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chemical engineering education

CHEMICAL ENGINEERING DIVISION OF AMERICAN SOCIETY FOR ENGINEERING EDUCATION

WINTER 1970

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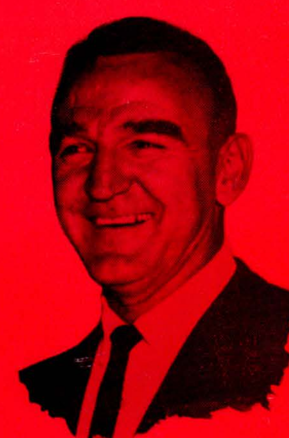

Johnny McKetta of **TEXAS**

INNOVATIONS IN CHE EDUCATION

Chemical Engineering Education

VOLUME 4, NUMBER 1 **WINTER 1970**

Departments

Feature Articles

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HELP !!

With this issue the staff at the University of Florida begins its third year of publishing CEE. We are certainly pleased with the overwhelming and enthusiastic response of our readers; we are equally pleased that we have received during the past year the support of eight donors, 21 industrial advertisers, and 39 university advertisers. In addition we received donations from nearly 100 departments of chemical engineering.

So far this year however, our commitments for income from donations and advertising are only 50% that of last year. Also while 92 departments have placed orders for bulk subscriptions to CEE, over 50 chemical engineering departments listed in Chemical Engineering Faculties have not yet sent in any contributions for 1970. We are therefore asking your help in the following: 1) If your department is not listed below, you might want to make sure that it continues to receive CEE. 2) If you read and enjoy CEE, you can help us by telling our advertisers and donors and letting them know that their support is recognized and appreciated. With your help we hope we can continue to serve you and the profession in the publication of a journal that all seem to agree is greatly needed.

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Department chairmen were sent additional copies of the Special Graduate Education Issue for distribution to those seniors who are interested in graduate education. Additional copies of this issue are still available on request.

For the current issue department chairmen are being sent the number of copies for which they ordered bulk subscriptions. (Those departments whose requests have not been received as yet will be sent token copies in order to provide some continuity.) The new subscription policy is as follows:

1. Chemical Engineering Departments may request a definite number of copies at $4/year for each of the four issues in 1970, with a minimum contribution of $25/year. (They may pay for these through departmental funds or faculty contributions or both.)

2. ASEE-Chemical Engineering Division members may request (on the following form) individually addressed copies to any address and pay $6/year starting in January 1970.

3. Libraries and other subscribers that are not members of the Chemical Engineering Division of ASEE may subscribe as before at $10/year.

R. Br. Bennett, Bus. Mgr. CEE
Department of Chemical Engineering
University of Florida
Gainesville, Florida 32601

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from our READERS

Roberts Updates Data

Sir:

The Fall, 1969 issue of "Chemical Engineering Education" contains an article by Ralph A. Morgen entitled "The Chemistry-Chemical Engineering Merry-Go-Round." Table III of this article states that a "light chemistry" chemical engineering curriculum should consist of 24 semester credits of chemistry and that a "strong chemistry" curriculum should contain 36 semester credits of chemistry. A few paragraphs later, Dr. Morgen states that "The twenty-three institutions in Table II with accredited undergraduate chemical engineering curricula in 1967 all come within these limits."

As chairman of the Undergraduate Curriculum Committee at Washington University (St. Louis), I recently made a brief survey of the chemistry requirements in chemical-engineering curricula at other universities, using the 69/70, or in some cases the 68/69 school catalogs as sources of information. The seventeen schools covered in the survey were arbitrarily selected, but I believe that they represent a reasonable cross-section of the chemical engineering departments in the United States. Ten were state schools and seven were private. The total number of semester credits of chemistry required in these seventeen curricula rangd from a low of 15.3 to a high of 30.0. The average requirement for the schools was 23.1 semester credits and the median was 24.0 semester credits. Seven of the seventeen schools fell at least 4 semester credits short of Dr. Morgen's "irreducible minimum" of 24. Not one of the schools required the 36 hours for a "strong chemistry" rating. Furthermore, the 36 semester-credit criterion for a "strong chemistry" program is *outside* the 99 percent confidence limits of the sample population.

Interestingly, the mean chemistry requirement for the seven private schools is 20.8 credits, and that for the state schools is 24.7.

The difference between these means is stitistically significant at the 95 percent confidence level. Five of the seven departments requiring less than 24 semester credits of chemistry were in private institutions.

On the basis of these results, it appears that the statistics presented by Dr. Morgen do not reflect the current situation among Chemical Engineering Departments. Chemistry requirements seem to have been reduced since the data leading to Table III of Dr. Morgen's article was compiled. However, since all but one of the seventeen schools surveyed required coursework in each of the three major areas of chemistry, it may well be that the present statistics reect a "numbers game" rather than a signficant drop in requirements.

The problem in reconciling these statistics with Dr. Morgen's may also result from the use of the term "semester credits." The present statistics are based on the use of two semesters per school year rather than three quarters. For schools on the quarter system, the number of semester credits was calculated by multiplying the number of trimester credits by ⅔.

George W. Roberts
Washington University

ChE educator

A New Mold
JOHN McKETTA
University of Texas

JAMES A. JOHNSON
Publications Editor
University of Texas
Austin, Texas

(Submitted by Dr. Eugene H. Wissler, Chairman, Department of Chemical Engineering, University of Texas)

To those who know him, John J. McKetta is a hard man to place. Just when one thinks he has this man figured out, some new facet of McKetta's character literally bursts forth in a rush of action. Most likely the acquaintance is left bemused, fascinated, and often as not, doubting that he really does know him.

Those who do not know him, should. John McKetta possibly holds more positions than any engineer today which affect both industry and education. According to the records, he is the only man who concurrently has been on the Boards of Directors for the ECPD, the EJC, and the ECAC and ECRC of the American Society for Engineering Education (ASEE). These positions converged during 1967-68-69.

Add to them the chairmanship of the 18-state Southern Interstate Nuclear Board (1967-68), the chairmanship of the Texas Atomic Energy Advisory Committee (since 1964), the advisory boards of at least a dozen major periodicals, plus committees in several professional societies, and the span of his interests begins to unfold.

But John McKetta is not a "joiner." Far from it. He belongs to these organizations because his professional concerns lie in their areas; and he has served them in many working capacities because there is no such thing in his makeup as passive involvement.

Nor do these activities constitute a new role. Back in 1962, when he was president of the AIChE, he already had been a national director of AIChE for five years. As president, his career was just 16 years out of college.

He still serves on four AIChE national committees. The same kind of working participation

is found in his past and present positions in the American Chemical Society (ACS), American Institute of Mining, Metallurgy, and Petroleum Engineers (AIME), and the American Gas Association. In perspective, McKetta's credentials do not reveal the true man. Actually, they enable him to meet important persons—and that is where the action is.

One may fairly inquire about the real motivations of this man whose 23-year career continues its three-dimensional expansion, whose quiet voice is listened to wherever he is, who still is almost a generation away from retirement. Put simply, John McKetta is dedicated to engineering education. Examining a detailed list of his organizational positions, one finds that most of his activities have been centered around some aspect of education.

