by the department since its founding.

We have attempted to steer a middle road between the extremes of pure empiricism on the one hand and engineering science on the other. As a result the ChE B.S. program has no strong "idealogical" bias.

THE DEPARTMENT TODAY

- **Faculty and Staff**—The staff is comprised of eight professors, two adjunct professors, one adjunct lecturer, six research engineers, one technician and an administrative and secretarial staff of three. A listing of the faculty and their major technical interests is given in Table 1.
- **Students**—There are 135 undergraduates majoring in ChE at Case and 25 resident graduate students. We have experienced a significant increase in undergraduate ChE enrollment in the past year, although not such a dramatic upturn as seen at some institutions. We have not, however, had a decline in the average SAT scores of our entering freshmen. They have, in fact, been slightly increasing, counter to the national trends—The average mathematics and verbal SAT scores for the 1976 freshman class were at the 99th and 95th percentile respectively. Combined mathematics and verbal SAT's run about 1250. ChE has a reputation on the campus as being one of the more demanding curricula and we consistently attract excellent students.
- **Research**—There is a very active graduate research activity underway. Research expenditures in the Department totalled $465,700 during the past year, a very high figure for only 8 full time faculty. An unusual feature of the present



Undergraduates in the Diamond Shamrock Computer Room.

One unusual feature of the graduate program is the Instructional Television Network (ITN). Courses are offered from the campus live or on videotape to employed engineers in the Cleveland area.

research support is that about half of it comes from private industry.

The largest single effort is an industrial project for the development of a new gas treating process conceived by Professors Adler, Brosilow, Gardner and Dr. William Brown, a recent Case graduate. The new process has substantially lower investment and operating costs than competing processes and promises to have a major impact in the chemical and related industries. Another large project involves the catalysis of coal gasification, done under the direction of Professors Gardner and Angus with ERDA support.

A project of great potential is a joint computer development effort with the IBM Corporation on applications of APL in ChE. "A Programming Language" (APL), while devised and implemented between 1960 and 1965 by IBM, has required the present generation of computer systems for full utilization of its capabilities. The result is a powerful notational scheme that allows coding at a much higher level than FORTRAN, and is similar to the notation of matrix algebra. Hierarchical systems which interface an APL host to experiments are being developed. By using small microcomputers coded to execute APL commands, data acquisition and computation on acquired data bases can run efficiently. Real time control functions are being studied as well. The APL project is directed by Professor Mann.

An unusually strong effort is underway in laser application studies including laser doppler flowmeters, transport property measurement by light scattering and laser holographic machining. This work involves Professors Edwards, Mann and Angus. The university effort in environmental engineering is centered in ChE. There are several projects in industrial wastewater treatment, e.g., ozone treatment and cyanide disposal. Professors Prober and Melnyk direct this effort. We also have an active research effort in membrane processes, surface transport and interfacial dynamics under the direction of Professor Mann.

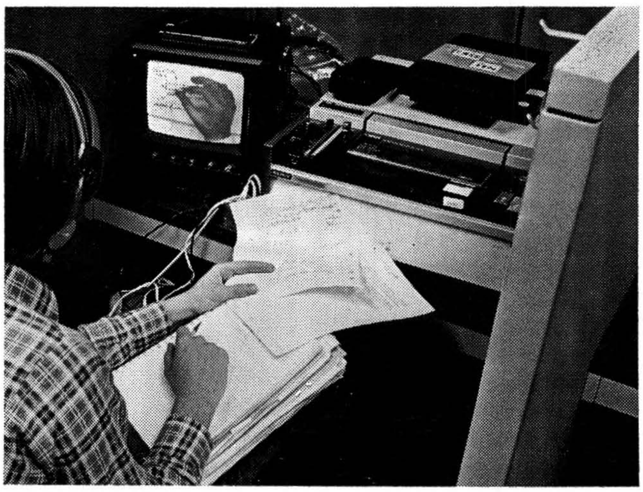
We have always had a strong program in systems and control. One aspect of the present work is the development of inferential control schemes and their application to onstream distillation columns and reactors at Exxon, Marathon and Mobil Oil Companies. This work is directed by Professor Brosilow.

• **Industrial Support**—Industrial sponsored contract research is done through the DICAR Corporation, a for profit corporation owned by the university. This arrangement permits us to accept non thesis and confidential research from industrial companies. The work is mainly in process development and is conducted in part by full time research engineers.

Unrestricted grant support from various companies is also received. These include: Air Products Co., Atlantic Richfield, CWC Industries, Diamond Shamrock, Dow Chemical Co., duPont Corporation, Lubrizol Foundation, Monsanto Corporation, PPG Industries and the Procter and Gamble Fund.

BALANCED CURRICULUM

WE HAVE ATTEMPTED to steer a middle road between the extremes of pure empiricism on the one hand and engineering science on the other. As a result the ChE B.S. program has no strong "ideological" bias. We require a total of 131 to 135 credit hours (depending on elective sequences). The ChE part of the curriculum includes courses in energy and mass balances, separation processes, transport phenomena, thermodynamics, chemical reactor design and a unit op-



Taking courses over the Case Instructional Television Network. Courses are televised to employed engineers in the Cleveland area.

erations laboratory. The ChE sequence is terminated with a two semester capstone course in Process Analysis and Design. This latter course makes extensive use of the computer aided design systems, FLOWTRAN.

The curriculum contains required laboratory courses in mathematics (computation), physics, chemistry, laboratory methods and techniques (instrumental) as well as the senior unit operations laboratory. In addition, all students have the option of doing an experimental undergraduate research project. This can be used to fulfill the 5 course elective sequence offered to all students. Other elective sequences, which are virtually "minor" fields, include Management, Polymer Science, Environmental Engineering, Computing, Systems and Control and Biomedical Engineering.

A full range of graduate courses is taught by the department as well. Both M.S. and Ph.D. degrees are offered. One unusual feature of the graduate program is the Instructional Television Network (ITN). Courses are offered from the campus live or on videotape to employed engineers in the Cleveland area. This program has been in existence now for several years and the department has recently had its first M.S. graduate, Mr. Monty Reed of the Timken Company, who did all of his course work over television.

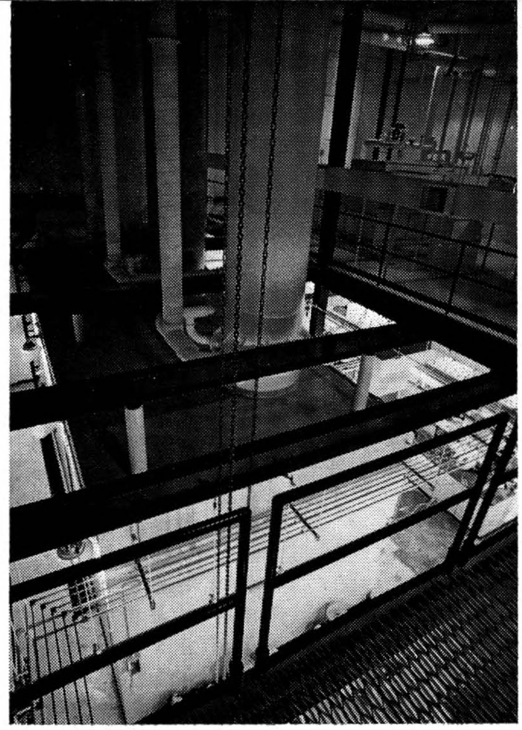
INSTITUTIONAL SETTING

THE ChE DEPARTMENT is one of the fifteen engineering and science departments that make up Case Institute of Technology. Case, in turn, is one of the major components of Case Western Reserve University. This latter institution was synthesized in 1967 from the predecessors, the old Case Institute of Technology and Western Reserve University.

Case Institute is a small selective college; we have only 1136 undergraduate students. The total enrollment of the university, including all the graduate and professional students is 8279. The endowment, capital plant and faculty make Case Western Reserve one of the countries largest private universities.

The university is set within a large complex of parks and educational and cultural institutions on the eastern side of Cleveland known as University Circle. This is especially fortunate, for our next door neighbors are the Cleveland Museum of Art and Severance Hall, the home of the Cleveland Orchestra.

The ChE faculty participate in a wide range of



A top view of the high pressure test cells showing the large vertical vent stacks.

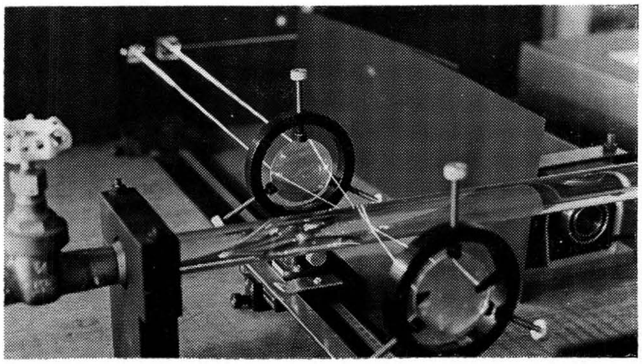
other professional activities in addition to their principal jobs of teaching. A few of these are listed to give an idea of the scope of these efforts.

- **Professor Nelson Gardner's research group recently won the National American Chemical Society prize for the best paper on coal. Professor Gardner has also been selected twice as a National A.I.Ch.E. tour speaker and gave the opening plenary lecture at the U.S. Bureau of Mines coal catalysis conference last spring.**
- **Professor Edwards' research in laser doppler flowmeters has received international recognition. He was invited to give the opening plenary lecture at the Biennial Turbulence Symposium and was also twice selected as a Visiting Scientist by the Danish Atomic Energy Commission.**
- **Professor Adler will serve as Conference Chairman of the 1977 Engineering Foundation Biennial Meeting. Professor Angus recently returned from a sabbatical year at the University of Edinburgh where he was a Senior NATO Fellow and Visiting Lecturer.**
- **Professor Prober is editor of the CRC Press Monograph Series on Water Pollution Control Technology and was Coordinating Editor for the CRC Handbook on Environmental Control. Professor Brosilow is serving on the National A.I.Ch.E. Machine Computation Committee and recently spent a sabbatical year at the Technion in Israel. Professor Mann has given many invited papers on membrane dynamics around the country and will organize the symposium for the Colloid division of the ACS on "Application of Surface Science to Problems in Biology and Medicine".**
- **Professor Melnyk recently received one of the two national awards from the Technical Association of the Pulp and Paper Industry for excellence in research on wastewater treatment with ozone. Professor Bikerman, one of the nation's leading authorities on foams and surface phenomena, recently published a book entitled "Foams" (Springer Verlag).**

TEACHING AND RESEARCH FACILITIES

IN 1975, WE RECEIVED a $2,500,000 anonymous alumni donation to provide our department with a ChE building. The existing Smith Building on the Case Campus has been completely renovated for the ChE Department. We moved to our new quarters in January, 1976.

The Albert W. Smith Building includes: a large undergraduate Unit Operations Laboratory; an undergraduate projects laboratory; a computer room; a high bay area for process related research; three re-inforced concrete, vertically vented chambers for hazardous and high pressure research; graduate and undergraduate water pollution control laboratories; acoustically isolated room; constant temperature and humidity room; instrument room; two classrooms (one designed for television instruction); library-reading room and the normal complement of offices and research laboratories.



A laser anemometer experiment of Professor Edwards' for measuring flow in pipes.

The four story building gives us approximately 30,000 square feet of net usable floor space.

The new facilities give us a unique opportunity to further strengthen the size and scope of the Chemical Engineering activities at Case. With the completion and equipping of the building, we have acquired absolutely first rate instructional and research space. Some of the special features of the facilities are outlined below.

We have just received a $185,000 grant from Diamond Shamrock Corporation for the equipping and maintenance of the Diamond Shamrock Computer Center within the ChE department. This is part of a larger university wide grant by Diamond Shamrock. The computer will be installed early in 1977 and will be tied into the campus wide mini-computer network.

The computer will be housed in the second floor computer room, designed for this purpose. The room has its own separate air conditioning unit, the outer room wall has a vapor barrier to permit better humidity control. Electric wiring is run directly from the mains to minimize perturbations from other electrical equipment. Seven phone lines are provided for further flexibility in connecting to other computer terminals and equipment in the building.

We have what we believe to be a virtually unique high pressure and pilot plant area for an academic ChE department. At the south end of the basement is a 2,515 square foot laboratory area known as the Annex. This two story open room is divided at the first floor level by a metal grating floor. The laboratory is designated for high pressure and hazardous work, and is used primarily for energy and coal related research.

The roof is fitted with two blow-out roof panels, each 6 by 38 feet, which will open at an overpressure of 25 pounds per square foot to protect the integrity of the structure. In case of a solvent spill or flammable gas leak, all electric power can be shut off except for explosion-proof lights and exhaust fan.

Six separate gases are piped into the room through high pressure lines from a gas storage shed outside the building. The lab is provided with walk-in and overhead hoods and all laboratory services.

Within the high pressure lab are three test cells for performing very high pressure and hazardous experiments. Two cells are 10 by 10 feet and one 6 by 10 feet; all have 10-foot headroom.

Since the laboratory is located within a busy campus area, conventional venting of the cells through a blow out side wall could not be used. Instead, the cells are vertically vented through three separate 42-inch diameter steel stacks extending some 45 feet up through the Annex roof. This very unusual design may be useful in other similar locations; we would be happy to share our experience with others.

The computer will support terminals for interactive classroom use. It also will provide "hands

We have what we believe to be a virtually unique high pressure and pilot plant area for an academic ChE department.

We have just received a $185,000 grant for equipping and maintaining the Diamond Shamrock Computing Center within the ChE department. The computer will support terminals for interactive classroom use. It will also provide "hands on" experience for undergraduate and graduate students, provide data acquisition and processing for research experiments and will be used in a new computer controlled unit operations laboratory experiment.

on" experience for undergraduate and graduate students, provide data acquisition and processing for research experiments and will be used in a new computer controlled unit operations lab experiment.

The cells have 18-inch thick reinforced concrete walls, containing 20 tons of steel reinforcing bars and 115 cubic yards of concrete. The circumferential rods are welded into continuous members. The cells rest on a 20-inch thick reinforced concrete foundation pad which, in turn, rests on the underlying shale.

Entry to the cells is through rear doorways fitted with 1-5/8 inch thick steel plate doors. Visual access is via a port with a heavy sliding steel plate cover. Numerous pipe sleeves are cast through the concrete walls to permit entry of services.

The large cells are designed for bending and tensile stresses of 3900 lbs./square foot and the smaller for 9000 lbs./square foot. The cells will contain an explosion resulting from the rupture and ignition of a hydrogen cylinder or high pressure autoclave.

ENVIRONMENTAL AND LASER LABS

LABORATORIES FOR undergraduate instruction and graduate research in environmental engineering are on the third floor. The instructional lab has space and utility drops for five separate permanent experiments to demonstrate flocculent and zone settling, aeration, biological treatment and reverse osmosis. Within the lab are a preparation room and a holding room. These chambers, each 6 by 7 feet in internal dimension, are used for the preparation and storage of biological samples at controlled temperatures ranging from 0 to 35°C.

The entire south end of the second floor is taken up by a 2160-square foot graduate research laboratory designed for precision optical and laser application studies. This work includes laser doppler anemometry, light scattering and laser machining. Light-tight drapes divide the room into three separate dark areas. An enclosed wire cage storage area and 440 V, 100 A electrical service are provided in addition to the normal laboratory services.

An acoustically and electrically isolated chamber is placed within the large second floor laboratory. This room provides electrical isolation and sound attenuation of greater than 80 decibels for certain types of precise research.

Adjacent to the large second floor lab is a small constant temperature room. The room temperature is controllable to ± 1°F over the range 68 to 78°F; relative humidity to ± 2-1/2% over the range 40 to 70%.

TABLE 1

CASE ChE FACULTY

ROBERT J. ADLER, Ph.D. 1959, Lehigh University.
Chemical Reaction Engineering, Mixing, Mathematical Modelling, and Separation Processes.

JOHN C. ANGUS, Ph.D. 1960, University of Michigan.
Laser Applications, Coal Utilization, Electrochemical Processes, Crystal Growth.

JACOB J. BIKERMAN, Ph.D. 1921, University of St. Petersburg (Russia).
Foams and Colloidal Phenomena.

COLEMAN B. BROSILOW, Ph.D. 1962, Brooklyn Polytechnic Institute.
Digital Simulation, Automated Design, Control of Chemical Processes.

ROBERT V. EDWARDS, Ph.D. 1968, Johns Hopkins University.
Laser Applications, Photochemistry, Chemical Kinetics, Bioengineering.

NELSON C. GARDNER, Ph.D. 1966, Iowa State University.
Coal Gasification, Surface Chemistry, Thermodynamics.

ROBERT E. HARRIS, Ph.D. 1968, Northeastern University.
Process Simulation, Computer Aided Design.

THOMAS LIEDERBACH, M.S. 1961, Case Institute of Technology.
Career Development, Professionalism.

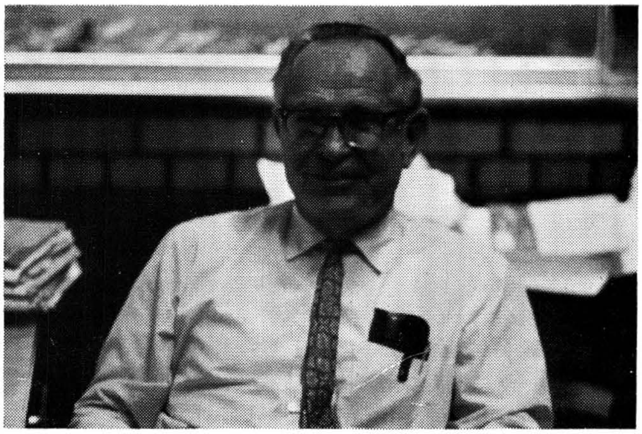
J. ADIN MANN, JR., Ph.D. 1962, Iowa State University.
Surface Phenomena, Membrane Technology, Laser Applications, Computation.

PETER B. MELNYK, Ph.D. 1974, McMaster University.
Wastewater Treatment, Process Simulation, Mixing.

RICHARD PROBER, Ph.D. 1962, University of Wisconsin.
Water Pollution Control, Ion Exchange, Membrane Processes, Electrochemical Processes.

ChE educator

Ralph Peck of Illinois Tech



DAVID MILLER
Total Systems
Downers Grove, Illinois 60515
and
DARSH WASAN
Illinois Institute of Technology
Chicago, Illinois 60616

BORN IN WINTER to American parents on a ranch in the province of Saskatchewan when it was still a frontier area, Ralph Peck, Professor of Chemical Engineering at Illinois Institute of Technology, spent his early days acclimating himself to the hardships of farm life. When he was two, his father died and left his mother with Ralph and his older brother, Benajhar, with the responsibility of managing their homestead.