Going deeper, in face of his many interests (he travels more than 100,000 miles a year), it has been said that John McKetta sometimes also is the Dean of Engineering at The University of Texas in Austin. That's unfair. A majority of his trips are to see educators at other colleges, to exchange ideas, to lay plans for future engineering education. Along the way he may visit industrial leaders, accept gifts or other support for

Beginning September '69 Dr. McKetta became Executive Vice Chancellor for Academic Affairs for The University of Texas System. Presently, the academic affairs of four universities are under his direction with plans for two new universities in the near future. — Editor.

UT's Engineering Foundation, convince someone's high-schooler or a graduate student to come to Texas, or recruit new faculty members.

Underlying these travels is Dean McKetta's firm conviction that industry and engineering education must have the closest possible ties. It makes sense, because industry is the chief customer and beneficiary of the college's graduates. In turn, industry provides a lion's share of scholarships and Foundation funds, those extras which spell the difference between an ordinary school and a great one.

The industrial-educational relationship extends deeply into the affairs of the college. During peak recruiting periods, McKetta has coffee in his conference room every morning with company representatives. Industrialists make up the boards of visitors to the departments.

McKetta himself has been a catalyst in broadening the scope of the Engineering Foundation Advisory Council's role from one of raising funds and monitoring expenditures, to include comprehensive studies of curricula, facilities, and guidance on future trends in education. The Council, incidentally, includes the heads and top executives of some of the largest firms in the country. Meeting three times a year, an observer would think this group of 20 was the board of directors of a corporation. He wouldn't be able to single out John McKetta from the others.

That's where McKetta unintentionally fools a lot of people. A broad-shouldered man of medium height, his build tells of work as a youth in Pennsylvania coal mines; his stance suggests a fighter (he was a regional Golden Gloves welterweight champion); his rolling gait could only be that of a man of intense drive. Dressed stylishly, brief cases in hand, fellow airline passengers take him for a successful business man as he studies papers enroute. They'd never know differently, even if they struck up a conversation with him about business.

Although he doesn't "look like a dean" or a traditional academician, he is equally at home among educators. He discusses educational problems with an insight matched by few; only his incisive way of cutting through red tape and fuzzy notions to go directly to the crux of a matter reveals the unique brand of practical logic for which he is noted.

McKetta's ability to bring industry and education to the table in objective harmony perhaps is best illustrated in his leadership of an unusual organization of several years' standing but no official status whatever. The body is made up of the deans of the 12 public and private engineering schools in Texas, and 12 industrial leaders. It is called "The Council of Engineering Deans and Their Industrial Counterparts."

About three years ago the Coordinating Board of the Texas College and University System turned to this group for help in designing a master plan for education in the state. Meeting irregularly at such times as the two dozen busy men could get together, in November, 1968 they submitted "An Advisory Report on Engineering Education in Texas" that well may become a classic guideline for other states.

McKetta can only be viewed as an entrepreneur. UT's College of Engineering has been noted since 1964 for its pioneering efforts to improve the teaching effectiveness of its faculty. McKetta certainly didn't invent the idea of better teaching (that undoubtedly predates Socrates, Plato, and Aristotle), but he must be numbered among a tiny handful of contemporary educators who saw a need and actually did something about it. The result has been a change in attitudes in the college, a marked improvement in rapport and teacher-student relationships, and measurable improvements in student motivation as well as learning.

So rewarding have been the outcomes, in fact, that McKetta felt justified in working for two years on the powers that be to scrounge, beg, argue, and twist arms for resources with which to establish a Bureau of Engineering Teaching, complete with a full-time PhD engineering teacher-director. Opening its doors last fall, insofar as is known, it is the only office of its kind in the nation.

It may be a sad commentary, but a textbook on educating engineering teachers at college level has yet to be written. Dean McKetta and his staff are on the way to writing their own textbook. Being planned right now is a special school in the college specifically for making professors out of engineers.

If it doesn't shrink on their backs, why should it shrink on yours.

Animals wear leather all their lives. And they don't worry about rain or dirt or cracking or hardening.

But as soon as they lose their hides, that's when the trouble can start. Without protection, baseballs can shrivel up, mini-skirts become micro-skirts, size 9 shoes become size 8.

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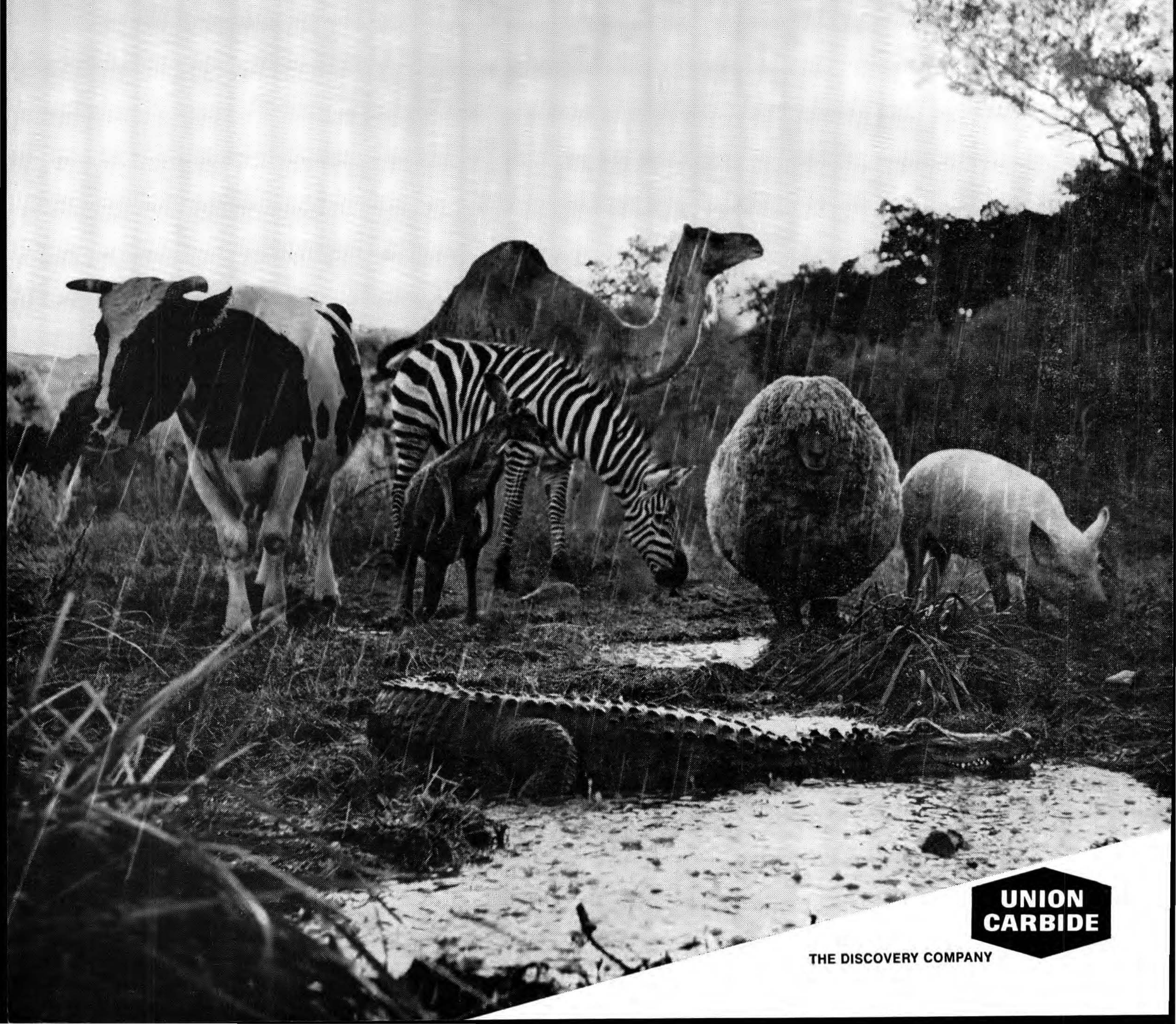


UNION CARBIDE

THE DISCOVERY COMPANY

In October, 1966, at the opening meeting of the year's series of faculty meetings on teaching effectiveness, McKetta voiced something that was, and is, both a philosophy and a policy:

"WHEN ONE ACCEPTS a position as a university faculty member, he should expect to write proposals for research, equipment, and special projects; to publish articles, reports, papers, and books; to keep up-to-date in his professional field; to serve on councils, boards, and committees; to maintain the best possible relations with alumni, legislators, and the business and industry of the region—in short, to be a responsible member of the community and to participate in many of its activities.