His mother remarried when Ralph was nine and he helped trail the family horses when the family relocated in Alberta. An old German settler they met along the way sternly lectured Ralph about his being out of school and the importance of education. The young boy followed the advice, rising early to ride a horse to the one-room school house. He and his brother later went to the high school twelve miles away, living together in a one-room shack during the week, taking care of horses and milking a cow for board, and returning to the farm on weekends to help. These early rigors left Ralph with a zest for outdoor life and an incentive to escape the hard farm life in the north. It also left him with a love of gardening and a skill in cooking which still persist.

EDUCATION IN MINNESOTA

BECAUSE OF STRONG ties to his father's relatives in Minnesota, where his parents originated, the young brothers migrated in 1928 to the University of Minnesota for their college education. An advisor steered Ralph from chemistry into ChE as a field that was just opening up. An aunt sponsored his application for citizenship and became his guardian. His uncle helped him get summer jobs at the Cremet macaroni plant, giving young Ralph an early introduction to the food processing industry and the drying problems which were to become a major thrust of his future research.

Ralph received his BSChE degree with distinction in 1932 and, with drought and depression in Canada, stayed on for graduate work in chemistry and mathematics at Minnesota. As a graduate assistant, he collected radon for the famed F. H. MacDougall, whose physical chemistry book was an early classic, and initiated his long-standing interest in thermodynamics as a teaching assistant in the course.

Peck studied electrical conductivity and dielectric constant with George Glockler as his advisor, resulting in several publications and the PhD in 1936. The famed chemist Melvin Calvin was a labmate and another Minnesota friend, Ed Piret, was an usher when Ralph married Joyce Mullen, who had spent the summer typing his thesis. The wedding was moved up to August so Ralph could accept a job as instructor at Drexel

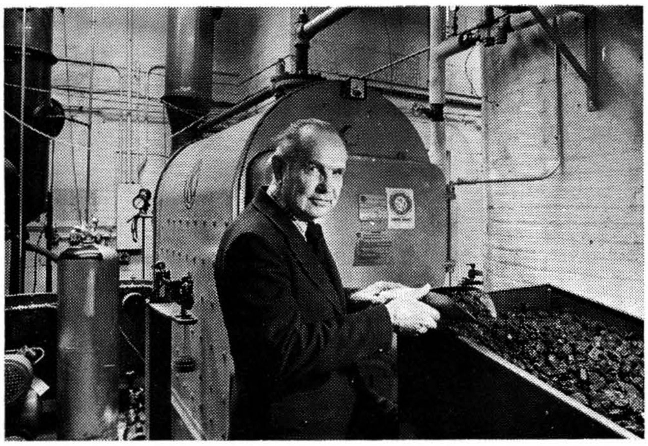
Institute of Technology. To his amazement he was turned down on application for final citizenship papers on the grounds that he was already a U.S. citizen because of his parentage.

When the Pecks arrived in Philadelphia, Department Head Henry Rushton, who had hired him, had moved on. Ralph worked with the late Henry Ward, who became Department Head at Kansas State University, and the late Harding Bliss. Among his students at Drexel were Vince Uhl and Ralph Troupe, who loved to challenge him with unusual problems.

BEGINNING THE IIT YEARS

THE PECKS WOULD usually spend their summers travelling and camping. In 1939, they went to a meeting at Penn State where Ralph was hired by Dean Linton Grintner and President Henry T. Heald (later the head of the Ford Foundation) of Armour Tech, which later became IIT. He was to work as an instructor for the ChE department founded and headed by Harry McCormack [1]. They continued their trip around the country and into Mexico and came to Chicago, which has been their home, except for visits abroad.

A summer course taught by visiting professor Barney Dodge rekindled his interest in thermodynamics. It was during this period when Peck began supervision of 100 Master's and 32 PhD dissertations. Ralph was promoted to Assistant Professor in 1941 and spent the war years working on the freeze drying of foods and spray drying of blood plasma. His principle interests developed in heat transfer, thermodynamics, kinetics and reactor design, and energy conversion, and these persist to the present. His students always found him available for technical or personal assistance, both in his open-doored office and at home.



Ralph Peck was co-inventor of the coal/sulfur abatement/fertilizer process.

It was in this period that he began his long and productive associations with other institutions on the IIT campus, the IIT Research Institute and the Institute of Gas Technology, and developed his numerous industrial consulting activities. This consulting lead him into studying the drying of abaca fiber of Costa Rica as a substitute for hemp for rope, drying of fertilizer and foodstuffs, storage of liquidified gases, and the gasification of coal, and many other problems. Although much of Peck's published work has a fundamental nature, it invariably arose from the need to solve real problems.

In 1944 he was advanced to Associate Professor and, in 1950, his contributions were recognized by a full Professorship. In 1953 he assumed the Department Chairmanship (succeeding Henry Rushton who left for Purdue after a 7-year stint as Chairman), a post he held until 1967 [1].

Research has always been a means rather than an end for Peck. His list of over forty journal publications is marked by the diversity of subject matter. Signs of his practical bent are the three patents which have been issued in his name.

PECK IN INDIA

IIT WAS ONE of the first American schools to welcome students from India who came on government grants, and a large number of students came in the 40's and the flow continues to date. The Pecks welcomed students into their home, with special emphasis on those left on campus during holidays. Baseball games, with participation by those playing for the first time, have become legendary.

Because of his many Indian friends and as an outgrowth of the partition of India, he was invited in 1959 to spend a year helping set up a ChE department, using funds from U.S. wheat loans, at Punjab University in the beautiful new city of Chandigar, north of New Delhi. The Pecks, including sons Keith and Bruce and daughter Gail, travelled extensively throughout India with Ralph, who made a survey of all engineering schools in the country. While they were in Calcutta, they were hosted by a former

In 1973 he received IIT's annual Excellence in Teaching Award. In addition, he was given the ASEE Western Electric Fund Award for teaching excellence for 1975-76.

student who Ralph had reluctantly flunked out of IIT. That student, now a millionaire business man, was grateful for being steered out of a profession not making the best use of his talents.

Ralph's frontier heritage showed when he bagged an antelope on a hunting trip and dressed and butchered the carcass, storing the meat temporarily in the ChE department freezer. While Ralph was preceding, by way of the Orient, the family's return to Chicago, his eldest son Keith was killed in a tragic accident. The family received extraordinary assistance from the U.S. government in locating Ralph and returning the body.

ISRAEL VISIT

BECAUSE THE DEPARTMENT had run so well under acting chairman Bernie Swanson, Peck accepted the invitation of Bill Resnick, head of the ChE department at Israel's Technion (and former IIT professor), to introduce Ralph's unique teaching style to the Israelis in the 1962-63 school year. One of the highlights of this style is the abundant use of the ten-minute "drop quiz," accompanied by a laugh as a challenge to the students. He surmounted the language barrier by use of a translator.

During this year the Pecks camped from the Arctic Circle to the Red Sea and contemplated the probability of bumping into former student Bob Miller while photographing the Champs de Elysee. In addition to a productive year of teaching and research, working with David Hasson, Dan Luss (then a graduate student) and Sam Seidman, Ralph was asked by the Israel Ministry of Development to review various desalination processes, including the controversial Zarkin freezing process.

DIVERSE RESEARCH INTERESTS

RESEARCH HAS ALWAYS been a means rather than an end for Peck. His list of over forty journal publications is marked by the diversity of subject matter. Signs of his practical bent are the three patents which have issued in his name. His scholarly writing activities includes a review of drying with D. T. Wasan in the "Advances in Chemical Engineering" series and he is currently preparing the section on drying for John McKetta's new "Encyclopedia of Chemical Processing and Design."

Even as he approaches formal retirement, he currently has several studies supported by grants from a variety of agencies. The National Science Foundation is supporting a study of the kinetics of Methanation while the Illinois Institute for Environmental Quality sponsors coal combustion research.

A recent activity arising from his consulting work was the invention, with former student Ladd Pircon, of a process for removing the particulate and sulfur pollutants from burning high-sulfur Illinois (or other) coal and converting these pollutants into useful fertilizer, instead of the usual nonnewtonian sludge. This process, which is in the pilot-plant stage, has attracted considerable attention in the popular and professional press and was featured on a TV program. The development of this process emphasizes the importance of ChE roots in chemistry and, as Ralph often cautions, the process comes first—followed by analysis, rather than the converse.

A Product of Peck's Puddle.

TEACHING ACTIVITIES

RALPH PECK'S devotion to research has never come at the expense of his teaching. In 1973 he received IIT's annual Excellence in Teaching Award. In addition, he was given the ASEE Western Electric Fund Award for teaching excellence for 1975-76.

Along with his university teaching, he has participated in industrial short courses in drying theory and technology and, in the summer of 1972, taught a drying course at the University of Sao Paulo, Brazil. In 1976 he taught in Algeria as part of a team from the Institute of Gas Technology.

A list of the students whose dissertations he supervised would include many well-known names from the academic, industrial and government sectors. Peck is a Fellow of AIChE and active member of ACS, ASEE, Phi Lambda Upsilon and Sigma Xi. He has organized and chaired many symposia on drying at national society meetings.

Peck accepted the invitation . . . to introduce his unique teaching style to the Israelis in the 1962-63 school year. One of the highlights of this style is the abundant use of the ten-minute "drop-quiz," accompanied by a laugh, as a challenge to the students.

ONE OF THE MOST important strengths of the Peck family is their annual trip to their summer home in the wilds of northern Minnesota. Except for trips abroad, all teaching and consulting work comes to a halt at the end of the spring semester. Originally acquired by Ralph's geologist brother as payment for the brother's services, the Pecks became owners of 40 acres, and the cabin they built together with Benajhar, when the brother's career took him to the southern U.S. They acquired 40 more acres in 1949 and the lake on the property, dubbed Peck's Puddle in fun, is so listed on Geological Survey maps.

Then the cabin burned down in 1962, the family later rebuilt it by hand, except for a bulldozer and "redimix" concrete. It now contains most civilized comforts, with the notable exception of a telephone. Avoiding the temptations of more work, Ralph is an avid fisherman, boater, swimmer, and gardener. He credits this annual break with his professional activities in keeping him fresh the rest of the year (renewal theory?). The family has now been augmented by Bruce's wife Barbara and Gail Green's husband Jeff and the three grandchildren, Kelly, Kristi and Jason.

COMMUNITY ACTIVITIES

SUPERIMPOSED ON his professional activities, Ralph has always found time for community involvement. Although he is not religious, he is often involved in church-sponsored activities, such as the YMCA. He and Joyce have been long-term supporters of the Ada S. McKinley Community House in the ghetto area near IIT. They worked actively with the Gresham Community Council to welcome and help new neighbors when their neighborhood became racially mixed. The Pecks membership in the Ethical Humanist Society of Chicago lead to their early involvement in the nonviolent aspects of the peace movement. Ralph is an avid, and often unconventional, bridge player and the lunchtime games between brown-bagging faculty and graduate students have become part of IIT's legend. One of the authors (D. M.) remembers stalling a last hand to avoid a 10-minute quiz in Peck's after lunch Heat Transfer class, only to hear Peck announce a good problem he has thought up while waiting for the author to cover or duck a lead to the dummy. He will long remember Peck's cheerful public post mortem of how the author blew both the bridge hand and the quiz. □

Ph.D. Students

Bakshy, Stanley	Linden, Henry R.
Bloomer, Oscar T.	Lokay, Joseph D.
Carr, Norman L.	Marek, Cecil J.
Chase, Curtis Alden, Jr.	Rai, Charanjit
Clauson, Warren S.	Reddi, Mullapudi M.
Eakin, Betram E.	Ryant, Charles J. J.
Ellington, Rex T.	Sareen, Sarvajit S.
Fagan, Walter	Sheth, Narendra J.
Garud, B. S.	Smith, Neal D.
Gidaspow, Dimitri	Snow, Richard
Griffith, Russell T.	Staats, William R.
Hesson, James C.	Tavakoli-Attar, J.
Jee, Benny C.	Uno, Seiji
Kauh, Jae Y.	VonFredersdorff, Claus
Khoobiar, Sargis	Vyas, Kirit C.
Kisaukurek, Bilgin	Wagner, Edward F.

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1. R. C. Kintner and D. T. Wasan, Chemical Engineering Department-Illinois Tech, Chem. Eng. Educ. *5* (3) 108 (1971).

A recent activity arising from his consulting work was the invention, with former student Ladd Pircon, of a process for removing the particulate and sulfur pollutants from burning high-sulfer coal and converting these pollutants into useful fertilizer.

ChE lecture

THE WORLD OF SURFACE SCIENCE*

D. O. SHAH
University of Florida
Gainesville, Florida 32611

SYNOPSIS

The domain of surface science is perhaps one of the most interdisciplinary areas of modern science and technology. Monolayers provide a unique system to determine experimentally the cross-sectional areas of surface-active molecules and to study reactions and molecular interactions at surfaces. Surface chemical aspects of membranes, cornea and tear are discussed. The mechanism by which surface-active polymers stabilize a thick aqueous layer on cornea is elucidated.

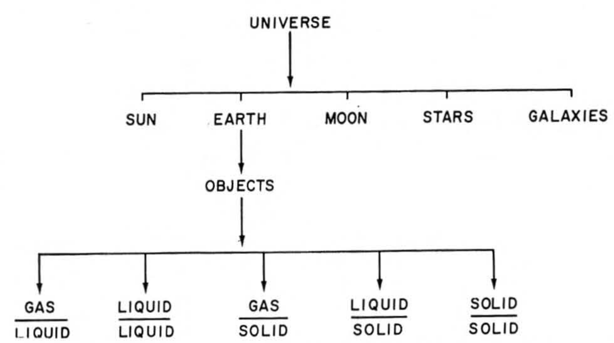


FIGURE 1. All objects are surrounded with one or more of these five interfaces.

The engineering applications of surface science range from agricultural sprays to oil recovery including areas such as catalysis, coatings, dispersions, electronics, flotation of minerals, lubrication, and retardation of evaporation from lakes and reservoirs. Among biomedical areas, the applications of surface science extend from anesthesiology to zoology including fields such as artificial implants, biomembranes, biolubrication, lipoproteins, lung surfactant, ophthalmology, pharmaceuticals and pharmacology.

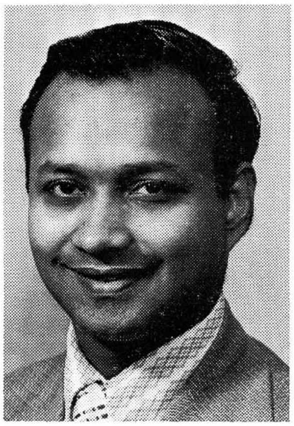
*This paper was selected by the Board of Judges of the Faculty Forum of the University of Florida for the "President's Scholar Award" for 1975-76.

EDITOR'S NOTE: In this issue, *CEE* continues a new department—ChE LECTURES. We intend to publish seminars and lectures on important areas of modern chemical engineering. If you feel that one of your seminars or lectures on a certain topic would have pedagogical or tutorial value and would be of general interest to our erudite readers, please send the manuscript to the editor for review. We would appreciate comments from our readers on this new department as well as suggestions for authors of papers.

ALTHOUGH THE importance of surface science has been recognized for more than a century, it is only during the last few decades that we have seen rapid advances in the understanding of surface phenomena. In this presentation I would like to review briefly various principles of surface science and where appropriate would like to present the highlights of the research carried out in my laboratory during the past decade.

Let me begin with a quotation of an oriental proverb which says, "The color of the world you see depends upon the color of the glass you look through." In general, a scientist attempts to look at the Universe through his own glass. When one looks at the Universe through the glass of surface science (Figure 1), one sees that it consists of Sun, Earth, Moon, Stars, Galaxies, etc. When one looks closer to the Earth, one finds that it is full of objects; and that each object is surrounded by a surface or an interface. Fortunately, all the interfaces can be grouped in five major classes, namely, gas/liquid, liquid/liquid, solid/liquid, solid/gas, and solid/solid. All objects are surrounded by one or more of these basic five interfaces. All of these interfaces have a common property called surface tension or surface free energy. There is also a class of compounds called surface-active compounds (or surfactants) that decreases strikingly the surface tension or surface free energy of these interfaces.

A surfactant molecule has two functional



Presently Dr. Shah is a professor of Chemical Engineering, Anesthesiology and Biophysics at the University of Florida.

He received his undergraduate training at the University of Bombay and subsequently his doctoral degree from Columbia University in 1965, where he worked in the laboratory of the late Professor J. H. Schulman.

He spent, subsequently, a year at NASA Ames Research Laboratory in California conducting research on chemical evolution and the origin of life, and surface chemical aspects of the origin of membranes. Later he moved to the Biological Oceanography Division of Columbia University and investigated the dispersion of oil-spills, retardation of evaporation and wave damping by thin films of surface active agents and surface chemical aspects of sea water.

Since 1970, he has been at the University of Florida with a joint appointment in Chemical Engineering and Anesthesiology Departments. Dr. Shah has published in the areas of biological and model membranes, chemical evolution and the origin of membranes, monomolecular films, foams, microemulsions, improved oil recovery, surfactant-polymer interaction, boundary lubrication and surface chemical aspects of lungs, vision and anesthesia.

Dr. Shah received the University of Florida's **"Excellence in Teaching Award"** in 1972-73, **"President's Scholar Award"** in 1975-76, and **"Outstanding Service Award"** in 1975-76.

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parts, namely, a hydrophilic (water soluble) or polar part, and a lipophilic (oil soluble) or nonpolar part. The lipophilic part is usually a long hydrocarbon chain. Schematically a surfactant molecule can be represented by a nonpolar (tail) and a polar group as shown in Figure 2. A polymer also can be surface-active if it has two functional groups, one hydrophilic and the other lipophilic (Figure 2). The properties of a surface-active compound are determined by the balance between its hydrophilic and lipophilic characteristics. If the chain-length is relatively short (less than 12 -C-C- bonds in length), they are called water soluble surfactants since the polar group drags the entire molecule in water. However, when the chain-length is greater than 14 or 16 -C-C- bonds in length, the compounds are called insoluble surfactants. They do not dissolve in water because of the long hydrocarbon chains.

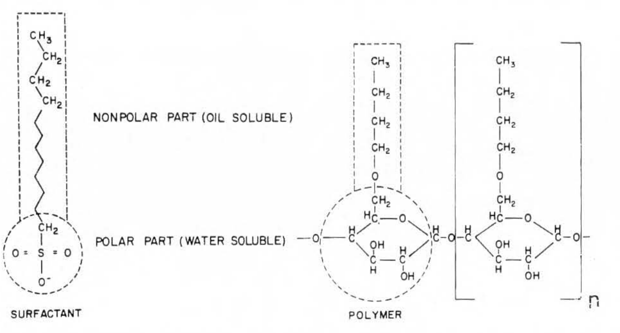

FIGURE 2. The structure of surface-active molecules. The broken line shows the separation of polar and non-polar parts of the molecule.

MOLECULAR AGGREGATES

IF THE CONCENTRATION of a soluble surfactant in water is increased gradually, at a specific concentration of the surfactant, the solution properties such as osmotic pressure, surface tension, viscosity, electrical conductivity, and density abruptly change [1]. This concentration is called critical micelle concentration (CMC). It has been established from theoretical considerations as well as experimental determinations that surfactant molecules begin to form aggregates, called micelles, when surfactant concentration is increased beyond the critical micelle concentration (Figure 3A). In general, the micelles are spherical aggregates of surfactant molecules about 40-100 Angstrom in diameter and are in equilibrium with single molecules (or monomers) in the bulk solution (Figure 3A). The critical micelle concentration depends upon the structure of surfactant molecules as well as physicochemical conditions such as temperature, pH, and the ionic composition of the solution.

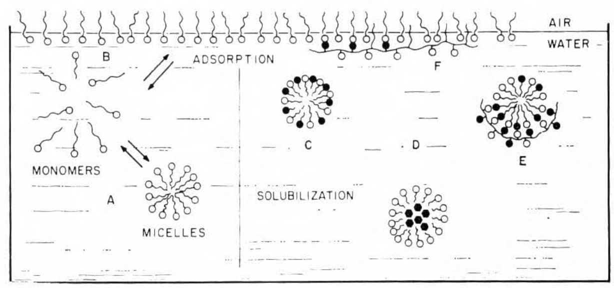

FIGURE 3. A schematic presentation of adsorption, micelle formation, and solubilization processes in surfactant solutions.

If a soluble surfactant is dissolved in water, it tends to absorb at the gas/liquid, liquid/liquid, or solid/liquid interfaces. The adsorption phenomenon results in a greater concentration of surfactant molecules at the interface as compared to that in the bulk solution (Figure 3B). For many surface-active drugs and pharmacological agents, their concentration at the membrane surface will be considerably greater than their bulk concentration [2].

The formation of micelles in an aqueous solution creates a local nonpolar environment within the aqueous phase. Oil soluble molecules such as dyes, pigments, nonpolar oils, or oil soluble vitamins can be dissolved within the micelles (Figure 3C, D). The solubilization of such molecules in micelles is greater if they also possess polar groups.

If a surfactant solution contains a surface-active polymer, then adsorption of the polymer can occur at the micellar surface (Figure 3E). The structure of lipoproteins, particularly low density lipoproteins in blood serum, resembles this situation in which a protein is adsorbed on the aggregates of lipid (i.e., biological surfactant or fat) molecules [3]. If a surface-active polymer is present in the solution, then a mixed, absorbed film of polymer and surfactant also can occur at the interface (Figure 3F). In several biological membranes, the protein-lipid association is believed to resemble this type of association [4].

Surfactant molecules can be considered as building blocks. One can make various types of structures of surfactant molecules by simply increasing the concentration of surfactant in water and adjusting proper physicochemical conditions such as temperature, pH, and the presence of various electrolytes [5, 6]. Figure 4 schematically shows various structures that are formed in the surfactant solution upon increasing the concentration of a surfactant. Upon increasing the concentration of surfactant, spherical micelles become cylindrical and subsequently the cylindrical structures become hexagonally packed. If concentration is further increased, the lamellar structures are formed. Upon further addition of surfactant, the lamellar structures are converted to a hexagonal

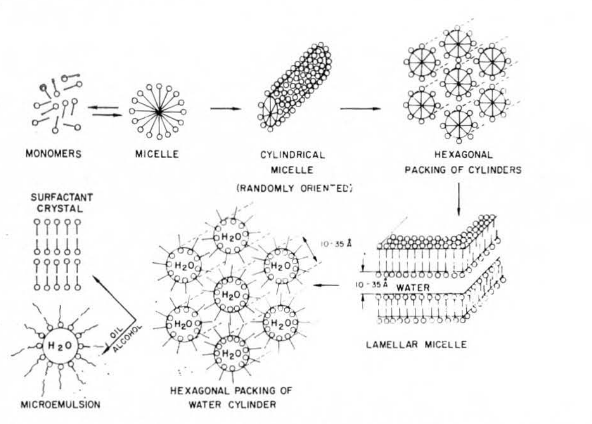

FIGURE 4. A schematic presentation of structure formation in surfactant solution depending upon the concentration of surfactant as well as physico-chemical conditions.

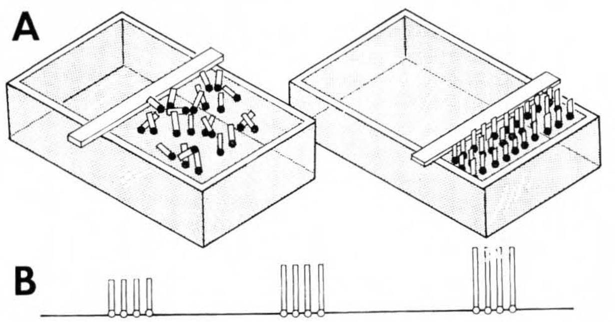

FIGURE 5. (A) schematic illustration of a monomolecular film at air-water interface.
(B) orientation of surface-active molecules with increasing chain-length at air-water interface.

packing of water cylinders. Upon addition of oil and a short-chain alcohol, one can convert such water cylinders into a water-in-oil microemulsion. The structures of these systems are well established from X-ray diffraction studies [7, 8]. It is possible to induce a transition from one structure to another by changing the physicochemical conditions such as temperature, pH, addition of monovalent or divalent cations in the surfactant solution [9]. The cylindrical and lamellar structures often are called liquid-crystalline phases since they have flow properties as liquids and a certain degree of crystallinity as solids. They have very unusual electrical and rheological properties [10-12]. It should be emphasized that the scheme shown in Figure 4 is a general scheme and a surfactant may skip several phases depending upon its structure and the physicochemical conditions.

INSOLUBLE SURFACTANT AND MONOLAYERS

IF THE HYDROCARBON chains are sufficiently long (greater than 16 -C-C- bonds), the surface-active molecules will be insoluble in water. When such insoluble surfactants are dissolved in organic solvents, and a drop of the solution is placed on the water surface, these molecules will spread at the air/water interface. In general, the surfactant molecule does not evaporate because the polar group is anchored on the water surface and it does not dissolve because the long hydrocarbon chain prevents the molecule dissolving into water. In this way, one can produce a monomolecular film of floating molecules of an insoluble surfactant at the air/water interface. In general, one can fill a tray of Teflon or plexiglas with water up to the rim of the tray. A measured quantity of surfactant solution in an organic solvent such as chloroform, benzene, or hexane can be placed by a microsyringe on the water surface. The solvent molecules evaporate or diffuse into the water leaving the insoluble surfactant molecules at the surface. A glass slide is placed at one end of the trough (Figure 5A). By horizontal movement of the glass slide one can compress this monomolecular film and bring molecules closer to one another. However, as the film is compressed, at a specific film area, the molecules will stand side by side with their polar groups in water and hydrocarbon chains in the air. By measuring the area of the film as well as calculating the number of molecules deposited on the surface, one can determine the average area per surface-active molecule in the monolayer. In a closed packed state, the average area per molecule is close to the cross-sectional area of the surfactant molecule. Thus, an insoluble monolayer is a system which allows the direct experimental determination of the cross-sectional area of the molecules.

Monomolecular films or monolayers represent a two-dimensional state of matter since their height, which is about 20-25 Angstrom, is negligible compared with their length and width. Analogous to the states of matter in three dimensions, monolayers also can exist as two-dimensional solids, liquids or gases and can undergo temperature-dependent phase transitions from one state to another [13, 14].

The engineering applications of surface science range from agricultural sprays to oil recovery including areas such as catalysis, coatings, dispersions, electronics, flotation of minerals, lubrication, and retardation of evaporation from lakes and reservoirs. . .

When the monomolecular film is compressed by moving the glass slide, the surface tension decreases (Figure 5A). The decrease in surface tension often is called surface pressure which indicates the state of compression of the monomolecular film. The higher the surface pressure, the higher the state of compression of the monomolecular film. The surface tension is measured by a torsion balance from which a thin platinum blade is suspended in water at the air/water interface.

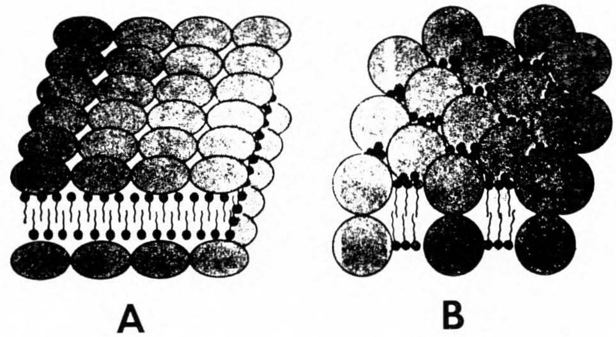

FIGURE 6. (A) Davson-Danielli model for structure of biological membranes.
(B) Lipid-protein mosaic model for the structure of biological membranes.

From the surface pressure measurements one can prepare a plot of surface pressure vs. average area per molecule. This plot is equivalent to pressure vs. volume curve for gases in three-dimensional state. In 1920, the concept of the specific molecular orientation at interfaces was a novel idea, but there was no experimental proof for this concept. Langmuir [15] used monolayer approach to establish that surface active molecules have a specific molecular orientation at the air/water interface. He studied monolayers of various fatty acids of different length containing 16 to 32 carbon atoms. Experimentally, he determined the cross-sectional area of molecules in the compressed monolayers of these fatty acids. To his surprise, he observed that although the fatty acids studied were of different chain-length, the cross-sectional area determined was the same for all fatty acids suggesting that they must be oriented vertically to the surface (Figure 5B). If they were oriented in any other way, the increasing chain length would have caused an increase in the average area per molecule. For establishing this concept of the specific molecular orientation at interfaces, Langmuir later was awarded a Nobel Prize [16].

APPLICATIONS OF MONOLAYERS

SINCE IT IS DIFFICULT to visualize at a molecular level how properties of a monolayer are related to various phenomena, I have prepared the following few diagrams to emphasize the role of monomolecular films in these phenomena.

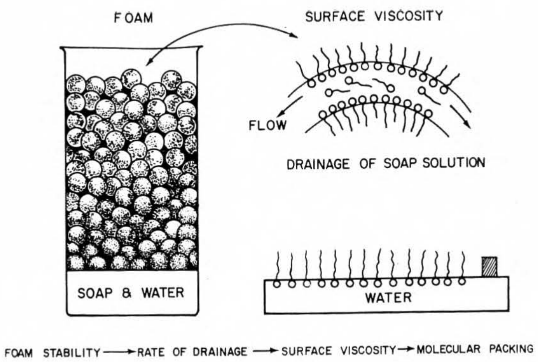

FIGURE 7. The schematic presentation of factors influencing foam stability.

Figure 6 shows two conceptual models for molecular arrangement of lipids and proteins in biological membranes [17, 18]. In the Davson-Danielli model (Figure 6A), the lipids (i.e., biological surfactant) are arranged as a continuous bilayer and protein is believed to be adsorbed on both sides of the lipid bilayer. The second model, (Figure 6B) which is based upon the current thinking about the structure of biological membranes, visualizes a discontinuous lipid bilayer interdigitated by protein molecules. Irrespective of which of these models is a more accurate description of molecular arrangement in membranes, the orientation and packing of lipid molecules in membranes are similar to that in monomolecular films of the lipids at the interface. Using a monolayer approach, one can determine lipid-lipid, lipid-protein and lipid-metal ion interactions that may occur in biological membranes [19-21].

Figure 7 schematically shows a foam column produced by a surfactant solution. The stability of the foam column depends upon the stability of individual soap bubbles. A soap bubble is a thin layer of surfactant solution which has the adsorbed film of surfactant on both sides of the soap film. The stability of the soap film depends upon the rate of drainage of solution in the film, which subsequently depends upon the state of adsorbed surfactant film. We have observed [22, 23] that a closer packing of surfactant molecules in the adsorbed monolayer leads to a higher surface viscosity of the adsorbed monolayer, which subsequently decreases the rate of drainage of solution within the soap film, and hence increases the foam stability.

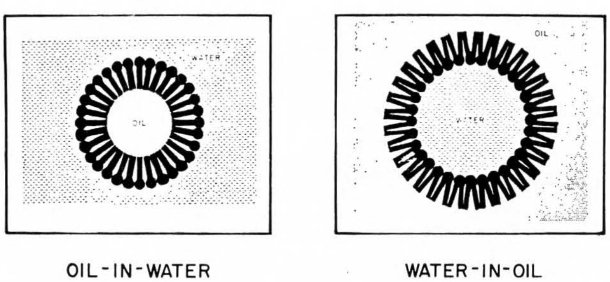

FIGURE 8. A schematic presentation for the structure of emulsion droplets and orientation of surface-active molecules at the oil-water interface.

Figure 8 schematically shows the role of monolayers in stabilizing oil/water emulsions. It has been known that oil and water do not mix. However, if a surfactant is added to oil-water mixture, one can produce a relatively stable emulsion. Depending upon the relative amounts of oil and water as well as the physicochemical conditions, one can produce oil-in-water or water-in-oil type emulsion. In either case, each droplet is coated with a surfactant monolayer (Figure 8).

Figure 9 shows the role of the monomolecular film in boundary lubrication of metallic surfaces. Here a surfactant attaches itself to a metal surface due to the interaction between the polar group of the surfactant with the metallic surface. When such monolayer-covered surfaces slide against one another, the frictional forces decrease considerably. Since sliding of hydrocarbon chains past one another does not offer too much resistance, the coefficient of friction decreases strikingly. Moreover, the adsorption of such monomolecular film of surfactant on metal surfaces also protects the surface against wear from friction.

The domain of surface science is perhaps one of the most interdisciplinary areas of modern science and technology. . .

The monomolecular films of fatty acids or fatty alcohols also are employed for reducing evaporation of water [24]. In many countries such as Israel, India, and Australia this approach is used to decrease evaporation of water from lakes and reservoirs.

Figure 10 shows one of the concepts of surface science, namely, contact angle and wettability. When a drop of water is placed on wax, Teflon, or plexiglas, the drop rests on the surface with a finite angle called contact angle. If the contact angle is greater than 90°, the liquid does not wet the surface. If one adds a surfactant or "wetting agent" in water, the contact angle on wax or

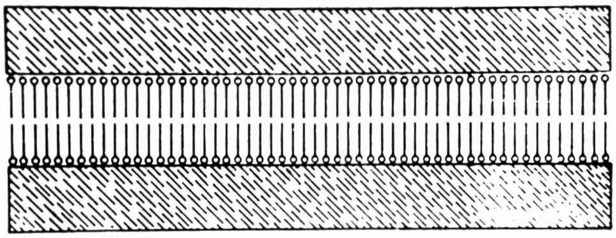

FIGURE 9. A schematic presentation of the orientation of surface-active molecules at the metal surface in boundary lubrication.

Teflon decreases dramatically and may approach zero. Hence, normally nonwettable surfaces can be wetted by water if surfactants are added to water [25, 26]. This phenomenon is of considerable importance in agricultural sprays since the herbicide or insecticide will not be effective if the drops from the spray do not stay on the leaves or fruits (because of their waxy surface) and fall on the ground. However, if one adds a surface-active agent to the spray, it changes the contact angle and permits droplets to stick and spread on the leaves and fruits providing protection from insects and other diseases (Figure 10). This phenomenon is also of central importance in the wetting of contact lenses and in many problems related to cornea and tears [27].

UNSATURATED FAT AND MOLECULAR AREA

AT PRESENT, considerable emphasis is placed on the desirability of "polyunsaturated fat" and the undesirability of "saturated fat and cholesterol" in diet. To determine the differences in the cross-sectional area and surface properties of lipid (fat) molecules with identical polar group but different degree of unsaturation in their fatty acid chains, we took lecithins from four different sources [28]. The four lecithins were, respectively, dipalmitoyl lecithin, egg yolk lecithin, soy bean lecithin, and dioleyol lecithin. The first and the last lecithins were synthesized in the laboratory. Lecithin is a common component of biological tissues and membranes. As shown in Figure 11, the surface-pressure-area per molecule curves of these four lecithins were different suggesting that the nature of hydrocarbon chains influences the average area per molecule of lecithin. The order of average area per molecule is as follows: dipalmitoyl lecithin < egg lecithin < soy bean lecithin < dioleyol lecithin. The fatty acid compositions of these four lecithins also were determined separately by the gas chromatography of fatty acids.

Figure 12 is a schematic presentation of these four lecithins in monomolecular films based on monolayer and gas chromatography data. These results indicate that the degree of unsaturation or the presence of double bonds in fatty acid chains influences the average molecular area of lecithins and subsequently influences the intermolecular spacing between lipid molecules. If one assumes that the average area per molecule is a circle with a radius "r"; then the intermolecular spacing is 2r. If we consider areas of 51.9 Å^2, 73.8 Å^2, 78.1 Å^2, and 87.5 Å^2 per molecule at a surface pressure of 20 dynes/cm for dipalmitoyl, egg, soy bean, and dioleyol lecithins, respectively; the corresponding intermolecular spacings are 8.1 Å, 9.7 Å, 10.0 Å, and 10.6 Å suggesting that a change of 0.3 Å to 1.5 Å in the intermolecular spacing is brought about by the degree of unsaturation of fatty acid chains. Further, we have shown that such small changes in intermolecular spacing strikingly influence the hydrolysis of lecithin monolayers when snake venom is injected under the monolayers. We have established that the degree of unsaturation of lecithins also influences their interaction with calcium ions in the solution as well as their association with cholesterol in monomolecular films (19, 21, 29, 30).

In summary, monolayers provide an extremely useful system to study cross-sectional area of surfactant molecules and to elucidate the effect of unsaturation on the intermolecular spacing, and hence on the reactions and molecular interactions at interfaces [31].