"BUT WE ALL KNOW that these many activities must never overshadow our greatest concern—the student. If our responsibilities to, and concern for, the student ever become secondary, we will be violating the trust we accepted when we joined the faculty."

Dean McKetta greets new faculty member Dr. William G. Lesso. All incoming faculty members are given a special orientation program, with emphasis on better teaching.

This statement was made prior to the breakout of turmoil on campuses across the nation. As in so many instances, McKetta again was early, and dead on target. It is not with foolhardiness, but with confidence, that he encourages his 3,200 students to have a healthy discontent and to constructively inquire into the "why" of things both social and technical.

John McKetta conforms to his own philosophy. Everyone in the college must teach; there are no full-time research positions on the faculty. He has been a teacher at Texas since 1946. His teaching load had to change when he was chairman of the Chemical Engineering Department in 1950-52, and again in 1955-63. As dean of the college since 1963, he has managed to continue work with five or six graduate students, and in some semesters to teach a course.

Just before the fall term opens, McKetta and his department chairman annually meet for two and a half days at some pleasant, secluded lake inn or ranch in the hill country west of Austin, to discuss ideas, problems, and plans for the coming year. Once a chairman commented, "This seems like a retreat." "Heck, no," McKetta retorted, "it's an advance!" Chairman's Advance it became, and continues so.

At last count, McKetta's published papers were approaching 170, mostly on chemical engineering. He has been author, co-author, or editor on 16 books, and is on publishers' advisory boards for several standard reference works. This past October 1969 the AIChE gave McKetta the Warren K. Lewis Award for Excellence in Chemical Engineering.

Although little time is left for hobbies, McKetta does have one relaxing passion. When his faculty is with him on group trips, given a spare evening, he wants to play poker. Mad poker. Wild poker: duces wild, one-eyed jacks wild, baseball, hairpin, spit-in-the-ocean. Just for fun.

This man from Pennsylvania, via Tri-State College in Indiana (BS, Honorary DE, Distinguished Alumnus, Board of Regents), and University of Michigan (BSE, MS, PhD, Distinguished Alumnus, Honorary Sesquicentennial Award 1967), has come a long way. He has a long way yet to go.

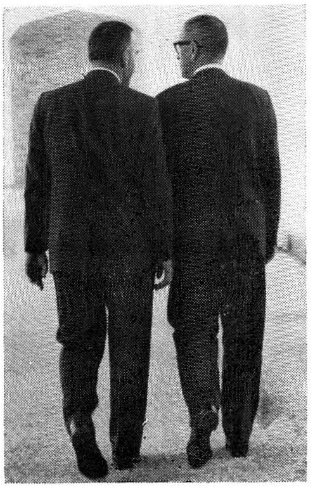
It seems that the mark of Texas is upon him. He loves its people, its industry, its climate, its frontiers, its problems, its opportunities. John McKetta swears he has orange blood (UT's colors are orange and white).

He'll prove it, too. He often wears an orange tie, or one with a Longhorn on it. In a platform, or at a party, he is likely to unbutton his coat and show its orange lining, to the surprise and delight of everyone.

A couple of years ago he acquired a deluxe home pool table for visitors. After it was set up in the game room of his lakeside home, he had the green felt covering removed and a Darrel Royal (football) Burnt Orange cover put on. Pool on an orange table, anybody?

He is Johnny to intimates and elder statesmen. To his faculty, he is John or the Dean.

Early this year, Joe J. King, Houston business man and engineer, offered a gift to the University for establishing an engineering professorship in his name. Joe had one condition, though: " . . . provided Johnny McKetta is named the first recipient." The UT System Board of Regents agreed.



Deans McKetta and Amstead, in a quiet moment, discuss plans, make decisions, and ponder new problems.

Chemical engineers, those who probably have known John McKetta longest and best, should have no fears that he has deserted or grown away from them. Addressing a South Texas Section, AIChE meeting late in 1967, his opening remarks were:

"I have taken pride in being a member of AIChE for many years. It is a special honor to be allowed to speak to you today.

"You know, as a dean of engineering responsible for educating thousands of young men and women to take their places in the profession, my interests must be as diverse as all the broad fields of engineering. But it is always refreshing to come back home and rub elbows with men in chemical engineering, my first love and the field with which I have a permanent romance. . ."

John McKetta's multiplicity of activities defines the man, but it still leaves him hard to categorize. Above all, he is an individualist and his own man.

He fits no traditional mold. He is a new mold, a new kind of leader, intent on producing a new breed of young engineers with a deep sense of social relevancy, strengthening the initiatives of both education and industry, and developing the knowledge and talents of the finest young persons ever to seek an education.

These are not impossible goals for a man like John McKetta.

ChE book reviews

Conservation of Mass Energy
J. C. Whitwell and R. K. Toner
Blaisdell Publishing Co., (1969), 496 pp.
Waltham, Mass.

The authors have produced a challenging book for students taking their first course in chemical engineering. The introductory chapter describing the function of the chemical engineer in industrial practice is well done and could serve as a model for informing high school students about the field of chemical engineering.

Their approach to the problem of unit conversion is not the traditional unit equation and conversion factor method but is heuristic. The intent being to get the student to think.

The section on independent balances and variables in the material balance chapter is considerably more advanced than usually found in texts at this level, making use of Amundsen's matrix method for determining the number of components in a system. A supplement to the chapter on material balances treats in detail the degrees of freedom available in process specification.

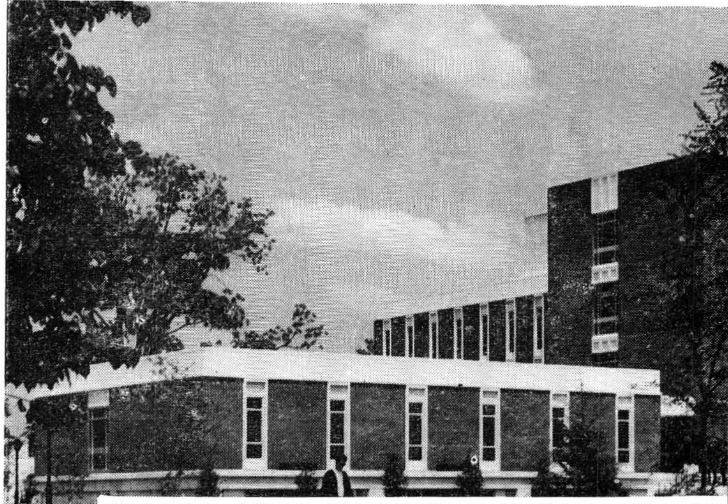
The chapter on transients covering both time and position dependent processes may be too advanced for the average student at this level. It may be appropriate to skip the position dependent transient, delaying this material until it occurs in the treatment of stagwise and continuous contactors in subsequent courses. A later section deals with transients associated with heat transfer operations.