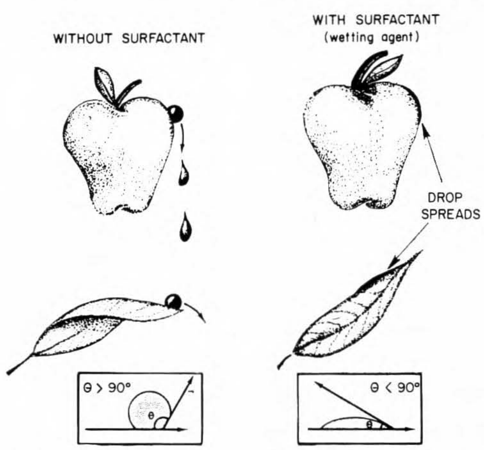

FIGURE 10. A schematic presentation of the role of contact angle and wettability in influencing the effectiveness of agricultural sprays.

MONOLAYERS AND OIL SPILLS

The contraction of an oil spill is an interesting application of monolayers.* In the event of an oil-spill, the oil continues to spread because of the natural surfactant in the crude oil. These natural surfactants have a certain spreading pressure and, as a result, the oil continues to spread at the air/water interface. However, if one deposits a film of another surfactant with a higher spreading pressure around the oil-spill, then the deposited monolayer causes contraction of the oil-spill. In other words, the deposited film, having a higher surface pressure, causes the oil-spill to contract. The most fascinating message that comes out of this observation is that the monomolecular film of

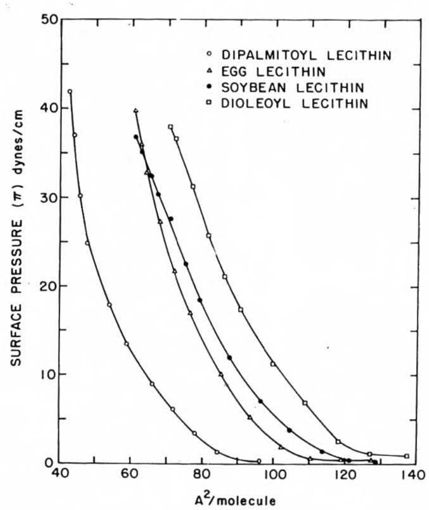

FIGURE 11. The surface pressure-area curves for four lecithins with different fatty acid compositions.

surfactant pushes a crude oil layer that is two million times thicker than its own thickness ($\approx$25Å). This observation leads to the conclusion that for contraction of oil-spill, it is the spreading pressure that is a predominant factor and not the thickness of oil or surfactant layers. Spreading such a surface-active material around the oil-spill from a helicopter can prevent further spreading of the oil-spill and can thicken the oil layer at the air/sea interface and hence facilitate the collection procedures. Spreading of such films near the shore-line also can prevent the oil-spill from contaminating the beaches. Since we are using monomolecular films for this purpose, the danger of

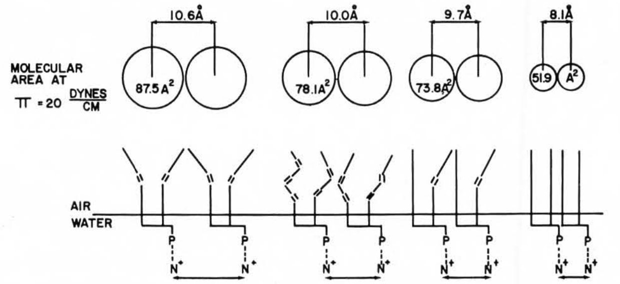

FIGURE 12. A schematic presentation of the effect of double bonds on the intermolecular spacing in lecithin monolayers.

contaminating the beaches with surfactant is extremely negligible and most of the surfactant used for this purpose would be biodegradable. Moreover, one would require extremely small amounts to produce monomolecular films.

Figure 13 shows the three-dimensional view of the application of surfactant solutions or microemulsions in tertiary oil recovery from petroleum reservoirs. Usually the oil wells are drilled in a five spot pattern in such a way that the microemulsions or surfactant solutions are injected into the central injection well. The surfactant formulation solubilizes the oils or decreases the interfacial tension at the oil/brine interface in the reservoir and displaces the oil towards the production wells at the four corners. If appropriate surfactants are injected, then the sandstone and rocks in the reservoir are cleaned and the oil is displaced effectively towards the production wells.

SURFACE PROPERTIES OF POLYMERS AND TEAR SUBSTITUTES

IT IS FASCINATING that most of the phenomena mentioned previously such as retardation of evaporation, wettability of surfaces and lubrication take place every time we blink. Figure 14 schematically shows our concept [32, 33] of various phenomena that occur in the outer portion of the eye (i.e., cornea, tear, and the film of meibomian oil at the air/tear interface). Many people usually above 40 to 50 years of age suffer with a condition called "dry-eye syndrome." In this situation, the thickness of the tear film decreases considerably because of lack of fluid in the eyes. Between the blinks the thickness of the tear film decreases to such a low value that the tear film breaks and develops dry spots on the cornea. If one blinks under these conditions, there is considerable friction between the inside of the eye lid and the dry spots on the cornea. This may lead

*Mr. A. Tamjeedi, an undergraduate student in Chemical Engineering, presented this paper at the Students AIChE Chapters competition at Baton Rouge, Louisiana and was awarded a second prize for his work in this area, 1973.

to damage of the corneal surface. Several pharmaceutical eye drops containing polymers are available to stabilize a thick layer of water on cornea. However, there is no scientific evaluation of the effectiveness of these available artificial tears or tear substitutes.

We studied the flow dynamics and the thickness of tear film in the eye using a slit-lamp fluorophotometer. The eye drops containing a fluorescent dye (fluorescein) are instilled into the eye of the patient or volunteer. In general, the intensity of fluorescence is related to the thickness of the tear film. We found that the tear-film thickness decreases between blinks due to drainage by gravity. However, if one adds a drop of a surface-active polymer solution (such as polyvinylalcohol (PVA), hydroxypropylmethylcellulose (HPMC)), or a commercially available tear substitute, the film thickness increases between blinks. Figure 15 schematically shows our explanation for the effect of polymers in thickening the tear film between blinks. A surface-active polymer would adsorb at the air/tear interface. When one blinks, this adsorbed film is compressed just like a monolayer spread on the tray filled with water (Figure 5). After the blink, the lid is moved upward, and the compressed film of the polymer spreads in the upward direction to occupy the clean surface at the air/tear interface. When the compressed film of polymer moves upward, it drags water as the sublayer. This phenomenon of surface flow from high surface pressure to low surface pressure is called *Marangoni effect.* To establish that water can be dragged by a polymer film, a simple experiment using a glass slide was carried out as shown in Figure 16. One end of a wet glass slide was dipped into a polymer solution and it was observed that the polymer solution begins to climb on the wet glass slide. From fluorescence measurements, the thickness of the moving film was determined. To our surprise we found that the thickness of films of various polymer solutions measured in this system was the same as that measured in the eye. Table I shows the thickness of various polymer solutions dragged on a vertical glass slide. We also carried out similar experiments using a monomolecular film of Polyvinylalcohol (Table I). Here again, we found that the thickness of the layer of water dragged by a monolayer was 13 microns which is the same as the thickness of the layer dragged from the polymer solution. In other words, the increase in the thickness of the tears in the eye can be accounted for by a monomolecular film of polymer at the air/tear interface. This study again points out the importance of surface activity of polymers in assisting and providing comfort to patients with "dry-eye syndrome."

TABLE I

Polymer		Thickness (μm) of water layer dragged by polymers*
Barnes-Hind wetting soln.	58 cp	22
Adapt†	70 cp	17
Presert†	18 cp	16
Lacril†	28 cp	14
Visculose†	130 cp	11
PVA	120 cp	18
PVA	20 cp	12
HPMC	120 cp	12
HPMC	20 cp	9
Monomolecular film of PVA		13

*Surface Area of Trough = 0.52 cm^2
†commercially available artificial tear solutions

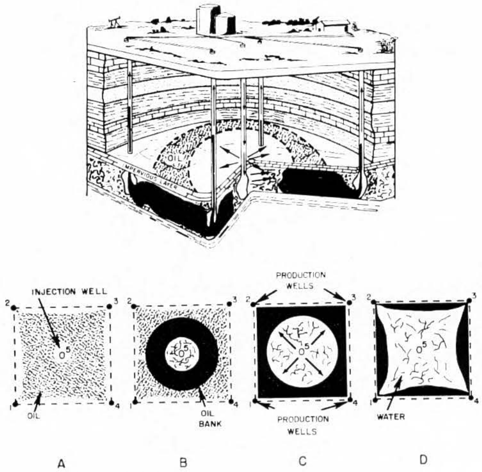

FIGURE 13. A schematic presentation of a petroleum reservoir. The lower part of the diagram shows how injection of a surfactant formulation moves the oil towards the four production wells.

APPLICATIONS OF SURFACE SCIENCE

• **Agriculture and food technology**—The effectiveness of various herbicides and insecticides in agricultural sprays are determined by their wetting of leaves and fruits. The presence of surfactants (wetting agents) in agricultural sprays strikingly improves the effectiveness of the sprays and contributes to a greater production of crops. The emulsions also find considerable application in food products such as salad dressings, margarine, whipped cream, puddings, etc. Surface chemical aspects of protein-lipid associations also are important in determining the texture of food such as cakes and pastries and work is being done in this direction using the principles and techniques of surface sciences.

• **Energy**—The surfactant solutions and microemulsions are important in improving oil recovery from petroleum reservoirs. Another interesting application is in the area of combustion efficiency of various oils. Recently, it has been shown that if one injects a fine dispersion or emulsion of water and oil in furnaces, the efficiency of conversion of oil into heat is improved considerably. Although the exact mechanism is not established, the fact still remains that emulsification of oil and water improves the combustion efficiency.

• **Environment**—Principles and techniques of surface science find many applications in environmental problems. The dewatering of phosphate slimes, sludge formation, coagulation, and flocculation in many waste-water treatment plants rely on the surface interactions. The surface reactions and adsorption on activated carbon are very effective methods for removal of trace contaminants. Fibrous coalescers also are used for the removal of oil droplets from a few parts per million concentration in the effluent streams of many industries. Here the attachment of oil drops to the fiber and their subsequent coalescence play an important role in the separation of oil. The use of surface films as oil herder for the contraction of oil-spills has been discussed. The presence of films at the air/water interface also causes wave-damping of small ripples. This observation has been used in developing the instrumentation for remote sensing of oil-spills. In all these systems and processes, the principles of physics and chemistry of surfaces and surface-active agents are involved.

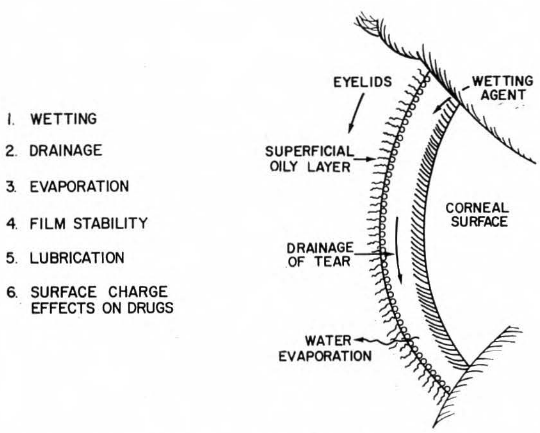

FIGURE 14. A schematic presentation of various surface phenomena occurring in the eye.

. . . monolayers,provide a unique system to determine experimentally the cross-sectional areas of surface-active molecules and to study reactions and molecular interactions at surfaces.

• **Industries and engineering**—The surface science is involved in coating processes. For example, the production of magnetic tapes in which a dispersion of magnetic oxide is coated on polyester tapes. The stability of the dispersion and the strength of adhesion depend on the surface interactions. Other applications of surface science are found in the manufacture of inks, paints, pigments, nonstick cooking wares, etc. The textile industry also utilizes considerable quantities of surface-active substances in the form of wetting agents, emulsions, dye-solubilization and other processes. The contact angle and wettability also enters into water-proofing of textiles, roofing material and similar systems. Many lubricants also involve the use of hydrocarbon oils and various surface-active agents as additives. The physics and chemistry of thin films are used extensively in the electronics industry. As discussed previously, the production of petroleum and petrochemicals also utilizes many processes which are in the general domain of surface science. The field of catalysis is based on surface interactions between the substrate molecules and the catalyst surface. The formulations of soaps and detergents for household uses also are based on surface properties of surfactants. In the world about 10^9 tons of minerals are processed every year by the use of flotation technology which again relies on the adsorption of surfactant on mineral particles. Many office stationeries such as NCR papers (no carbon required papers) use microencapsulation of powders to coat these papers. The microencapsulation is one of the most interesting applications of surface and colloid science to industrial processes.

• **Biology and medicine**—Many principles and techniques of surface science are relevant to the understanding of the properties and functions of biological membranes. It has been suggested [17] that the spontaneous formation of membranes played an important role in the origin of prebiological cells during the chemical evolution which was followed by the biological evolution. These techniques are being used to elucidate the mechanism of action of many drugs, anesthetic agents, and pharmacological agents on membrane properties. It has been established during recent years that conduction of electrical signal along a nerve fiber is strictly a surface phenomenon occurring in nerve cell membrane. As discussed previously the surface properties of polymers are also relevant to the performance of tear substitutes in the eye. These concepts can be also extended to the wetting of contact lenses and the comfort for the eye. The solubilization of oil soluble vitamins in

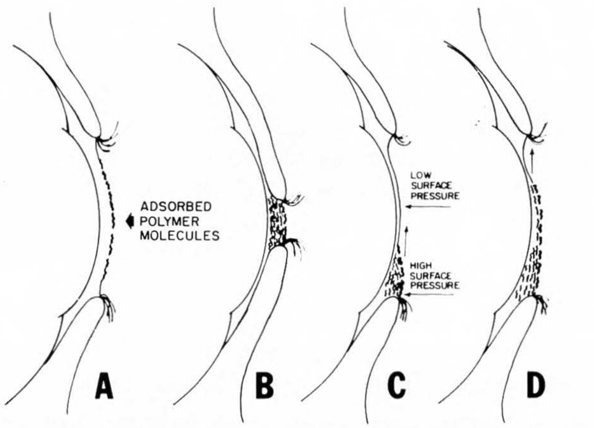

FIGURE 15. A schematic presentation of the effect of adsorbed polymer film at the air-tear interface in upward movement of water after a blink.

micelles, the fat absorption in intestine, lung stability and the function of pulmonary surfactant, synovial fluid and lubrication of bone joints, dental integuments, and the development of various nonthrombogenic surfaces for artificial organs and implants all draw significantly on surface science.

• **Pharmaceuticals**—Various pharmaceutical products such as ointments, skin lotions, creams, microencapsulation of drugs for sustained drug-delivery, birth control foams, etc. are being formulated and developed using principles and techniques of surface science. Some of these have been discussed previously.

In summary, I would like to emphasize that from the research activities I have carried out in the past decade, I have become convinced that the surface science is one of the most important facets

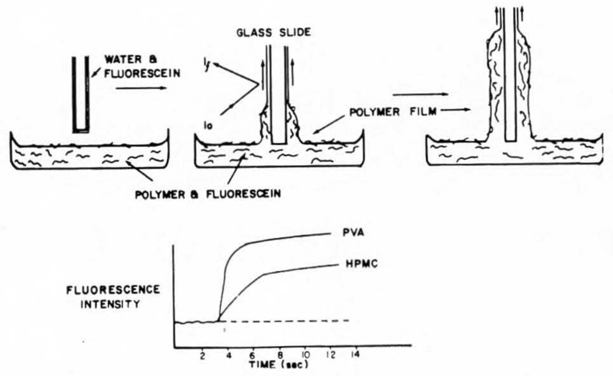

FIGURE 16. The slide technique used to measure the thickness of water layer dragged with a moving polymer film.

of science. It is related to many natural processes and systems; it is one of the unique branches of science that finds so many diverse and wide-ranging applications in engineering, biology and medicine.

It is only during the past few years that we have seen rapid advances in understanding the complexities and unique properties of surfaces. I believe we are still at the shores of surface science, and we have a whole ocean to explore! Over the years I have also become convinced in my belief that "research is an art. Just as an artist enjoys painting a picture, or a poet enjoys writing a poem, a scientist does research for his own enjoyment, regardless of its appreciation by others, although it is nicer when it is also appreciated and enjoyed by others." As I began this article with a quotation, I would also like to end it with a quotation from a poem by Tagore, which very appropriately says, "My friend, drink my wine in my own cup to appreciate its sparkling bubbles." □

ACKNOWLEDGEMENTS

I would like to thank Professor Bolduc (Education), Professor Nevis (Electrical Engineering and Physics), Dr. Tham (Anesthesiology and Chemical Engineering), and Professor Walker (Chemical Engineering) for critically reviewing the manuscript and for many constructive suggestions. The financial support for the research presented here was provided by the National Science Foundation, National Institute of Health, Environmental Protection Agency, the Florida Heart Association, and the University of Florida, which is gratefully acknowledged.

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ChE curriculum

PROCESS CONTROL ENGINEERING AT UT PERMIAN

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THE UNIVERSITY OF TEXAS of the Permian Basin, was opened in the Fall of 1973 to serve the more than 300,000 people in the oil-rich Permian Basin, the state of Texas, and the nation. Offering programs in three colleges: Management, Arts and Education, and Science and Engineering, the university operates as an upper level institution providing junior, senior, and graduate level courses. Students are accepted after completing at least 60 hours of work at another institution, usually a junior college. Designed from the outset to provide unique and innovative programs and to employ proven teaching techniques, both new and old, the university has embarked on a number of distinctive educational and operational tracks. These are perhaps best exemplified by the program in Control Engineering. It is the purpose of this paper to describe that program.

THE NATURE OF A CONTROL ENGINEER

CONTROL ENGINEERING is a unique engineering discipline, as different from other disciplines as they are different from each other. It is inherently multidisciplinary in character requiring expertise from a number of diverse disciplines. That expertise must be brought to bear, however, in a way that is unique to control engineering. Control engineers are concerned with complex systems, systems with elements from many physical domains, systems that are almost always in a transient state, systems that must perform with precision and accuracy.

A suitable control engineering curriculum must emphasize accurate measurement and control of variables, modeling and dynamic response of elements and systems, sophisticated and functional methods of analysis and design, and the commonality of systems from all domains. To successfully build a program of this type, it is necessary to have faculty with broad experience and an interdisciplinary background and that are willing to work freely across discipline boundaries.