The section of the book dealing with energy balances is less satisfactory than the preceding sections. Many topics are brought up and then dropped as being beyond the scope of the text. The explanation of the kinetic energy term in the overall energy balance is not very satisfactory.

Phase diagrams and enthalpy concentration diagrams are not mentioned. This seems unfortunate in view of their usefulness in tying together material and energy balances.

The text is adequately supplied with worked out example problems. There are a large number of problems for student use following each chapter. These are graded in difficulty and in addition a group of problems in each chapter has extraneous data supplied. Hopefully these problems will encourage the student to think before starting the problem solution.

Edgar V. Collins, Jr.
Iowa State University



DELAWARE

JACK A. GERSTER*
University of Delaware
Newark, Del. 19711

The Department of Chemical Engineering at the University of Delaware offers a wide variety of services consistent with the demands of the technical community, both local and world-wide. Local needs are important, because northern Delaware is a large chemical manufacturing and research center; beyond the state line to the north and east lies the even larger chemical and oil refining industrial complex which borders the Delaware River from above Philadelphia to below Wilmington for more than 30 miles. The university, located 12 miles west of Wilmington and the river in the town of Newark, offers a small college-town atmosphere for its students, yet, is only a half-hour's drive from either the Chambers Works, duPont's largest manufacturing plant, or from Getty Oil's 100,000 barrel a day oil refinery. It is never a problem explaining to Delaware high school students what a chemical engineer is, the kind of work he does, or where he might be employed.

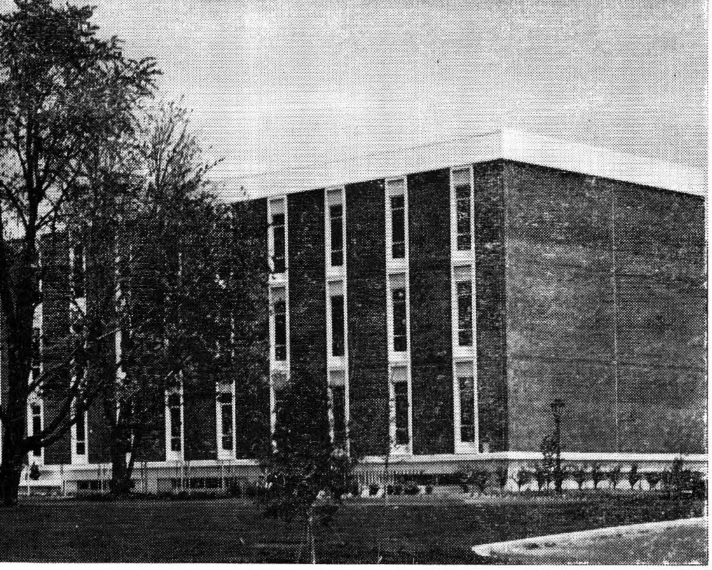
Delaware is nevertheless, a small state having only 3 counties and a population of just over one-half million; University of Delaware, with its 8,000 undergraduate and 2,000 graduate students, is the only institution of higher learning in the state offering training in most of the professional areas, including engineering. Originally a state university, Delaware is now a state-related agency receiving income both from the State legislature and from its endownment, the latter being fairly substantial.

Although some chemical engineering training was available at Delaware prior to World War II, it was not until 1946 that the number of undergraduate students became significant and graduate work was offered in depth. The first PhD degree was awarded in 1948. The department chairman at that time was Allan P. Colburn, an outstanding chemical engineer whose reputation in heat and mass transfer was first developed while working under Olaf Hougen at Wisconsin and later under T. H. Chilton at the duPont Experimental Station. (Colburn's career was presented in detail in the previous issue of this journal.) Colburn's spark-plug personality and driving enthusiasm attracted a small nucleus of outstanding faculty. In 1946 this group included O. P. Bergelin, whose research on shell-side coefficients and shell-and-tube exchangers remains as the classic basis for design of such equipment.

Colburn also hired J. A. Gerster and R. L. Pigford for Delaware's teaching staff during this period. Gerster assisted Colburn in his research on nonideal solutions, extractive distillation, and tray efficiencies for a brief period, then took over this assignment when Colburn was moved up into higher administrative positions at Delaware in 1947 when Pigford was brought in as Department Chairman.

THE "COLBURN YEARS" at Delaware provided an educational philosophy which has been carefully followed, updated, and amplified during the next 19 years while Pigford directed the fortunes of the department; the same philosophy remains in effect today. **Colburn, in spite of**

***After the receipt of this article, CEE learned that Prof. Gerster died January 20, 1969 in Newark, Delaware. Dr. Gerster received his BE, MS, and PhD in chemical engineering from Ohio State University. In 1962 he was named winner of the Professional Progress Award of the American Institute of Chemical Engineers "for important contributions to research, especially in distillation and to chemical engineering education." CEE joins the profession in mourning the loss of this outstanding Chemical Engineer.**



his great theoretical knowledge and background, was nevertheless primarily an engineer, and insisted that chemical engineering research have practical value; the practical value could be eventual rather than immediate, but it had to be there in order to merit his interest. This requirement by no means eliminated the need to apply fundamental science or basic mathematics to correlate or explain a result, in Colubrn's opinion. For example, he successfully used the best available two-phase flow theory for correlating condensing film coefficients for the case of turbulent vapor flowing downward in cooled vertical tubes. On the other hand, complex problems not amenable to full theoretical treatment still received Colburn's attention, provided they were of practical interest; he searched for the unique and characterizing experiments necessary to define and predict the desired result, and was usually able to develop recommendations for use in design regardless of the complexity of the situation.

Colburn and Pigford set high standards in their course teaching. At the graduate level, two-semester sequences were made available in each of the basic chemical engineering subjects such as thermodynamics, kinetics, fluid mechanics, and transport processes. Usually most of the important topics of the subject were taught during the first semester, including both basic principles and applications. This permitted the master's students, who usually took only the first semester courses, to be fully trained in a wide variety of subjects. In the second semester of these courses, more specialized topics were covered: an example would be the teaching of fluidization and two-phase flow in the second semester of the graduate fluid mechanics course. Applications of fluidization and two phase theory would be included. The second semester courses always included study of current literature so that by the end of the two-term sequence, the student became familiar with knowledge of the subject updated to the present time. Graduate courses remain structured in this manner today, as the value of the procedure has been proven many times.

All of the basic graduate courses devote some time to the solution of short, practical problems which most often have a design flavor, but may also be directed toward characterizing a particular piece of operating equipment or process, or may illustrate the workings of a strictly research-type apparatus. Although the graduate course in design synthesis is not taken by a majority of the graduate students, inclusion of design-type problems in the regular courses meets much of the need for preparing masters' students for industry and PhD students for their qualifying examinations.

A successful innovation is graduate teaching developed over the past several years is the use of "term teaching." In this approach several professors—usually three—have joint responsibility for a given course. Each contributes lectures on topics related to his own expertise but in a manner that is related to what the others are doing and to the basic subject matter as well. This practice has been particularly successful in the second semester of the two-term courses described above.