GENERAL GOALS

STARTING A NEW engineering program in a new university, especially one where judicious departure from tradition is not only tolerated but encouraged, provides a rare opportunity to take a new approach to engineering education. The control engineering program has attempted to take a cautious and rational approach to substantial change. Program goals, for example, call for technical competence in breadth and depth and a demonstrated high level of communication, management, and interactive skills. More significantly different from tradition, however, are the additional program goals of developing in graduates the desire and the ability to continue learning, of providing a program that meets efficiently the individual needs of students, and gives students with sufficient innate learning capacities a maximum chance for success. Accreditation is, of course, an important program goal.

Since the courses are also offered for variable credit, there are essentially no fixed course boundaries. Students may thus enter a study area at a point consistent with their background and exit when they have successfully completed the collection of modules appropriate to their specific degree plan.

A coherent curriculum design results when aimed toward a specific and well-defined set of

*Recent revision of a paper presented at the annual meeting of the ASEE-CED, Colorado State University, 1975.

degree objectives. From the degree objectives, it is possible to identify the supporting objectives down to the expected entrance level of students, in this case, the beginning of the junior year. These supporting objectives can be subdivided to form the courses or study areas necessary to accomplish the curriculum. Usually, a given objective specifies a broadly applicable problem-solving process and need not be tied directly to a given physical domain such as chemical, electrical, mechanical, etc. In this way, it is possible to use different applications vehicles to illustrate and learn the given process. One may learn about the basic processes in modeling and simulating second order systems, for example, by using electrical, mechanical, fluid, thermal or other systems as illustrations. The multi-disciplinary nature of control engineering makes it important to give some attention to all applications areas while placing emphasis in the areas appropriate to the individual student's goals. By specifying the appropriate set of problem-solving capabilities along with the content areas that are germane, a highly individualized curriculum can result.

The specific degree objectives are of utmost importance in the design of a curriculum and of courses for that curriculum. For those that may be interested, the objectives are included as an appendix.

STUDY PLANS AND COURSE STRUCTURE

ALTHOUGH ONLY A single degree designation is currently authorized, a broad range of individual curricula is possible through formulation of a specific, individually tailored degree plan for each student. Working in close association with a faculty adviser of his or her choice, a student works out the degree plan which, while meeting all the external constraints, is best suited to the entrance competencies and career goals of the student. Personal interviews, current testing data, job experience, previous academic records, and limited special testing are currently used as bases for establishing points of entry into the program. An extensive program of pretesting will be undertaken for the first time in the Fall of 1975.

Courses designed for this program are each divided into several small modules of instruction, each module specifying carefully what is required of the student. Modules are studied in a sequence so that each builds on and reinforces the previous one and so that interrelationships among study areas are carefully delineated. Since the courses are also offered for variable credit, there are essentially no fixed course boundaries. Students may thus enter a study area at a point consistent with their background and exit when they have successfully completed the collection of modules appropriate to their specific degree plan. Additional flexibility is provided by selecting variations in objectives and application areas within a module to support a particular program. To formulate such a degree plan, the amount of credit in a given course area is specified; currently in units

L to R: Drs. Charles M. Fry, Clyde H. Sprague and George H. Quentin.

Charles Max Fry received the B.S. degree in aerospace engineering from the University of Oklahoma in 1965, the M.S. degree in mechanical engineering from Rice University in 1967, and the Electrical Engineer and Ph.D. degrees in electrical engineering from Southern Methodist University in 1972 and 1973, respectively. From 1967 to 1970 he was employed as an Aerodynamics Design Engineer with LTV Aerospace Corp., Dallas, Texas. Dr. Fry was an LTV Corporation Doctoral Fellow at Southern Methodist University from 1970 to 1973. Since 1973 he has been Assistant Professor of Engineering at U. T. Permian Basin.

Clyde H. Sprague received the B.S. degree in mechanical engineering from Kansas State University in 1958. From 1958 to 1961 he was employed at The Johns Hopkins University Applied Physics Laboratory in Silver Spring, Maryland. He received the M.S. degree in mechanical engineering from Kansas State University in 1963. From 1963 to 1973 he was with the Department of Mechanical Engineering at Kansas State University. Two years were spent on leave at Purdue University where the Ph.D. degree was completed in 1967. He moved to UT-Permian in January of 1973 as Associate Professor and Coordinator of Engineering.

George H. Quentin received the BChE (1955) from Rensselaer Polytechnic Institute, and the M.S. and Ph.D. (1965) in Chemical Engineering from Iowa State University. Background includes diversified experience with DuPont, National Distillers, and Monsanto Companies. Following several years on the Chemical Engineering Faculty at the University of New Mexico, he joined the University of Texas of the Permian Basin as an Associate Professor on the Faculty of Engineering.

of not less than 1 credit hour. This generates a conventional-looking transcript. Specific requirements for a student to earn the designated credit are worked out and contracted informally. A more formal process for this is evolving but the informal process works adequately for our small student population.

SELF-PACED INSTRUCTION AND COURSE MANAGEMENT

To use effectively the flexibility built into the course structure and degree formulation system, most course areas are offered on a continuous enrollment, self-paced basis. Consequently, students may enter the program at any time, and take up to two full semesters to complete a course under justifiable circumstances. This requires that most self-paced courses be available at all times. Simultaneous proctoring of several courses by both students and faculty results in efficient and full use of instructor time, even with small individual course enrollments.

Courses designed for this program are each divided into several small modules of instruction, each module specifying carefully what is required of the student.

Good course management plays an important role in the relative success of a self-paced course. Neglect of the management aspect of self-paced course design is common and often leads to disenchantment with the method. Significant time and effort have been devoted to the evolution of a workable management system at UT Permian, and much has been accomplished. Although the system is far from perfect it is improving steadily. Management is an important component in all self-paced courses but is critical in this engineering program where most or all of a given student's load may be self-paced.

A RANGE OF DEGREE PLANS

ALTHOUGH THE CONTROL Engineering degree is of sufficient breadth to prepare students for a variety of career opportunities, all students are expected to develop control system design expertise in one or more selected applications areas. Efficient degree planning for these diverse fields of application requires significant breadth of selection in math, in engineering science, and in engineering design. This is accomplished by developing a minimal central core in each area surrounded by a coherent collection of additional work from which to choose. In visualizing this approach, it is important to recognize that there are no fixed course boundaries so great flexibility is possible.

To illustrate the breadth of possible curriculum planning, two contrasting degree plans are outlined in the table below. One is appropriate for an engineer interested in chemical process control, the other is oriented toward flight control applications in commercial or military aviation or aerospace. These degree plans should be interpreted as representative of what is planned or possible, not as specific requirements for a degree although they do indicate minimal credit in an area. It is also important to note that differences in content and objectives between equal credits in a given study area contribute to a difference in the two plans not evident in the table.

ENGINEERING DESIGN

A SIGNIFICANT PORTION of this component of each Control Engineering degree plan is devoted to formal training and realistic experience with project engineering and management. At present, the engineering management training is handled by conventionally offered, formal management courses. These will eventually be tailored to and integrated with the project engineering activity.

The engineering project experience is provided by courses in Authentic Involvement. In this area, students are organized into teams of four or five students, possibly some that are not engineers, to pursue a lengthy engineering project. Projects are solicited from industry, public service institutions or other appropriate sources. Specific criteria for screening potential projects have been established to insure their realism and suitability. Students work in teams, under faculty supervision, and as consultants to the industry. Each team is expected to carry out all of the functions of a normal project team assigned to such a problem and to conclude the project with a formal, oral and written report to the client agency.

Authentic Involvement is the capstone of the degree program and serves to reinforce previously acquired engineering competencies; to develop confidence and competence with the engineering

TABLE 1. REPRESENTATIVE BUT CONTRASTING DEGREE PLANS.

		Chemical Process Control Orientation	Flight Control Orientation
English		6	6
Humanities and Social Science	History	6	6
	Government	6	6
	Other	3-6	3-6
Basic Science	Inorganic Chemistry	8	8
	Advanced Chemistry (Physical & Organic)	8	0
Mathematics	Analytic Geometry & Calculus	9	9
		(content of advanced math selected to fit program)	
	Advanced Math	6	6
Engineering Science	Simulation	1-3	1-3
	Statics	1	1
	Dynamics	2	3
	Mech of Mat'ls	2	2-3
	Mat'ls Science	2	2-3
	Systems Analysis	4	6
	Thermodynamics	6	3
	Fluids	3	3
	Heat Transfer	3	2-3
	Electronics		3
	Measurements	0-3	3
	Separation Processes	3	
	Chemical Reactor Operations	3	
Engineering Design	Introductory Control System Design	3	3
	Computer Control	3	0-3
	Modern Control	0	3
	Engineering Management & Economics	3-6	3-6
	Engineering Project	3-6	3-6

design process; to develop and apply management, communications, and interaction skills so students experience a role as close to engineering practice as is possible in a university environment.

UNIQUE FACILITIES

Although facilities are usually of secondary importance, those being used for this program are as unique as the program. The University is housed, almost in its entirety, within a single building. One wing is used for conventional classrooms, offices, computer center, instructional media, administrative offices, and other service facilities, the specific room configuration being established with snap-in walls easily rearranged to meet changing needs.

The laboratory wing consists of three fully carpeted floors that are totally open and without walls except for a few offices and special purpose rooms around the periphery. Laboratory activities are carried out on mobile lab benches, some with all quick-connect utilities for wet experiments, some dry for other experiments. All tables have removable tote-trays for storing collections of experimental supplies in the stockroom for individual checkout. Utility outlets and drive-in fume hoods are distributed throughout the area. Tables are designed so they may be connected to form a chain of benches for group laboratories. All other furniture in the laboratory is movable to facilitate organization of the space for immediate needs.

The laboratory facility is used by all disciplines in the University and provides, in ad-

Continued on page 31.

USING SUMMER FACULTY-STUDENT CONSULTANT TEAMS TO SOLVE INDUSTRIAL PROBLEMS

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THE INDUSTRIAL EMPLOYMENT of a summer student between the junior and senior year or between the senior and first-year graduate school often is received by the student with mixed feelings. The experience can be a good one, with a challenging and interesting assignment, good supervision and understanding, and include a sense of community and identity. On the other hand, often summer experiences can leave a student perplexed and frustrated. He or she is not always treated with respect or given very challenging assignments. A stranger in town who feels out of touch with the community. The supervisor does not have adequate time to really provide him with a background to carry out a meaningful assignment in the short period time that is available, and the management does not know exactly how to treat him because he is the result of a public relations program.

During the first three weeks in September 1975, a group of four upcoming seniors, a graduate student, and a faculty consultant spent three weeks at the Yorktown refinery of Amoco Oil Company on four projects related to the wastewater treatments of refinery effluents. These four projects lasted only three weeks but because of good planning, excellent cooperation from the refinery and a good student mix, all the shortcomings often found with summer jobs were overcome. In addition, the technical achievements and maturity of approach were amazingly high. And what was originally thought to be primarily a public relations approach to better recruiting turned out to be quite successful whether measured from a public relations or technical contribution standpoint.

Last fall, while interviewing for Amoco at Virginia Tech, Jerry Arkis discussed with Don Michelsen the use of faculty-student consultant teams as a means for solving industrial problems. Because our unit operation lab occupies most of late July and August between the junior and senior year, the possibilities of using student study group was limited to an eight week period before Unit Operations Laboratory or a three week period following Labor Day prior to the beginning of fall classes at Virginia Tech. Following the exchange the faculty consultant drafted a brief description of consulting faculty-student team possibilities which could be expanded depending upon Amoco's interest. It was suggested that these teams might be used to solve a process development or plant project, complete an energy survey or process control analysis, or study the refinery's waste treatment plant.

The waste treatment area is a good area in which to work because . . . a high level of technical know-how is not required before an understanding of the problem is appreciated.

PLANNING PROCEDURE

IN APRIL, AMOCO invited the faculty consultant to visit for further discussion. The faculty member toured the facilities with Gene Echols and exchanged ideas on how students might be effectively used to study a number of waste treatment problems in the refinery. The refinery is committed to an activated sludge process for treating its biological wastes, but has some degree of flexibility in terms of what might be installed before and after the activated sludge facility. By late afternoon, Echols and Michelsen had defined four possible areas for student investigation.

Subsequently, the faculty consultant completed a proposal describing the four project areas, project definition procedures involving the students, procedures to be followed in carrying out the studies, and a budget. The financial arrangement was made independent of the university. An important goal was to have students identify the projects as their own rather than an assignment delegated by Amoco and/or the faculty consultant. The proposal was shared with the four students selected from six applicants who expressed interest in carrying out this project after Unit Operations Laboratory in the Fall of 1975. Prior to going down to Yorktown in late May, the students and faculty discussed Amoco's treatment procedures, general expectation being placed on the students, and agreed on student project area assignments.

By late May the proposal had been approved by Amoco and the four undergraduate students, plus the faculty consultant visited Yorktown in order to tour the refinery including the waste treatment facilities, and to discuss and exchange ideas on the individual projects. By day's end the students had a good understanding of their project. Prior to revisiting the end of July, each student was responsible for completing a literature search and background study on his project area and for preparing a presentation using flow charts of planned activities for early September. On Monday, July 28, 1975, the four students plus a fifth graduate student (Honcho) and the faculty consultant discussed their approach to the problems with representatives from Amoco Oil in Yorktown including James Grutsch, the Environmental Director for Standard of Indiana. The students' plan of attack differed considerably from the earlier discussions. They recognized increased emphasis on the pretreatment of the waste water following API separator, industrial concern for the aeration and stabilization of the sludges, and decided not to pursue work on the crude desalter but rather to spend that time in the API separator area. Following their flip chart presentation, James Grutsch gave an overview of the operation of the Amoco operation in Texas City. His ideas verified much of what the consulting team had decided Amoco should be doing in Yorktown. After considerable discussion, the four projects were defined. In effect, only one of the students' projects was changed in any significant manner.

The four projects selected for study were as follows: 1) a study of the performance and capabilities of the API separator, as well as the feasibility of using a coalescer following the API separator, 2) a pilot dissolved air-flotation system following the API separator to remove dispersed oil and suspended solids, 3) evaluation of final filter using newly installed equipment including a dual polymer flocculation system, and 4) a plant study of sludge settling in their backflush pond, including the use of polymer addition, turbulence in the backwash pond; and a laboratory study on air stabilization of backflush solids.

It was suggested that summer faculty-student consultant teams might be used to solve a process development or plant project, complete an energy survey or process control analysis, or study the refinery's waste treatment plant.

The students were very busy during the next five weeks completing the rather intensive Unit Operations Laboratory at Virginia Tech; therefore, when they arrived on Labor Day to start work on the second of September, the first day was spent discussing each project assignment. The first week was spent laying out test work, fabricating equipment, and becoming familiar with standard laboratory tests. Because of good understanding with management, laboratory, shop and plant personnel an atmosphere of good cooperation and encouragement was achieved—essential if any progress was to be made in three weeks. Equipment modifications were quickly made. A favorable union situation gave the students considerable freedom to design and fabricate much of their own equipment.

Projects were reviewed after the second week with Amoco management. By that time the students had completed their Introduction, Background and Theory, and Procedure sections which included plans, equipment, chemical analyses, data reduction, and presentation of expected results section. Monday, September 21, 1975, the students, Honcho, and faculty member gave a final oral report of the results of the study using flip charts.

Each student had completed a rough draft of his report and the results were presented to five representatives from the Amoco refinery. The three hour session included an individual presentation by each of the students involving their projects, a report of the short-term recommendations by the group leader, and a discussion of long-term recommendations to meet the BPT goals by 1977 by the faculty consultant. The long-term recommendations on the use of a DAF and equalization pond system are in conflict with present plans for Yorktown. A final report was completed by November 10, 1975, which included a write-up by each of the students and an overall Summary, Introduction and Recommendations section.

What was originally thought to be primarily a public relations approach to better recruiting turned out to be quite successful whether measured from a public relations or technical contribution standpoint.

PARTICIPANTS' RESPONSIBILITIES

ALTHOUGH THE STUDENTS could call on support from faculty consultant, Honcho, and Gene Echols from Amoco, the students were given most of the responsibility for carrying out their individual projects. This was reinforced by the oral presentation given the end of July which laid the groundwork for the students to start immediately after Labor Day. A significant amount of flexibility was provided while on site. The faculty consultant was in the plant four days although he did spend a number of Sundays reviewing projects with individual students. The Honcho was necessary to provide technical assistance, interact on numerous questions, provide liaison with Amoco and to encourage students when bogged down. He acted as an intermediary and yet as much as possible direct interaction of the students with refinery representatives was encouraged. The students did much of their own work and were free to go into the shops and work directly with Amoco personnel. The team lived together in two adjoining kitchenettes with the Honcho and faculty consultant. The group ate together during the week but tended to scatter during the weekends. Because of the close proximity, the two conducted studies around the API separator working together closely, and the two operating the filter and backwash worked together. A two man team effort developed.

The faculty consultant's responsibility centered primarily on setting up the projects, making sure the teams got off to a good start, setting some guidelines and directions for the overall projects, and reviewing the results and recommendations closely.

The waste treatment area is a good area in which to work because of short induction period. That is, a high level of technical know-how is not required before an understanding of the problem is appreciated. The students picked up a grasp of the subject rather quickly. However, prior to hands-on experience, the students had difficulty relating literature to plant operations. Books on industrial waste treatment are abundant and provide background, but until the student is directly involved appreciation of the literature is difficult. As a result, background and theory and the significance of the literature were initially glossed over. During the three week work period, the level of appreciation increased and the results and comparison to the literature represented a real contribution.

The biggest analytical stumbling block came in the analysis of the oil and grease using freon extraction. The standard procedure for conducting these tests is time-consuming and subject to error. The students spent two or three evenings at the end of the project completing these analyses, yet this was crucial to the study in Yorktown because of an oil carry-over problem from the API separator into the biological basins. As the refinery moves toward the installation of an activated sludge process, a more elaborate oil and suspended solid removal procedure will be necessary in order to insure good oxidation.

The level of technical throughness with which the students approach their individual problems was truly remarkable and the magnitude of the results are really quite impressive. It has provided the basis for a number of conclusions and recommendations which suggest a review of current and future plans for waste treatment.

CONCLUSION

THROUGH PROPER organization and planning a short-term three week consulting team project can be conducted with significant technical and public relations payoff with students contributing in a very responsible fashion. A combination of introductory visits and a presentation by the students resulted in a strong committment to their project area. Once motivated the students moved ahead quickly wih their project. In addition, a strong sense of comradarie developed from living in those two adjacent kitchenettes and working together in two man teams. □

PROCESS CONTROL:
Sprague, Quentin, Fry
Continued from page 27.

dition to strictly laboratory needs, proctoring areas, study carrels, open study areas, small seminar areas, media-areas; in short, all of the facilities needed to carry on individualized, self-paced, or small group course activities. In this way, the open laboratory serves almost all of the needs of the engineering program in a very efficient utilization of space, furnishings, and equipment. Only a few activities require other spaces. Since the same open laboratory is used by all disciplines in the University for all of the functions named above, there is considerable interaction among students and faculty from these different areas.