Maintaining high quality in chemical engineering education over the years has been possible only because of the insistence in quality in the selection of faculty members. It is not possible to list all faculty in the department since 1946, but changes have been relatively few and stability has existed through the years. Currently, the faculty numbers thirteen: J. A. Gerster, (Ohio State) is Chairman; C. E. Birchenall (Princeton), A. B. Metzner (MIT), and J. H. Olson (Yale) are Professors: M. M. Denn (Minnesota), T. W. F. Russell (Delaware), and J. H. Schultz (Carnegie-Mellon), are Associate Professors; and B. H. Anshus (Berkeley), B. C. Gates (Washington), J. D. Eliassen (Minnesota), J. E. Katzer (MIT), M. R. Samuels (Michigan), and S. I. Sandler (Minnesota) are Assistant Professors. Further, the Dean of Engineering, E. W. Comings, is a chemical engineer by training and directs a graduate thesis from time to time. All of the faculty just mentioned have PhD degrees

Pigford . . . strongly required that both courses and research have engineering relevance.

and all have a strong, traditional chemical engineering background with abilities to teach a wide variety of courses (except for two of the professors in the Materials Science area, Birchenall and Schultz). Yet each has his own special interests, but, because of the breadth of background, each has the technical competence to change or add to his interests—as each has done in the past and will continue to do in the future as new developments occur. The faculty also maintains contact with industry by consulting work, by informal contacts with engineers from industry, by attending technical meetings, and by various kinds of committee work.

DISCUSSION OF DELAWARE'S chemical engineering faculty is not complete, however, without mentioning three long-term faculty members who are now teaching elsewhere: Robert L. Pigford, John R. Ferron, and David E. Lamb. Pigford influenced the growth and stature of the department during his period as chairman (1947-1966) more than anyone else. He implemented and improved upon Colburn's policies, and added many important innovations. **He strongly required that both courses and research have engineering relevance. Course problems or thesis work which were no more than mathematical exercises were not condoned. Yet, on the other hand, Pigford was a strong applied mathematician, and believed that students should both know and be able to apply mathematics in their studies;** he was one of the first to use computers in his research and strongly motivated the university to obtain its first computer. Pigford also innovated a short course in electronics for the department's PhD students, and introduced the requirement of an oral proposition for this same group. Development by the student of an oral proposition—which is a fully-documented research proposal not related to the thesis—provides training for the PhD student in conceiving and planning a research problem; such training is vital for anyone planning a career in research, yet often this phase of the student's own research is completed by the thesis advisor before the student enters the scene. (Today the oral proposition is presented by the student during the oral part of his PhD qualifying examination. The oral part is preceded by the written part of this examination, which is eight hours long and administered over a two-day period.)

Pigford was also the prime mover in promoting a new building for the department. Although the building was barely under construction when Pigford moved to the University of California at Berkeley in 1966, his contributions to the planning and in developing funding were very substantial.

John R. Ferron is the second former Delaware faculty member whose impact on the department merits attention. After a career at Delaware spanning the years 1958-1969, Ferron became, in September, 1969, Chairman of Department of Chemical Engineering at University of Rochester. Dr. David E. Lamb joined the Delaware Chemical Engineering Faculty in 1956. He became the first Chairman of the Department of Statistics and Computer Science at Delaware in 1965; he retains his interest in chemical engineering but no longer teaches in the department.

At this point the individual areas of interest and research specialties of the current faculty might be listed:

Dr. Gerster has interests in mass transfer, distillation, and applied thermodynamics; he has 45 published papers on vapor-liquid equilibrium, efficiency and performance of distillation towers, and tower control. He authors the "Distillation" section of Perry's Handbook, and in 1962 received the Professional Progress Award of AIChE. Dr. Metzner has over 50 papers to his credit, mainly in the areas of non-newtonian fluid mechanics and kinetics. His awards include: The Chemical Engineering Lectureship. ASEE, 1963; Colburn Award, AIChE, 1958, Wilmington Section Award, ACS, 1958; and U. N. Lacey Lectureship, Cal. Tech., 1968.

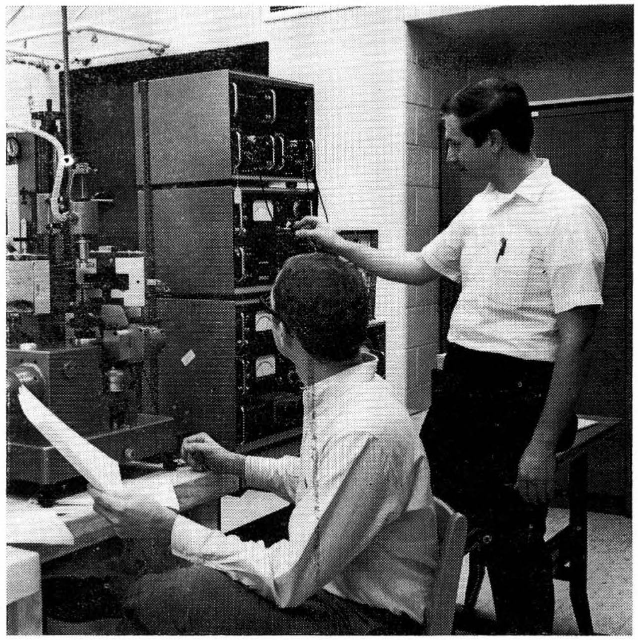
Dr. Birchenall is the author of the book, "Physical Metallurgy," and has published more than 70 paper, mainly on diffusion in metals and the mechanism of corrosion. Dr. Olson has published in the areas of catalysis and kinetics, mass transfer (particularly crystallization), turbulence, and automatic control. Dr. Russell is a well-known expert on two-phase flow in pipes, and in both pipeline and stirred tank reactors. Dr. Denn's new book, "Optimization by Variational Methods" has just appeared, and he has published 20 papers on optimization, automatic control, and non-newtonian fluid mechanics. Dr. Schultz uses x-ray diffraction and other techniques to characterize the crystallinity of polymers such as polyethylene in terms of their structure and treatment. Dr. Eliassen is interested in the fluid mechanics of liquid interfaces and in the related problem of emulsion polymerization. Dr. Samuels works in the computer solution of engineering problems and in the use of laser-Doppler flowmeter for flow-field determination. Dr. Sandler's field is statistical mechanics; his most recent paper is titled "Transport Properties of Partially Ionized Argon."

Both Dr. Gates and Dr. Katzer have interests in basic and applied catalysis; the former tends to emphasize gas

phase reactions, and the latter, liquid phase reactions. Dr. Anshus works in the area of fluid mechanics, particularly in flow stability.

The expanding size of Delaware's faculty — noted above to increase from 4 in 1946 to 13 in 1969, reflects the growth in numbers of undergraduate and graduate students over that period. As of September, 1969, there were 88 freshman chemical engineers and 43 seniors, nearly all of whom will probably graduate. **The number of undergraduate students have been increasing at the rate of 6 - 7% per year for the past six or seven years; this growth is unlike the national trend, which shows a nearly constant number of students being graduated each year in chemical engineering.** There is no definite explanation for this growth, but it is probably due to a combination of circumstances including Delaware's increasing reputation in the field and its rather favorable fee structure when compared with most of the competing private schools such as Lehigh, Carnegie-Mellon, Princeton, and MIT. At the graduate level, a peak of 65 full-time graduate students in residence was reached three years ago, but draft difficulties has reduced the figure to 49 for September, 1969. The average percentage of Asian and Indian students has remained constant over the past decade at about 6% of the total; this year, the number of English and Canadian students has been increased. Of the graduate students in residence, about half are PhD candidates. Delaware's PhD "production rate" (that is, the number which are graduated each year) has averaged nearly 10 for the past 5 years or so; only eight or nine schools in this country produce more than that.