STATUS OF THE PROGRAM

THE FOREGOING discussion has laid out the design goals, curriculum objectives, and curriculum implementation features for the Control Engineering Program at UT-Permian Basin. Underway only two years, the program has not, of course, fully realized all of these ambitions. The intent of this section is to evaluate the status of the program and its future.

The ultimate evaluation of any professional program comes from the performance of its graduates in practice. Too young to have many graduates and with little time-in-service for those that have graduated, any evaluation must necessarily be very preliminary. Students in or from this program have been favorably received by industry and graduate schools. Industries participating in our Authentic Involvement program have responded favorably both to the engineering competence of our students and to their abilities to document and communicate their work. Thus the external indicators of acceptance of our students are positive.

The educational environment in our program is entirely different from what most students have previously experienced. Inevitably then, there has been a period of adaptation as students learn to function efficiently in this new environment and as the faculty adjust the environment based on student successes and reactions. Some students have been unable or unprepared to adapt and have dropped from the program, but most have learned to take advantage of the flexibility. A significant number of students, with poor initial preparation or with a long lapse in their studies, have been able to develop and to succeed in the program only because of the individual pacing, one-to-one instructor help, and the opportunity to recycle until reasonable competency is achieved. Such students, although they have excellent latent potential, would not survive in a conventional program.

Although considerable progress has been achieved toward meeting the needs and maximizing the chance for success of individual students, much remains to be done. Needed are more formal premeasure procedures, self-study packages for areas of significant prerequisite weakness, a broader range of course offerings and more variety within courses, revisions and additions to existing learning materials, a more formal and elaborate validation procedure, development of laboratory facilities, and an ever-improving course management system. These areas of development are in various stages of progress, but all are underway. Resource limitations are believed to be the primary impediments to their rapid and successful conclusion. □

APPENDIX

Curriculum objectives for the Control Engineering program are as follows.

A graduate of this program should be able to:

- **Operate successfully as a member of a project design team to construct a proposed design solution to an authentic problem and to prepare and present satisfactory oral and written reports documenting the design.**
- **Demonstrate project management skills necessary to insure the successful operation of the team in the team design activity described above.**
- **Demonstrate successful acquisition and application of information relative to a topic for which little information is available in typical literature sources.**
- **Construct and support a prediction of the possible impact on society of a major event, invention, discovery, technological change, change in government policy or law, etc.**

Sir:

Almost invariably I have found that the demonstration has been a very effective teaching tool that was well received by students. To help myself and others who share my inclination, I am attempting to edit a compilation of demonstrations. I wish to concentrate on the field of ChE as a broader coverage is probably not practical. Accordingly, I would like to ask any potential author who knows of such demonstrations to contact me. Then we can make arrangements so that a common format is used and appropriate authors credits are given.

Prof. M. Duane Horton
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ChE laboratory

SYCONS, A SYSTEMS CONTROL SIMULATOR

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PROCESS DYNAMICS and Control is normally taught to ChE students in their senior year. At the University of Lowell this is a two semester course consisting of 3 hours of lecture in the fall semester and 1 hour of lecture and 3 hours of laboratory in the spring semester. The fall semester course is intended to provide a sound theoretical background in control theory with emphasis on mathematical techniques, open and closed loop systems and stability analysis (root locus and Bode diagrams). The spring semester consists of weekly lectures on advanced topics and laboratory work consisting of digital and analog computer techniques and experimental techniques using hardware such as pneumatic and electronic controllers, valves, level control systems and flow control systems.

In addition the university has established a college-wide digital control laboratory for the purpose of developing real time systems and demonstration programs for both teaching and research projects.

Three ChE seniors, (Dennett, Greenlee, LeBlanc) developed SYCONS as an elective senior project in conjunction with this laboratory, working under the direction of the senior author, (Wengrow).

SYCONS, which stands for Systems Control Simulator, is an interactive program written in BASIC which allows the user to simulate a closed loop block diagram of up to 30 individual components, consisting of a 3-mode controller (any combination of modes), step loads or setpoint, first and second order systems, and dead times. The transfer functions for components are shown in Table 1. The set point can also be a sine wave and the system may be run open loop.

TABLE 1
Transfer Functions for SYCONS

Transfer Function	Name	Comments
$X = R - Y$	Comparator	1st element in loop
$K_c[1 + \frac{1}{\tau_I s} + \tau_D s]$	Controller	Can be used as P, I, D, PI, PD, PID, ID
$\frac{G}{\tau s + 1}$	1st order	Specify G and τ
$\frac{G}{\tau^2 s^2 + 2\xi\tau s + 1}$	2nd Order	Specify G, τ, and ξ
$e^{-\tau s}$	lag	Specify $\tau < 5$
$X = Y + U$	Summing junction	Must be between each non-summing junction element.

With these combinations available, most common type control problems arising in ChE can be solved. The output consists of the time domain response of the final element in the loop.

The program philosophy is to allow the user to specify the control loop and provide answers in the least restricted fashion possible.

The machine used is a NOVA 1200 with 16K memory and disk storage. Input is through keyboard with CRT display or punched paper type and output is CRT, line printer or punched paper type.

Computing Algorithms—Each individual element is considered as a block with input, X, and output, Y. Summing junctions have an additional input U which may be zero and serve both to allow step changes in load and to convert the output of one block to the input of the next block.

Comparator—This element allows for negative feedback and is analogous to the comparator in real systems.

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Controller—A simple trapezoidal rule is used for the integral portion and a difference approximation is used for the derivative mode.

$$Y = K_c\left[X_t + \frac{1}{\tau_I}\left(\sum_{1}^{t-1} X_i + \frac{X_t}{2}\right)\Delta t + \tau_D \frac{X_t - X_{t-1}}{\Delta t}\right] \quad (1)$$

First and Second Order Systems—The relatively unsophisticated Euler method is used for the solutions of the first and second order differential equations. A time step of 0.02 is used throughout.

$$Y_t = G\frac{X_t - Y_{t-1}}{\tau}\Delta t + Y_{t-1} \quad (2)$$

$$Y_t = \left[GX_t - \frac{2\xi\tau}{\Delta t}(Y_{t-1} - Y_{t-2}) - Y_{t-2}\right]\left(\frac{\Delta t}{\tau}\right)^2 + 2Y_{t-1} - Y_{t-2} \quad (3)$$

Time Lag—The time lag is achieved by storing inputs in an array and recalling at the proper time. Because of array size limitations for BASIC, only time lags of 5 and less can be used.

$$Y(t) = X(t-\tau) \quad (4)$$

Also only one delay element may be used per loop simulation.

USE OF SYCONS

THE USE OF SYCONS is relatively simple and can be used by students of control with minimum instruction. The closed loop process shown in Figure 1 was run on the computer by way of illustrations. In the language of SYCONS it consists of 8 elements:

1. **Comparator**
2. **Controller**
3. **Summing Junction**
4. **First Order**
5. **Summing Junction**
6. **First Order**
7. **Summing Junction**
8. **Time Lag**

At each point in the program where a user must enter information, SYCONS requests the proper information giving the user the proper codes to assist in the input. Interested readers may request a copy of the program from the author.

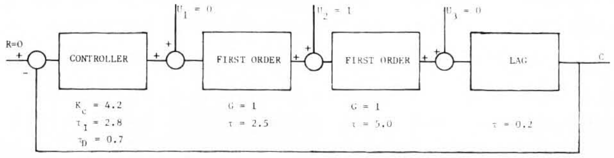

FIGURE 1. Block Diagram.

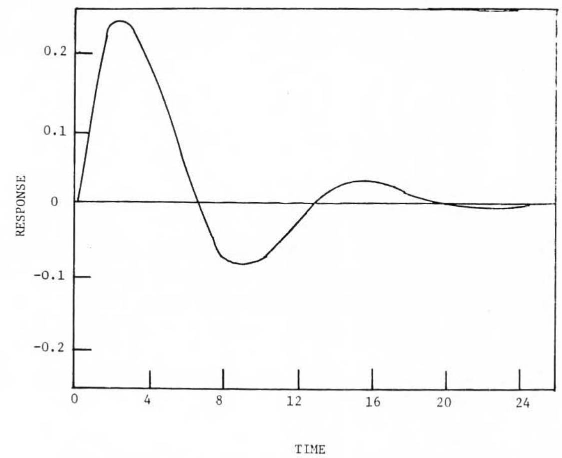

FIGURE 2. Response to step change in load.

Figure 2 is a plot of the time domain response of the last element.

Several additional techniques can be used with SYCONS. A sine wave can be used in the first load position (comparator set-point) and if the process is run open-loop the frequency response can be determined. The derivative mode of the controller can be used to generate an impulse function by putting a step change into the set point under open loop conditions and the integral mode will generate a ramp input under similar conditions. With an impulse input, data for Fourier analysis can be generated.

CONCLUSIONS

SYCONS APPEARS to work well and to be a versatile tool for both the learning of process control techniques and for the solution of complex transient responses.

It has been used by several students with some control background and was found to be simple to use and instructive in illustrating methods that were merely concepts.

A copy of the project report which includes the program listing, additional illustrated examples and the program logic diagram can be obtained from Digital Control Lab, College of Engineering, University of Lowell, Lowell, MA. 01854.

The authors acknowledge Prof. P. Burger and the students of the Digital Control Lab, University of Lowell, for their help and encouragement in this project. □

84th Annual Conference

Editor's Note: The four papers following were presented as part of a symposium at the Annual Conference of the ASEE at the University of Tennessee; Knoxville, Tennessee; June 1976.

Where Is the Roller Coaster Headed?

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THE DEMAND FOR engineers has been widely touted recently by such mass media publications as the Wall Street Journal and Time Magazine. This has generally been a result of reports emanating from the Engineering Manpower Commission. Professional journals have also vividly described the apparent disparity between engineering enrollments and projected demands for B.S. engineers. An example of this is the series "Supply, Demand and Utilization of Engineers" in *Chemical Engineering Progress* last year.

It appeared that engineering enrollments were on the decline up to the Fall of 1975. At that time, ChE Departments began to talk about a quantum surge in enrollments and fears of a boom and bust cycle were being mentioned at national AIChE meetings. It became evident that this was a nation-wide phenomenon. The National Career Guidance Committee of AIChE sought verification of this as well as other pertinent data to offer a true perspective of the increases. They conducted a survey of all ChE Departments in the United States and Canada which asked for estimates of projected B.S. degrees to 1979, past degree production data, present and future capacity data, trends in enrollments, attitudes toward coping with the increased enrollments and career guidance programs and needs. Were we really on an enrollment roller coaster and did we want to get off?

Will these and other survey results moderate the present enrollment rise and degree projections? Where is the roller coaster headed? Do we want to stop it? What action do you, the Professional Chemical Engineer, feel AIChE and ASEE should take?

TABLE 1

PERCENTAGE INCREASE IN FRESHMAN ENROLLMENTS

Percentage Increase	Number of U.S. Schools	Number of Canadian Schools
<0%	1	1
0- 9%	8	1
10- 19%	10	
20- 29%	10	
30- 39%	11	
40- 49%	10	2
50- 59%	10	1
60- 69%	12	
70- 79%	3	
80- 89%	2	
90- 99%	2	
100-109%	3	
110% +	2	
Median	40	40

One hundred nineteen of the one hundred thirty-six U.S. ChE Departments responded to the survey (see Appended copy) conducted in March and April of 1976. Thirteen of the seventeen Canadian departments also responded. Useful data was obtained from U.S. Departments representing almost 90% of the B.S. degrees granted. The Canadian schools reporting represented approximately 82% of the B.S. degree volume for that country. The survey results indicate that in 1978, 5328 Bachelor of Science degrees in ChE will be awarded by schools in the United States and another 523 by Canadian schools. This will be an increase of more than 50% over the average number of B.S. chemical engineers graduated between 1966 and 1975 for the U.S. The predictions also indicate the 1979 graduating classes will be 5656 and 698 for the United States and Canada, respectively. Only twice has the number of United States ChE Bachelors degrees exceeded 3800. In 1949 it was 4506 and in 1950, 4529.

The 119 United States ChE Departments are hoping to add between 98 and 117 new faculty positions in ChE to meet this enrollment surge. This increase in faculty will mean the United States will have the capacity for producing an estimated 6271 B.S. graduates per year. Present estimated United States capacity is 5785. The present estimated Canadian annual capacity is 649 B.S. degrees and a projected increase of four faculty positions will bring this to 680.

The survey first polled the chemical engineering departments on the increases in the freshman and sophomore enrollments. Tables 1 and 2 show the distribution of percentage increases. Generally, the largest increases were reported by small departments. The median reported freshman increase was 40% and the median reported sophomore increase was 30%. When the schools were asked if the number of highly qualified students which were likely to graduate in ChE had increased, 75% (62%)* said yes and 17% (31%)* said no. This is a good indication that the expanded student body can survive the rigors of a ChE program.

TABLE 2

PERCENTAGE INCREASE IN SOPHOMORE ENROLLMENTS

Percentage Increase	Number of U.S. Schools	Number of Canadian Schools
<0%	3	1
0- 9%	9	2
10- 19%	21	
20- 29%	18	3
30- 39%	11	
40- 49%	9	
50- 59%	12	3
60- 69%	7	1
70- 79%	3	1
80- 89%		
90- 99%		
100-109%	11	1
110% +	7	
Median	30	37.5

TABLE 3

ATTRITION RATE IN CHEMICAL ENGINEERING

Attrition Rate %	Number of U.S. Schools	Number of Canadian Schools
0- 4	3	
5- 9	1	
10-14	4	1
15-19	7	2
20-24	10	1
25-29	12	1
30-34	21	3
35-39	4	
40-44	10	
45-49	3	
50-54	14	1
55-59		
60-64	4	
80	1	
Median	30	23

The departments were then asked to supply their freshman-senior attrition experience. Table 3 illustrates the distribution and again the smaller departments usually experienced the larger rates. The median attrition rate is 30%. Thirty-four percent (0%) of the departments expect the attrition rate to increase, 11% (17%) to decrease and 49% (83%) to remain the same. Here again is an indication that the increased enrollments can be expected to appear as future graduates.

Not only are those selecting ChE initially increasing but those transfering into our field are also increasing. Eighty-eight percent (54%) of the responding schools found an increasing shift of degree major toward ChE at the B.S. level. Sixty-one percent (23%) found an increased shift at the M.S. level.

ESTIMATED GROWTH

EACH RESPONDENT was asked to estimate the number of expected B.S. degrees over the next four years. Table 4 summarizes the estimates that were supplied by U.S. schools. The number

*The numbers not in parenthesis are for the U.S. schools; those in parenthesis are for the Canadian schools.

TABLE 4

UNITED STATES ENROLLMENT PROJECTIONS

Year	Sum of Estimates	Number of Schools	Reported* 10 year average sum	Estimated Yearly Total
1976	3237	119	3190.7	3607
1977	3880	119	3190.7	4320
1978	4718	117	3145.7	5328
1979	4699	107	2951.3	5656
Present Capacity	4936	117	3030.7	5785
Future Capacity	5351	117	3030.7	6272

*Including an estimate by authors for 3 schools.

of schools that provided useful estimates are indicated. Also listed are the estimates of total degrees to be awarded. These are based upon the sum of 10-year averages provided by the schools that estimated future enrollments (for three of these schools, the authors had to estimate their 10-year average). This sum was added to the calculated average for the 17 non-answering schools plus the four who have ceased offering a degree in ChE. This total divided by the sum for the schools estimating future enrollments was multiplied by their estimates to obtain the projected yearly totals for the next four years. For the schools which did not provide 10-year estimates these were obtained from the number of graduates listed in "Chemical Engineering Faculties". Where values were missing these were estimated by the authors. The average number of U.S. Bachelors degrees was calculated to be 3552. The Engineering Manpower Commission estimates the average between 1966 and 1975 to be 3371 B.S. graduates. This is the

TABLE 5

CANADIAN ENROLLMENT PROJECTIONS

Year	Sum of Estimates	Number of Schools	Reported Ten Year Average Sum	Estimated Yearly Total
1976	255	13	320.3	312
1977	351	13	320.3	430
1978	427	13	320.3	523
1979	374	9	210.3	698
Present Capacity	530	13	320.3	650
Future Capacity	555	13	320.3	680

equivalent to an error of 5.37% or an over-estimation of 1.56 graduates per year for each of schools responding. The equivalent figures for Canadian schools are given in Table 5. The projected totals were estimated in a similar way. Table 6 gives the projected number of Bachelor level engineering degrees as estimated by the Engineering Manpower Commission in its publication "Prospects of Engineering and Technology Graduates 1975". To obtain the ChE bachelors degrees this was multiplied by 8-1/2%. This is the figure John Alden (*CEP*, Oct. 1975, pg. 25) estimated as the past and future percentage of total engineering bachelor degrees. The difference in these figures is astonishing. Since the vast majority of these prospective graduates are currently enrolled in ChE and each school estimated its own prospective number of graduates, the authors feel the figures estimated by this survey are reasonably accurate. In fact these figures may be a little low

TABLE 6

COMPARISON OF UNITED STATES ENROLLMENT PROJECTIONS

Year	Total U.S.* Bachelors Degrees	ChE** Bachelors Degrees	Estimate from Table 4
1976	40,600	3,450	3,607
1977	44,200	3,757	4,320
1978	50,700	4,310	5,328
1979	51,900	4,416	5,656

*Source: "Engineering Manpower Commission"
**8-1/2% of Total Bachelors Degrees

because the number of Master of Science degrees which will be granted to non-B.S. ChE degree holders must also be considered as part of the annual output of ChE's. The schools answering this question indicated 129 (22) of these will be granted in 1976 and 206 (39) in 1977. Currently at least 60 United States (8) schools offer organized programs in this sort and 13 (0) are planning to add such programs in the next few years.

Is this increase in students merely a perturbation about the mean or does it portend a substantial long term growth in B.S. ChE's? Most U.S. schools seem to feel that it may be permanent since 62 (3) of them are planning or hoping to add over 98 (4) new faculty positions. When asked whether there were any constraints upon the departments which would prevent them from increasing their faculty size, only 25% (15%)

TABLE 7

CONSTRAINTS WHICH MAY PREVENT THE ChE DEPARTMENTS FROM INCREASING THEIR NUMBER OF FACULTY MEMBERS

	U.S. Schools Number of Replies	Canadian Number of Replies
Money	60	11
Administration Policy	18	
Space (Laboratory or Classroom)	17	
Enrollment	10	2
Faculty	2	
Job Opportunities	2	
Resources	1	
Graduate Students	1	
Research	1	

said no. Those that answered yes listed the constraints given in Table 7. The overwhelming majority cited budgetary restraints of one form or another. It appears from the comments received that quite a few university administrations are putting a lid on the total number of faculty and any increase in engineering faculty would have to come at the expense of other departments.

The Survey indicates that 36 (3) schools feel they will exceed their estimated capacity by 1979. The authors anticipated this and asked the question, "If the number of freshman or sophomore ChE majors exceeded the largest number of ChE's which you felt you could reasonably graduate would you (a) increase the size of the faculty, (b) set a maximum number of students admitted to junior courses, (c) hire graduate students to teach undergraduate courses, (d) increase standards so more students flunk out of the program, (e) do nothing, (f) other. The responses varied and are given in Table 8 and 9. The favorite U.S. method of coping was to increase faculty. Increasing standards and regulating junior class size met with split decisions while using graduate students to teach met with disfavor. The most frequently noted alternative was controlling admissions at the outset. It is noteworthy that this appears to be the method favored in Canada since 6 of 13 schools indicated this as a course of action, and some stated they were presently employing it. The use of adjunct faculty was the second most mentioned alternative as a short-term means of helping a department through the present surge.

TABLE 8

UNITED STATES DEPARTMENTAL RESPONSES TO "If the number of freshman or sophomore chemical engineering majors exceeded the largest number of chemical engineers which you felt you could reasonably graduate, what course of action would you take?"

	Yes	No	Unknown
Increase the size of the faculty	56	22	14
Set a maximum number of students admitted to junior course	35	37	10
Hire graduate students to teach undergraduate courses	22	49	6
Increase standards so more students flunk out of the program	38	31	9
Nothing	5	31	5

This survey has quantified the present enrollment surge and projected an unusual situation in ChE education. Undoubtedly, many factors are responsible for the present situation and many others will affect the outcome over the next few years. Many questions come to mind as a consequence of this survey. Are the ChE departments on an enrollment roller coaster? Are the future plans of these departments for faculty additions realistic? Is this surge in enrollments due to publicity in the mass media, lack of jobs in other scientific fields, and/or lack of jobs for high school and college graduates due to the recession? Should ChE departments regulate their admissions or just bend with the breeze? Will there be enough job openings offering meaningful employment for the anticipated surge of engineers? Will these and other survey results moderate the present enrollment rise and degree projections? Where is the roller coaster headed? Do we want to stop it? What action do you, the Professional Chemical Engineer, feel AIChE and ASEE should take? □

TABLE 9

CANADIAN DEPARTMENTAL RESPONSES TO "If the number of freshman or sophomore chemical engineering majors exceeded the largest number of chemical engineers which you felt you could reasonably graduate, what course of cation would you take?"

	Yes	No	Unknown
Increase the size of the faculty	2	4	1
Set a maximum number of students admitted to junior course	3	2	1
Hire graduate students to teach undergrduate courses	0	5	0
Increase standards so more students flunk out of the program	0	5	0
Nothing	0	0	0

Practical Limits To Growth In ChE

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THE FOCUS IN THE PAST two years on national needs, with particular stimulus from our energy crisis, has excited new thinking about control of chemical change. A result is that ChE is a well-paid profession at entry. High school students in the United States have noticed the difference. Possibly for that reason there has been a boom in enrollment in ChE schools in the 50 states. Some schools report twice as many students enrolled in 1976 in the first class of ChE as in 1975. Perhaps the trend will continue, and perhaps it will not. In any event we do seem to be faced with acute personnel problems. They are problems that are nicer to have than those that relate to shrinkage of enrollments.

One of the items that engineering and science programs have not handled appropriately over the past few years is the matter of quality.

What really will control the growth of ChE enrollments? Should they be controlled? First, universities already have built-in controls by way of budgets that are tighter than ever before in the history of education. Even if a school wanted to double its total program, it probably would have trouble. It might allow an entering class to be twice the size of a previous entering class, but to have the total undergraduate enrollment twice that experienced over a couple of years ago would probably not be possible in terms of staff and supporting functions required. Therefore, the college budget is the first step in the control of ChE enrollment.

What is the second step? Students may be enamored with the idea of opportunities to help and to gain economic strength by way of the engineering profession, and particularly by way of chemical engineering. They may lose sight, however, of the difficulties in various curricula. Certainly ChE is a quantitative curriculum, and students have been known to fail in the program. Particularly students have had trouble with university chemistry. General chemistry, organic chemistry, inorganic chemistry, and physical chemistry are much more demanding and quantitative than ever before. To be a ChE requires that you move through the courses in chemistry. It probably is so that a fair fraction of a diverse group of students in the ChE curriculum will find difficulties with chemistry. So item two in control of ChE enrollments relates to the specter of chemistry. Also chemistry could be made even more stringent as a control point.

Third, one of the items that engineering and science programs have not handled appropriately over the past few years is the matter of quality. Since the end of World War II, we, in general, have been focusing upon quantity not at the total loss of quality but not with the same development of quality that we would have with emphasis on that attribute. So, as universities have large entering classes in ChE, it is incumbent upon the universities to have appropriate standards of performance so that in the subsequent years those students who really are not committed to the development of useful careers in ChE can be dropped. That has been a practice in some large schools for some time anyway. For example, admission standards could be minimal for the freshman year. Then a large number could be weeded out in the first year after knowledge is collected on their abilities. Perhaps more of that control will be invoked in the future in ChE.

FUTURE OPPORTUNITIES

A FOURTH CONTROL on growth of ChE enrollment could be found in careful examination of predicted employment opportunities. No one has yet figured out how to predict employment opportunities. If we ponder the costs for a new engineer in industry and the increasing ability of an engineer to work with effectiveness because of new tools and new computers, maybe the market will need fewer engineers per capita of population.

As part of the future employment opportunities for engineers, note should be made of the roles of engineering technologists and technicians. Employment interest in them has not been fully developed. As it becomes fully developed, there probably will be an increasing effort to have engineers work in the fullest professional sense as engineers. Engineering technologists would be ready to handle operational functions. If engineering technology does affect our work as suggested, there indeed will be fewer engineers hired but probably at much higher salaries and with much higher professional input to their jobs. That calls for better and even more demanding programs. That more intense professional development in itself could provide a strong governor on enrollment.

A fourth control on the growth of ChE enrollment could be found in careful examination of predicted employment opportunities.

No one truly can predict what lies ahead relative to what we have done in the past. Engineering obviously will have to help in meeting all national priorities and in keeping the country moving. Whether it will do its work more efficiently than in the past is our problem, and really that is the total crux of what engineering will be like ten years from now and what enrollment levels will be. □

Too Many Departments!

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THE CONTINUED HEALTH of our profession demands that the production of baccalaureate graduates in ChE be limited. A natural such limitation results from the acceptance of a simple premise, but it is nonetheless one that educators in ChE somehow still find to be debatable. The premise is simply that education in ChE at whatever academic level must be developed and presented by professors who are themselves active participants in the growing edge of the profession. And this is true for professors in all of the professions. For example, I cannot imagine the apprentice surgeon learning his skill from a master who himself does not practice surgery. Certainly also the young surgeon who aspires to be the creator of new techniques—to invent the heart transplant, as it were—will want to work with the best-known experts of the day. So it is also in ChE.

It is not enough merely to admonish our students to go out and be honest and apply common sense to this or that ethical situation. We must provide intellectually demanding exercises and exposure to the great ideas and thinkers of Western Civilization.

This participation by faculty at the growing edge of the profession is heavily dependent upon graduate students, for the neophytes are an extension of the personality of the major professor. In fact, to a marked degree, the reputation of professors is heavily dependent upon the quality of the graduate students that we have attracted over the years. It appears that our economy can absorb about 400 new PhD level ChE's per year. At a nominal rate of one new PhD per year per faculty member, this implies a total faculty in the universities of the country of about 400. Or, correspondingly, the need of our society for about 1000 MS graduates per year implies a faculty of about 500 if we take a production rate of about two new MS graduates per faculty member per year. Using this larger number, and with a critical density of about 15 faculty per department, this suggests that we need about 35 departments. A faculty of 15 could readily produce a baccalaureate group of 70 per year or a national production of about 2500 BS graduates per year. The numbers in this sort of nominal scenario are approximately the degree production that seems to fit our national requirements for new ChE's. However, the institutional structures for educating these new practitioners of our science and our art have expanded beyond all reason. We compare the above projections with the curent listing of 123 accredited departments in the United States with almost 1500 faculty members—and growing. The academic profession then is functioning as an excellent absorber of ChE talent that could be more productively utilized elsewhere. Innumerable variations on this theme are, of course, possible—the above exercise is merely typical—but the essential message of the analysis is that we have too many ChE departments. The excess capacity seems to be about a factor of two or three.

FEWER DEPARTMENTS

MOST IMPORTANTLY, fewer departments would produce a much more professional orientation than we now seem to impart to our students. And this new status would characterize our graduates at all three academic levels. One might well counter that it is not professional status that you achieve at all, but rather a snobbishness borne of exclusivity. This exclusivity does personify the elitism of our profession; but it also changes the point from which the new entrant into the profession views himself and his potential for contribution to our society. The change I propose does not atttempt to change a person's perspective on professional issues, rather it changes the point from which the perspective originates. It is not ideas that determine our professional status, rather it is our socio-economic status that determines our professional ideas and our self-perceptions. My discussions with many ChE's from all over the country produce a disappointment and a sadness by the self-perception of so many ChE's who see themselves as highly skilled technical employees of some great corporation. Yet the ChE is not merely a skilled employee of duPont—rather he *is* the duPont Company. And without his presence, the company could not exist. Attitudes and self-perceptions are enormously important. We will continue to have large numbers of our ranks who have technician-like perceptions of themselves and their work as long as the universities continue to inculcate such values. The greatest unmet task of our ChE departments is that of elevating the views and raising the expectations of our students. Although thermodynamics is an essential tool, it cannot be applied with professional character except from a background of values. It is not enough to merely admonish our students to go out and be honest and apply common sense to this or that ethical situation. We must provide intellectually demanding exercises and exposure to the great ideas and thinkers of Western Civilization especially in those areas that emphasize human values and ethics, and this attitudinal development is also enhanced by the vision of chemical engineering as a very special profession.

. . . fewer departments would produce . . . a much more professional orientation than we now seem to impart to our students . . . would insure the stimulation of high quality colleagues in other related disciplines, and facilities that are not thwarted by the critical mass phenomena.

Fewer departments would insure the stimulation of high quality colleagues in other related disciplines. Departments of chemical engineering are parasitic in a sense, for we feed off of the departments of chemistry, other departments of the college of engineering, and increasingly the departments of biochemistry and microbiology as well and even several departments of the college of medicine. Excellence in essential supporting departments is also relatively rare, and yet a ChE department cannot really thrive unless, for example, the chemistry department is also excellent. This co-existence of strengths exists on relatively few campuses, and yet this co-existence and this synergism is essential to insure the continued expanding ChE domain.

Fewer departments would insure faculties that are not thwarted by the critical mass phenomena. Just as ChE personifies synergism with other disciplines, so also is this the case within its own areas of specialization. A faculty of about ten seems to be on the lower bound of criticality, for a survey of the work of departments reveals that smaller ones are either just weak, or, if strong, that strength will be in a very few special areas of ChE. It is essential that students be exposed to ChE's who might be characterized as applied physical chemists and it is equally important that they see ChE's who exemplify the more engineering orientation. The strength of our profession is this dual character of the ChE as both scientist and engineer—and our faculties must be of sufficient breadth to provide models of both extremes, and at several points in between. Those students who are graduating, at whatever the academic degree level, from departments that do not have this character are not receiving the vision of the profession nor the attitudinal structure that they need for optimum professional practice.

ECONOMIC ADVANTAGES

THE FINANCIAL position of ChE's is clearly enhanced by this control on numbers that we seek. ChE services are required, persons with such skills are few, and therefore the price for such services will be high. Professional licensing by the states could protect the public against imitators. A graduate in biology can read a few books on the physiology and diseases of dogs, but state licensing protects the public against this individual unilaterally declaring himself a veterinarian and opening a pet clinic. So it could be in ChE.

As is the case with most organizational structures, attitudes, philosophies, and ambitions, the major obstacle to this (or any other) more professional orientation is our desire to make the change. Many self-proclaimed leading departments will not be interested, for they mistakenly feel that they have nothing to gain. The sleepy departments will not be interested for concerns of self-preservation, for they would see themselves going out of business. Yet we are all the healthier—just as the NFL is healthier—if we maintain only as many teams as can be supported in first-class style and be maintained at more or less comparable strengths.

How might it be done, for departments are not likely to vote themselves out of business. Certainly the advantages to the individual faculty member of consolidating two or three departments could be made compelling. The combined department would be more attractive in terms of quality of faculty, quality of facilities, and numbers and quality of students. The economics of consolidation would be attractive to state legislatures and boards of trustees, and certainly the long-term economies of scale could be used to extract short-term incentives to promote and to initially capitalize this new epiphany of ChE education. Certainly those deans who lose their ChE department would breathe a sigh of relief, for the ChE's are widely recognized as the nemesis of all deans of engineering.

Perhaps the dismal science of economics may yet push us to this more professional status but curiously from the motivation of the happenstance corollary of cost effectiveness. That would be a very positive result, but it certainly would not reflect the wisdom of the ChE community. We seem to know so much about the economies of scale; it is curious that we continue to ignore those ideas in our own business. □

Can We Limit Enrollment By Professional Society Action?

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IT IS QUITE clear that the demand for engineering graduates is difficult if not impossible to predict. User surveys have not proven successful and it seems doubtful that we will ever be able to make forecasts adequate enough for individuals, universities, industrial and government sectors to do reliable planning. Some engineers think that the answer is to limit enrollment at some number below the most pessimistic forecast and thus assure that those accepted into the profession have an opportunity to practice it. There are two ways to limit enrollment:

- **limit number of accredited colleges**
- **limit number of studnts in accredited colleges.**

The Engineers Council on Professional Development already limits the number of colleges and any discussion of this issue must consider tighter criteria for accreditation. The question of limiting the number of students has not received as much attention and this problem is considered here.

ENROLLMENT LIMITING PROCESS

FIGURE 1 ILLUSTRATES the enrollment limiting process and shows what information is needed to consider the question. The capacity by discipline of each engineering college needs to be known and the number of graduates capable of being produced in each discipline in any one year must be known. This later information depends not only upon number of students which can be graduated, but also upon raw material supply of high school or transfer students. Demand forecasts for at least four years in the future must be available for each discipline. A comparison can then be made between supply and demand and action initiated (Figure 2).

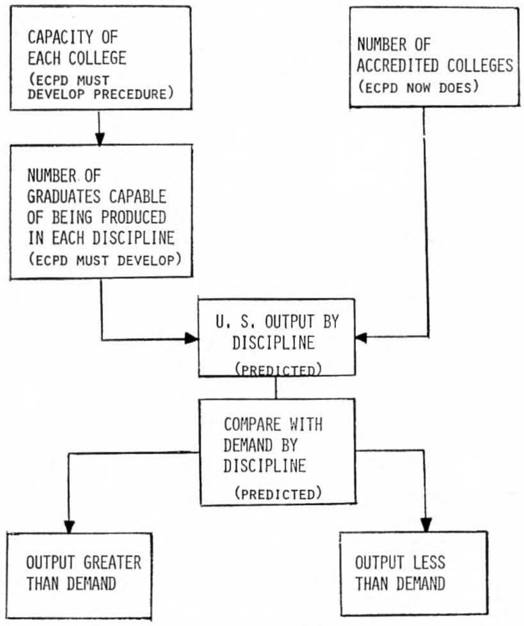

FIGURE 1.

When predicted output is greater than predicted demand and nothing is done, a cycle of over and under supply is created with very negative effects to the universities and to those employing engineers. To limit enrollment, departments or colleges must be eliminated or the number of graduating students in existing departments must be controlled.

Either course of action is difficult to carry out. There is a severe problem of time scale and it is essential to have adequate prediction at least four years in advance. This is simply not available at the present time with enough accuracy so that decisions of the sort needed can be made and enforced.

Furthermore, even if the predictions could be made with some degree of credibility, we must be able to predict the capacity of a college of engineering. This is a term used rather loosely. It is

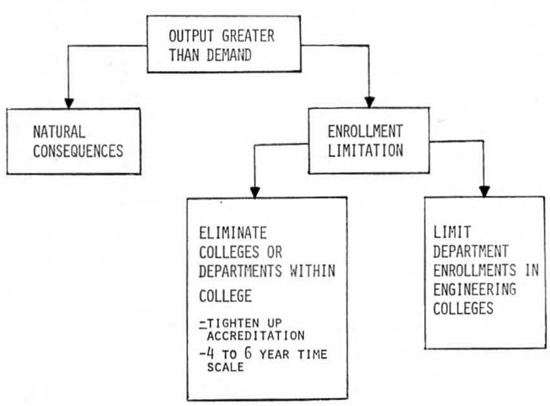

FIGURE 2.

defined in different ways by different people using the word—the admissions office thinks of capacity in terms of Freshmen who can be admitted, the provost thinks of capacity in terms of the total number of students who are in the college, the dean thinks of capacity in terms of number of students in each year in each department, the professional society thinks in terms of number of graduates.

A method of predicting department capacity for a given distribution of students by year has been proposed by Russell and Daugherty [1]. The main elements of their method are shown in Figure 3 and Table 1. It is a procedure which should

Some engineers think that the answer is to limit enrollment at some number below the most pessimistic forecast and thus assure that those accepted into the profession have an opportunity to practice it.

assure educational quality. It first evaluates the faculty's efforts in research, curriculum development, professional society service and academic service to realistically determine the time which can be devoted to undergraduate teaching. (Faculty course capacity factor). Departments which are nationally ranked have values between 0.4 and 0.5. Departments which have values close to 1.0 are not devoting enough effort to other activities to keep their teaching up to date and effective. Using the faculty course capacity figure, the maximum number of student spaces can be computed if the negotiated work load, number of full time faculty, and number of students per course are known. The maximum number of student spaces is then modified for the inadequacies listed in Table 1. Capacity is determined in terms of distribution of students by year.