DELAWARE'S UNDERGRADUATE curriculum is cast along traditional lines in many respects, but there are some features which are truly unique. For example, *freshmen are required to designate a preference for their major subject, and all of those choosing chemical engineering take a 2-credit course in engineering orientation taught by chemical engineer faculty.* The concept of what constitutes chemical engineering is taught by a simplified process design problem which involves the concepts of recycle, conversion and yield, cost factors, and net profit. Fortran programming is taught and used to solve the detailed calculations required in the design problem, and a plant trip is made to inspect the actual process under study. A second course for freshmen, taught by chemical engineering faculty,



Weissenberg Rheogoniometer for the Determination of Rheological Properties of Viscoelastic Materials.

may be elected in place of the 2-credit engineering graphics course. This second course is designated as a "chemical engineering seminar," and the class size is kept under 15. In this course students are guided into learning about and discussing a chosen chemical engineering topic such as, "Low Temperature Processes," "The Clam as a Chemical Engineering Operation," or "Plastic Flow Problems." In this course the close contatt with a senior faculty member cements the students' interest in chemical engineering at a time when he is mainly concerned with learning the fundamentals of mathematics, physics, and chemistry; it permits him to see in advance how these fundamentals are required and used in engineering practice.

Sophomore students take a two-semester sequence of a unified chemical engineering subject which includes not only the traditional material and energy balances of various chemical processes, but also training in "chemical engineering analysis." This latter subject includes practice in setting up differential equations—expressing mathematically all kinds of physical situations. In addition to the modelling, procedures for solving differential equations are covered. The mathematical procedures are taught (by chemical engineering faculty) mainly in the Spring Semester, after the student has finished three terms of calculus; a separate course in differential equa-

There are more than 100 billion barrels of potential new oil on the North American continent. But it will have to be dug—not pumped—out of the ground. It's in the form of low-grade hydrocarbon solids. Yet, the world needs so much more oil in years to come that Atlantic Richfield is already working on ways to extract it and get it moving. Projects like this take imagination and fresh viewpoints. The kind that come from young innovators like yourself. We need you—and your kind of ideas—to keep making great things happen. Talk to our interviewer when he's on your campus. Or write to: Manager Professional Recruitment, 717 Fifth Avenue, New York, N.Y. 10022.

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tions is no longer a part of the curriculum. The analysis training provides the proper background for transport processes and thermodynamics, both taugh as 2-semester courses in the junior year.

The chemical engineering senior year includes six trips to nearby chemical manufacturing plants. Seniors are required to take a full year of senior projects and a Spring Semester course in design. The value to the student of carrying out an individual research project is so great that the faculty is willing to spend the time and money involved on the individual instruction which is required. The type of the research performed is not too sophisticated and the equipment is necessarily simple, but the student's sense of responsibility and judgment is sharpened, and he learns to appreciate the many factors involved in solving a problem on his own. In a weekly projects conference period, students learn about statistical design of experiments and report on their research progress.

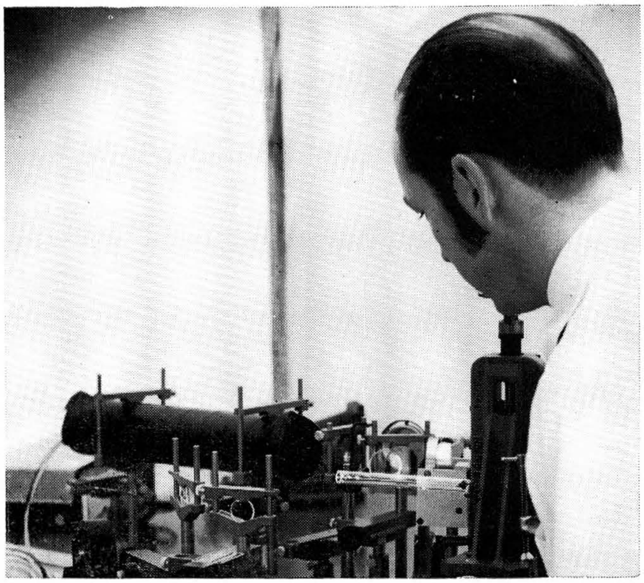
The senior design course has had many desirable improvements in the past several years. The duPont Company has assisted in the teaching of design by making avaliable a senior design engineer to handle the class for a six-week period during which one or more "case studies" or real design problems are solved under his guidance. For the last two years a Monsanto design problem—made available through Washington University (St. Louis)—has been used very successfully. DuPont has also agreed to prepare a case study for use by this class, and arrangements for this have already been completed. A regular faculty member has responsibility for the design course, and works jointly with the industrial representative. **The university-industry collaboration has produced a highly successful design experience for the seniors, requiring them to integrate most of their previous course experience to produce the needed process design.**

Seniors also choose two technical electives in their final year. These are commonly chosen from three senior-level courses offered by the department or from a listing of courses in the Departments of Chemistry, Physics, Mathematics, or Computer Science, or in the other engineering deartments which includes Materials Science. The departmental courses, which are more popular than the others with the students, are process dynamics and automatic control (a one-semester course) and a two semester sequence in characterization and processing of polymers. Some universities offer more technical electives in their curricula, but it is believed that only two technical electives can be accomodated in a sound four-year bachelor's program which includes all the necessary technical fundamentals: a year of organic and of physical chemistry; single semester courses in mechanics, electrical engineering, and materials science beyond the basic mathematics, physics, and chemistry; and the necessary chemical engineering courses described above.

Students in their third and fourth years are urged to take junior and senior level cultural courses, (eight 3-credit courses are elected from history, philosophy, or literature) even although they do not have the necessary prerequisites. The advantage of being associated with more mature students in upper level course material more than counterbalances the disadvantages of not having the required prerequisite. To offset this disadvantage, engineers may take such cultural courses on a "pass or fail" basis.

In addition to the regular 4-year bachelor's degree in engineering, Delaware offers a 4-year degree in "Engineering Administration." The engineering administration degree is of course not accredited by ECPD; students entering the program are made aware that they will not be eligible for membership in AIChE and will not be admissable for graduate study in chemical engineering.

MANY SEMINARS ARE OFFERED, in addition to the regular graduate courses. These vary greatly in size and in the breadth of coverage. The main departmental seminar brings experts in a wide variety of fields to its weekly meetings—the speakers are mainly from industry or other universities (often from abroad). But three or four smaller seminars are also usually available—these are run by the permanent faculty on topics of limited scope, sometimes related to the research of the faculty member and his group of students, sometimes not. The department's visiting professor and distinguished scholar programs also bring additional educational advantages to the graduate program. Visiting professors are in residence for one or two semesters, usually in place of a permanent faculty member on sabbatical leave; distinguished scholars are brought to the campus for from 2 days to a week for a series of formal lectures and informal meetings with students.



Laser-Doppler flowmeter measures point velocities without disturbing the flow field.

Another important aspect of the graduate program is the research effort. The research of slightly more than one-half of the department's full-time graduate students is directly sponsored by contracts with NSF, NASA, the Department of Defense (through a Project THEMIS grant), the University of Delaware Research Foundation, and private industry. The other (smaller) half of the graduate student group has completely free choice of thesis topic because they are funded by NSF traineeships, NASA or NDEA fellowships, teaching assistantships, industrial fellowships, or from a special grant from the DuPont Company for promotion of research by new faculty.

It is probably apparent that a thesis is required of all graduate students. Terminal master's candidates perform a six-credit thesis; doctoral candidates may either get a master's degree first (with its required thesis) and then proceed with a related or completely different dissertation topic, or they may by-pass the master's degree and work directly on their doctoral requirements, including the dissertation. (In the latter case, permission to by-pass the master's degree is not given until after at least one semester of graduate study has been completed, but the student nevertheless picks a thesis topic—based upon his likely program—when he first arrives, as do all graduate students). The desirability of performing a master's thesis has been widely debated particularly in recent years, and many universities have dropped the master's thesis requirement. **But Delaware's chemical engineering faculty strongly and uniformly support the master's thesis as a necessary part of graduate training.**

Because of Delaware's location, there is a large demand for graduate course work in chemical engineering in the late afternoon and evening hours for those employed in the area. On the average, four or five such courses are offered each semester with enrollment in each course varying from 15 to 40. The courses in general are the same as those offered in the daytime to the resident graduate students, although the instructors are mostly industry persons with PhD degrees whose teaching abilities are well-known to the university.

RESEARCH AND TEACHING of chemical engineering at Delaware is made much more attractive than in former years because of the large, handsome new building which now houses the department. The structure, erected at a cost of 2.3 million dollars, contains 65,000 ft^2 of floor space. It was first occupied in May, 1968. The building was designed to serve future needs: it can accomodate a faculty of 22, a graduate student population of 120, and an undergraduate senior class of 70.

The building is divided into two parts, a classroom wing, and a laboratory and office wing. The classroom wing contains three 40-seat classrooms; two of these can be made into a single 80-seat room. In addition, there is a senior design room containing large area desk tops with file drawers underneath, and two smaller conference rooms for small seminars or laboratory computation groups. Beneath these classrooms, which are on the main floor, is the chemical engineering shop. The office and laboratory wing has 3 floors and a fully-utilized basement; the wing is 250 ft long by 50 ft wide. There are laboratories at each end of the building running across the entire width of the building. The laboratories on the upper three floors are mainly for research, although there is also a process dynamics laboratory, a photographic area, and a standards laboratory.

The basement floor contains the undergraduate teaching laboratories and the metallurgy laboratories. The basement of the building also contains a "Computation Laboratory" which contains a Wang electronsc desk calculator with four consoles; an IBM key punch; and several computer terminals.

SOME CURRENT STUDIES IN LIQUID STATE PHYSICS*

1969 Award Lecture

Part 1. Structure of Liquids

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As IN THE STUDY of other phases of matter, elucidation of structure is important to the understanding of fluids. Although liquids often exist at densities comparable to solids, the fluid state of course lacks the well-defined long-range order of a crystalline solid. On the other hand, although the dynamic chaos associated with dilute gases is manifest in dense fluids, the movement of a molecule in a liquid is correlated with the location of its neighbors. This leads to a local or short-range order. Consider Figure 1 which might represent a collection of spherical molecules, with an arbitrary particle picked as reference. At a distance r from the reference particle, the density of other particles $\rho(r)$ will depend on time, but on the average will be a quantity dependent only on the distance r. Qualitative features of such a density function are apparent from elementary considerations: $\rho(r)$ must tend to zero as r goes to zero since additional particles cannot occupy the location of the reference molecule: at large r, the influence of the reference particle is nil, and $\rho(r)$ approaches ρ, the macroscopic density; at intermediate separations $\rho(r)$ may be less than or exceed ρ depending on whether the distance r corresponds to distances of repulsion or attraction between the particles. See Figure 2.

Let $g(r) = \rho(r)/\rho$, a quantity which thus goes to unity in a fluid for large values of r. This ratio g(r), which is called the radial distribution function, may be given generalized formal statistical-mechanical definitions. However, understanding of the behavior of fluids is often aided by the above density interpretation. This radial distribution function is the concept and quantity involved when one refers to the "structure" of a liquid. In addition to the explicit dependence on the distance r, the structure depends also on density and temperature: g(r) is a state function.

RELATION OF STRUCTURE TO MACROSCOPIC PROPERTIES

Most macroscopic properties of a fluid may be described in terms of g(r), usually in conjunction with the pair-wise intermolecular potential function u(r). As an example, the internal energy, equation of state, and compressibility have the following representation (for the first two we give particular versions applicable to a monatomic fluid, e.g., argon).

$$U = \frac{3}{2}\rho kT + \frac{\rho^2}{2}\int_0^\infty u(r)g(r)\ 4\pi r^2 dr \qquad (1)$$

$$P = \rho kT - \frac{\rho^2}{6}\int_0^\infty ru'(r)g(r)\ 4\pi r^2 dr \qquad (2)$$

$$\kappa_T = \frac{1}{\rho}\left(\frac{\partial\rho}{\partial P}\right)_T = (kT\rho)^{-1}\left[1 + \rho\int[g(r)-1]\ 4\pi r^2 dr\right] \qquad (3)$$

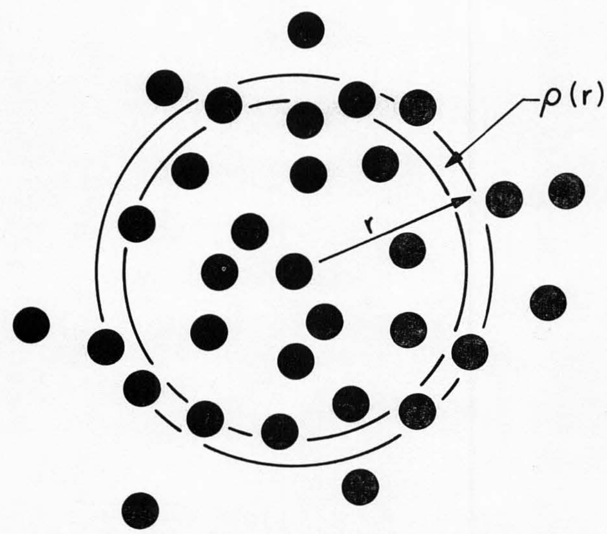


Fig. 1. — A representation of molecular arrangement in a fluid of spherical molecules.

*ChE Division Distinguished Lecture, sponsored by the 3M company and presented at the ASEE Annual meeting at Penn State, June 24, 1969. The research described has been significantly supported by the Chemistry Directorate of the Air Force Office of Scientific Research.

Cornelius Pings holds BS, MS, and PhD degrees from Caltech. He has received awards for his contributions to research and teaching and finds time for civic activities for the City of Pasadena. His research interests are in applied chemical thermodynamics and the physics and chemistry of liquids.

These types of expressions may be rigorously derived, and the reader is referred to a standard work in statistical mechanics[1]. Note however that the expression for U is almost obvious upon inspection. U is the sum of two terms, the first of which is the kinetic energy contribution normally attributed to a noninteracting monatomic gas. The second term represents a configurational energy; the integrand is simply the intrinsic intermolecular energy at separation r multiplied by the density of particles at that separation. The expression for P, although perhaps somewhat less transparent, also involves a sum of kinetic and configurational terms.