This capacity determination procedure has not been tested and modified by experience, a process which should take a minimum of two years. It is essential that this be done however, if the engineering profession is to consider the question of enrollment limitation.

If we suppose that adequate procedures are available to predict demand and predict capacity, the question of *how* to limit arises.

- **To limit number of departments, the ECPD must tighten accreditation standards in such a way that some number of schools will lose their accreditation. It is far from a**

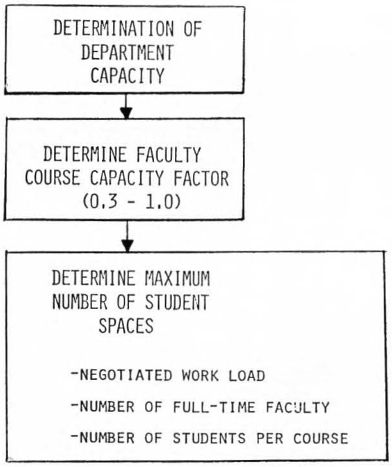

FIGURE 3.

trivial matter to decide how this should be done and almost impossible to control numbers within the time scales involved (6 and 4 year accreditations). Furthermore, what happens to those students enrolled in an institution which loses its accreditation? Many will continue and graduate.

- **To limit enrollments within departments, the ECPD must first determine capacity of each and every college it accredits. This is a task requiring a minimum of 6 to 8 years. Once capacity is known a means of prorating must be developed and each college informed of its "allowed" capacity. A means of so doing is not now available and even if this could be developed, the college or the university may not wish or may not be able to limit student numbers.**

It must be concluded that limitation of enrollment can not easily be carried out at the present time in any effective way.

WHAT SHOULD BE DONE

A means of determining capacity should be tested, modified and then formally accepted by the ECPD. This could be done by having ECPD inspection teams try out proposed procedures.

The capacity determination procedure should be made part of the ECPD inspection.

The U. S. capacity for producing engineers should be determined using the ECPD figures. This would then allow the engineering profession to better understand one part of the fundamental problem underlying over and under supply. □

TABLE 1

MODIFY MAXIMUM NUMBER OF STUDENT SPACES FOR DEFICIENCY IN

(1) Inadequate Laboratory Space
(2) Inadequate Numbers of Non-Academic Personnel
(3) Inadequate Numbers of Graduate Teaching Assistants
(4) Inadequate Capital Equipment Expenditures
(5) Inadequate Appropriations for Expenditure

Determine Capacity in Terms of Number of Students Per Year

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William D. Baasel is a professor of ChE at Ohio University. He received his bachelors and masters degrees from Northwestern University and his doctorate from Cornell University. He is the author of a book—"Preliminary Chemical Engineering Plant Design" and is secretary-treasurer of the ChE Division of ASEE. He has taught at Clemson College and held a Ford Foundation Residency in Engineering Practice at the Dow Chemical Company. He is a registered professional engineer in Ohio.

Michael D. Cise is a research scientist assigned to the Product Development Division of Eli Lilly and Company, Indianapolis. He received his B.ChE degree from the University of Dayton, Dayton, Ohio, and his M.S.ChE and Ph.D. from the University of Arizona, Tucson, Arizona. He is a member of A.I.ChE and local section Career Guidance Chairman as well as a member of the National Career Guidance Committee of A.I.ChE.

Henry A. McGee, Jr. is a scientist/engineer by education and by experience. He is professor and head of the ChE department at VPI & SU. His current research interest is the application of very unusual high energy chemistry to the development of highpowered chemically pumped lasers. He is active in AIChE and this essay is abstracted from a popular invited talk he has given around the country as an AIChE Tour Lecturer. His comments on teaching and research are as a participant rather than as an observer.

William H. Corcoran is Vice President, Institute Relations and professor of ChE at California Institute of Technology. He received his B.S., M.S. and Ph.D. from CalTech and later became director of Technical Development at Cutter Laboratories before returning to CalTech as professor. He received the Western Electric Fund Award of ASEE for 1960-70; the Civ Award of the Southern California Section of AIChE in 1970 and the Founders Award of AIChE in 1974. He was the Sixth Annual Phillips Petroleum Lecturer in ChE in 1971, and is the past chairman of the EE & A Committee of ECPD, the Publications Board of **CEE** and the E & A Committee of AIChE. He is currently the vice president of AIChE.

T. W. F. Russell is a Professor of ChE and Associate Dean of the College of Engineering at the University of Delaware. He obtained his bachelors and masters degree from the University of Alberta and after working as a design engineer with Union Carbide, Canada for three years, he obtained his Ph.D. from the University of Delaware. Professor Russell is a coauthor of "Introduction to Chemical Engineering Analysis" (J. Wiley 1972) and Structure of the Chemical Process Industries—Function and Economics" (McGraw Hill, in press).

Richard L. Daugherty is Assistant Dean of Engineering and Assistant Professor of Mechanical and Aerospace Engineering at the University of Delaware. He holds degrees in civil and mechanical engineering as well as a Ph.D. in applied science. Dean Daugherty handles budgetary and fiscal matters for the College and maintains a teaching and research load in structural mechanics and its application to filamentary composite materials.

ORGANIZATION OF A FUNCTIONAL ChE LIBRARY

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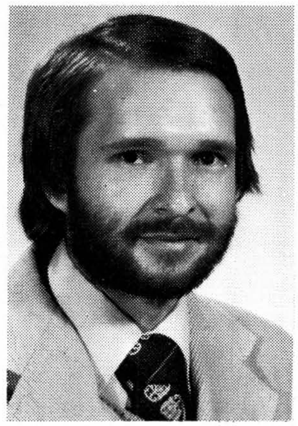
THE ChE DEPARTMENT of Clemson University maintains a library for the use of faculty, students, and visitors. Contained in an 800 square foot room, the library has, in addition to cases and shelves for book storage, a current periodicals display rack, tables and chairs, typewriters, calculators, and other supplies for the users of the library. In recent years the library's holdings have increased significantly. This, along with the fact that users don't always return volumes to their proper places, had begun to make it difficult to locate materials quickly.

A reorganization of the library was undertaken during a summer break of 1975 to alleviate this problem. This included discarding out-of-date material and reclassifying the library contents by a streamlined "subject area" system. The standard Dewey Decimal and Library of Congress Systems were considered, but it was decided that engineers don't think in terms of these systems. Instead, engineers tend to classify things in certain distinct subject areas that are not well defined by either of the standard systems. It was with this in mind that the following classification system has been instituted.



Eric H. Snider received his B.S. degree in Chemistry (1973), and the M.S. degree in Chemical Engineering (1975) at Clemson University, and is currently pursuing the Ph.D. curriculum in Chemical Engineering at Clemson University. He is a Professional Chemist, A.I.C. Accredited. His research interests are in air and water pollution analysis, systems development, and control.

THE CLASSIFICATION SYSTEM

THE FOLLOWING classification system has been found useful for cataloging the holdings of the department library at Clemson.

- **Chemical Abstracts.** Prior to 1962, the complete Chemical Abstracts series was received by the ChE department. Since 1963, only the Applied Chemistry Sections have been received. This results in a considerable saving of shelf space. The complete Chemical Abstracts are available at two other campus library facilities, the main university library and the Chemistry department library.
- **Bound Journals.** These include Industrial Engineering Chemistry, AIChE Journal, AIChE Transactions, Chemical Engineering Progress, and other pertinent journals.
- **Current Periodicals.** This category includes at least twenty-five current magazines and journals. Attractive display shelves were constructed to allow prominent display of the current issues of each publication. These fold back to reveal storage shelves for previous copies of each periodical. This provides a convenient and safe method of storing each year's copies until year-end binding time.
- **Miscellaneous Abstracts, Conference Proceedings, and Government Reports.** This serves as a catch-all category containing such things as issues of Air Pollution Abstracts (one of the faculty has major research interests in this area), and final reports of a number of Environmental Protection Agency sponsored projects.
- **Dissertations and Theses.** This section contains copies of the dissertations and theses done by graduate students of the department.
- **Engineering and Reference Texts.** This category is by far the most extensive in terms of total

number of books and number of subcategories. This category contains many of the standard references and texts which find most frequent use in the engineering disciplines.

CATEGORIES OF ENGINEERING AND REFERENCE TEXTS

DIVISION OF THE standard reference and classroom texts into specific categories was by far the most difficult part of the reorganization. Of necessity, the categories were chosen somewhat arbitrarily, depending on the number of books we had which might conceivably fall within a certain class. The system decided upon is detailed below.

- **Reference Books—This category includes many of the standard references most used by engineers and students, such as the Encyclopedia of Chemical Technology, Perry's Chemical Engineer's Handbook, C.R.C. Handbooks of Chemistry and Physics, Laboratory Safety, Organic Compound Identification, Tables for Probability and Statistics, and numerous others. No attempt was made to further subdivide this category into engineering references, mathematics references, etc.; however, if a library's holdings are extensive enough such subdivision could be made with little problem.**
- **General ChE Texts—This category contains the sophomore and junior level texts which serve as introductions to ChE. This group of texts is particularly valuable to undergraduate students who use its holdings for review purposes and as a source of supplemental information.**
- **Unit Operations—This grouping of texts contains general texts on the unit operations as well as specilized texts covering individual processes. Subheadings of the various unit operations could be used if warranted by a large number of texts.**
- **Thermodynamics**
- **Kinetics**
- **Plant Design and Economics—This category contains texts on general chemical process plant design, special equipment design manuals, and texts on economics in engineering.**
- **Process Dynamics and Control**
- **Mathematics and Computers in Engineering—If a large number of books are to be catalogued under this heading, subdivisions such as calculus, computer theory, programming languages, etc. may be found useful.**
- **Miscellaneous Engineering—Under this category are filed texts in the other engineering disciplines, environmental sciences, and physics.**
- **Chemistry—Subdivision into analytical, organic, physical, etc. may be made if the number of books warrants it.**
- **Miscellaneous Texts—This is another catch-all category containing such things as histories of major chemical firms, biographies of scientists, and other miscellaneous books.**
- **Engineering Writing and Communications—This category contains several useful texts on improving communciation of engineering information. A good dictionary is an indispensible part of this division. (Dictionaries are also conspicuously present in the Reference Books section.)**

After this classification system was devised, the physical arrangement of the categories on the shelves was agreed upon. At this stage, the outside spine of each book was labelled with an abbreviation of its category, and on the inside front cover was written the category and the shelf number to which the book is assigned. This facilitates easy and accurate refiling of material by all library users.

ACQUIRING LIBRARY MATERIAL

MANY FACULTY MEMBERS choose to donate their desk copies of current texts to the library. Many texts which are not in current use find their way from faculty offices onto the library shelves. Also, many faculty members receive periodicals, conference proceedings, and government reports in the areas of their research interests, and these are often donated to the library.

The standard Dewey Decimal and Library of Congress Systems were considered, but it was decided that engineers don't think in terms of these systems.

A major (but often little used) potential source of library material is the main library of the institution. For example, Clemson's main university library receives the A.S.T.M. Standards each year. The current three years editions are on the shelves, and previous editions are kept in storage. It was discovered by calling the main library that a fairly recent edition of this work along with many others, could be removed from storage and be placed on extended loan to individual department libraries. Although the current edition of these publications would be kept in the main library, there could still be great value in having a three- to five-year old edition available in the department.

LOANING POLICIES

WITH THE COMPLETION of the reorganization, the need existed to revise and enforce a loan procedure for the library materials. The following policies have been adopted:

Continued on page 48.

AUDIO-VISUAL AIDS SUBCOMMITTEE ACTIVITIES

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SEVERAL YEARS AGO I came to the realization that visual material on chemical process equipment is not as readily available to present chemical engineering students as it used to be. I came to this realization from a question asked by a student after we had been studying heat transfer. The student asked, "What does a heat exchanger look like?" The only picture of an exchanger in the textbook was a schematic drawing of the flow pattern through an exchanger, and this drawing was located several chapters ahead in the book from where the class was studying. I recalled one textbook from which I studied as a student, "Unit Operations" by G. G. Brown et al., had a number of good pictures of heat exchangers and other process equipment. As a result, I was able to obtain a visual understanding of chemical process equipment that I was studying. Present ChE students usually do not have such visual aids available to them.

After discussing this problem with my department head, he found an old copy (1957) of a strip film on heat exchangers. This film along with a script was made by the C. F. Braun Company for the Education Projects Committee of AIChE. In this film the fabrication of heat exchanger along with a description of some of its uses were presented. After showing this film to my class, I observed the students to be more motivated to study heat transfer. Most of the ChE students that I have taught seem to be able to relate to physical objects better than abstract concepts.

In this film the fabrication of a heat exchanger was presented. After showing this film to my class, I observed the students to be more motivated to study heat transfer.

William Beckwith obtained his B.S., M.S. and Ph.D. in Chemical Engineering from Iowa State University. He has been at Clemson University since receiving his terminal degree in 1963. He is presently chairman of the Audio-Visual Aids Subcommittee of the Educational Projects Committee of AIChE. His research interests are in educational technology and fluid mechanics.

With this experience I started searching for other films on chemical process equipment. I located a second strip film on fractionating columns that was also produced by the C. F. Braun Company. Unable to locate other films, I decided to make a sound-slide-show of one of my lectures on the uses of various kinds of pipe fittings. I discovered that it took me about ten hours to produce a ten minute show. Because of the time required to produce a ten minute show, I decided to learn who else has produced sound-slide-shows on chemical process equipment. Then if I could make a trade of shows, I could have two shows for the effort of producing one. I inquired into the present activities of the Education Projects Committee of AIChE and I was invited to join the committee to reactivate the old films subcommittee which was then renamed the Audio-Visual Aids Committee.

The first project of the A-V Committee was to survey the other ChE departments about their use and development of A-V materials. Questionaires were mailed to about 140 ChE departments, and sixty nine replies were received. Two questions were asked. One, list the names of the faculty members who are actively developing or using A-V material, such as 16 mm films, TV tapes or sound-slide-shows. Two, describe the A-V material being used by reporting the media employed, the name of the course in which the material was being used, a brief description of the material and who developed it.

SUMMARY OF SURVEY

A summary of the results of this survey is as follows. Overall, many ChE faculty members are experimenting with different types of A-V material for use in the courses that they teach. A number of schools use audio cassettes with or without slides to present operating instructions for laboratory equipment. There are some movie films being shown. The two most frequently shown film series are films on fluid dynamics of drag by Shapiro and the fluid flow film loops produced by the National Committee for Fluid Mechanics Films and distributed by the Encyclopedia Britanica Educational Corporation. Two textbooks are being written which will have accompaning sets of slides and audio tapes. Dr. C. M. Thatcher at the University of Arkansas is making a set of slides and audio tapes to supplement his book titled "Fundamentals of Good Chemical Engineering". Professor B. E. Lauer at the University of Colorado has made 1100 slides to accompany his textbook on ChE techniques. Outside of the 16 mm movie films on distillation columns by Fractionation Research Inc. and by Shell Oil Company, there were no other A-V material on chemical process equipment reported.

From this survey it was learned that Professor B. E. Lauer has prepared a catalog of available self-paced material which utilized video tapes. For more information about this catalog write to:

The Catalog
546 Fourteenth Street
Boulder, Colorado 80302

Another activity of the A-V Subcommittee was to have Professor M. W. Bredekamp to update his movie film list. Professor Bredekamp divided his revised list into six parts. Part one contains all the films believed to be pertinent to the teaching of undergraduate ChE courses. Some of these films listed have been reviewed and evaluated with a brief comment about the film. In the second part of his list, films which deal with specific chemical industries are reported. Then local sections of AIChE have reviewed and judged these films to be unsuitable for classroom use. In part three are the addresses of film distributors from which the films can be ordered. In part four of the listing are sources of film information from which Professor Bredekamp compiled his list, and in part five a list of films which were included in the previous year's film listing but which are presently not available. Professor Bredekamp has also included the results of the A-V Use Survey in the Sixth part of his film listing. It is hoped that this listing by Dr. Bredekamp will be published by AIChE.*

The first project of the A-V Committee was to survey the other ChE departments about their use and development of A-V materials.

The A-V subcommittee is presently seeking more people to work on projects. There is a need for people and for companies to produce A-V material on chemical process equipment. The subcommittee will act as a clearing house for the A-V material. I have a ten minute sound-slide-show on the applications of different kinds of pipe fittings which I would be willing to trade for a sound-slide-show on pumps. I also have a few copies of the A-V survey which I will be happy to mail to anyone on request.

The goal of the A-V subcommittee is to assist educators to locate A-V material and to promote the production of new material. By the trading of material produced by individuals, more A-V material at less cost will become available to all. □

* Publication X-91 "Chemical Engineering Educational Films" can be obtained for $4 by AIChE members and for $10 by non-members by writing to AIChE's Publications Dept., 345 E. 47th St., New York, New York 10017.

LETTERS: Continued

Sir:

I was very pleased to notice the inauguration of the feature "ChE Lectures" in the Summer 1976 issue of CHEMICAL ENGINEERING EDUCATION. I believe it is an interesting and instructive addition to your quarterly, and I heartily welcome it. The choice of R. Aris for the first lecture was superb, for, leaving the main content of the lecture aside, who could top the quote in the Conclusion. Do I hear a leopard stalking in the wilds of Pennsylvania. . . ?

Arvind Varma
University of Notre Dame

WORLD OF SURFACE SCIENCE: Shah

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ChE LIBRARY: Snider

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- Faculty and graduate students may check out any material contained in the library. Texts may be checked out for extended periods, subject to recall if needed. Reference books, journals, conference procedings, etc, may be checked out on overnight loan only.
- Undergraduate students may check out only texts and related material, on overnight loan only. Special reserve shelves are sometimes utilized by faculty who want to make available material for use only in the library. Special reserve material is not allowed to be checked out.
- Visitors from other departments on campus and from local industry may use any library material and may check out material upon approval of the department head.

CONCLUDING REMARKS

OF COURSE, NOT ALL ChE departments will find the classification system initiated at Clemson to be useful. The extent of subdivision will no doubt vary with the quantity of the holdings. The utility of any library is the ready availability of its materials; nothing is quite so frustrating as to waste valuable time searching for material that you know is there, if only you knew how to look for it. It was the purpose of our library reorganization to minimize this problem and to make our holdings available to all who need them.

The author expresses great appreciation to the ChE faculty of Clemson University for their assistance in choosing materials to be discarded and for suggesting additions to the classification system, and to the department secretaries, Mrs. Mary Ann Hayden and Mrs. Deborah Nelson for doing the cataloging and arrangement of the materials. □

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