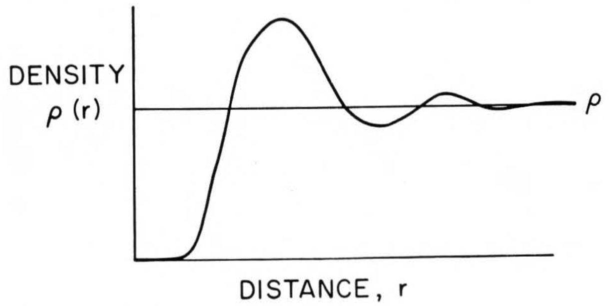


Fig. 2. — The local density in a fluid.

EXPERIMENTAL STUDY OF STRUCTURE

The intensity of coherent electromagnetic radiation, I_0, scattered from a monatomic fluid of N atoms at an angle 2θ by an incident beam I_o of wavelength λ may also be described in terms of g(r). For x-radiation the appropriate expression is

$$i(s) = \rho\int_0^\infty [g(r) - 1]\,\frac{\sin sr}{sr}\,4\pi r^2 dr \qquad (4)$$

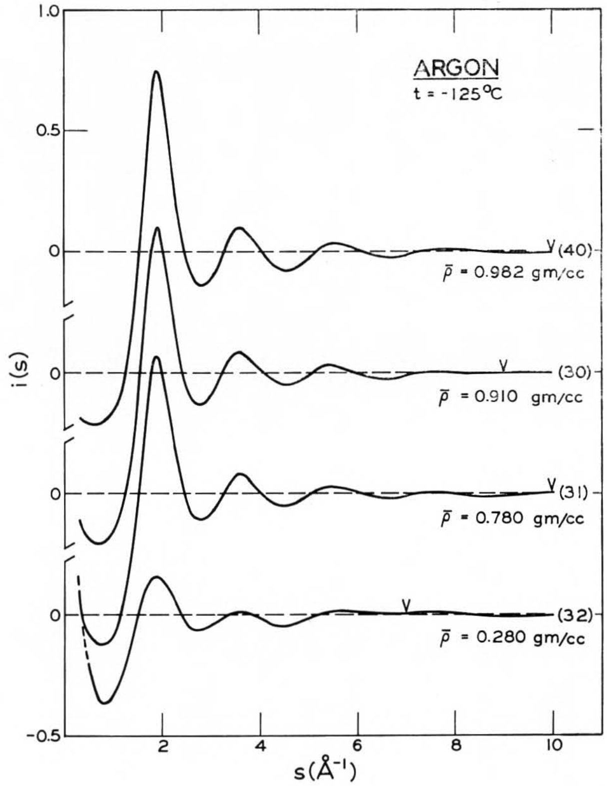


Figure 3

Fig. 3. — The argon intensity function i(s) at t = −125°C.

$$i(s) = I_\theta I_o^{-1} N^{-1} f^{-2}(s) - 1 \qquad (5)$$

$$s = 4\pi\lambda^{-1}\sin\theta \qquad (6)$$

f(s) is the atomic scattering factor for x-rays.

Equation 4 may be inverted by Fourier transformation

$$G(r) = g(r) - 1 = \frac{1}{2\pi^2 r\rho}\int_0^\infty s\, i(s)\, \sin sr\, ds \qquad (7)$$

It is through this expression that experimental x-ray scattering data may be used to determine g(r) or the "net" radial distribution function G(r). The author and his co-workers have been studying the structure of simple fluids, principally argon, for a number of years, and have now completed i(s) measurements at 19 different thermodynamic states. Figures 3 and 4 show i(s) and the corresponding g(r) information for four states of density located upon a common isotherm. Data for other states and extensive details of the experiments are available[2, 3]. In Figures 3 and 4, the damping-out of structural features, for example the number and height of peaks, is apparent in both i(s) and g(r) for states of porgressively lower density. If the fluid "had no structure" (no interactions between particles) then i(s) would be everywhere zero and g(r)

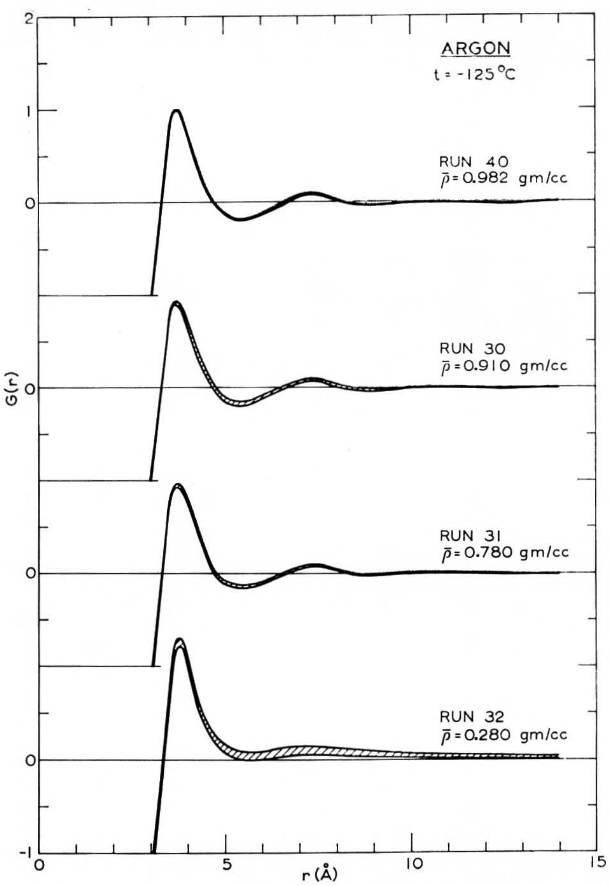


Fig. 4. — The atomic radial distribution function of argon at $t = -125°C$.

everywhere unity. The data shown are convincing evidence of structure or short-range order in the fluid and also a demonstration of the state dependence of that structure.

DIRECT CORRELATION FUNCTION

The direct correlation function C(r) was introduced by Ornstein and Zernike[4] in 1914 in a discussion of fluctuations and related phenomena near critical states. In those initial derivations and in subsequent uses, the direct correlation function has been assumed to short range in general and to remain short range and bounded in the limit as the critical state is approached. The formal definition of the C(r) is mathematical, and the quantity lacks the obvious immediate physical interpretation assignable to the conventional radial distribution function.

The direct correlation function may be defined by the following equation:

$$C(\underset{\sim}{r}_{12}) = G(\underset{\sim}{r}_{12}) - \rho \int C(\underset{\sim}{r}_{13}) G(\underset{\sim}{r}_{23})\, d\underset{\sim}{r}_3 \qquad (8)$$

Fisher[5] provides the interpretation that "the correlation G (r_{12}) between molecules 1 and 2 can be regarded as caused by (i), a direct influence of 1 and 2, described by the so-called direct correlation function, C(r_{12}), which should be short range [essentially having the range of the pair potential u(r)], and (ii), an indirect influence propagated directly from 1 to a third molecule at r_3, which in turn exerts its total influence on molecule 2." Such intuitive explanations are helpful in understanding the behavior of C(r) which is somewhat obscure since Equation 8 involves a convolution integration. However, C(r) still lacks the association with probability concepts or effective densities that normally are assigned to g(r) and related distribution functions. As an example, no simple statement about the behavior of C(r) for small radii can be made *a priori*. This is in contrast to g(r), for which the impossibility of

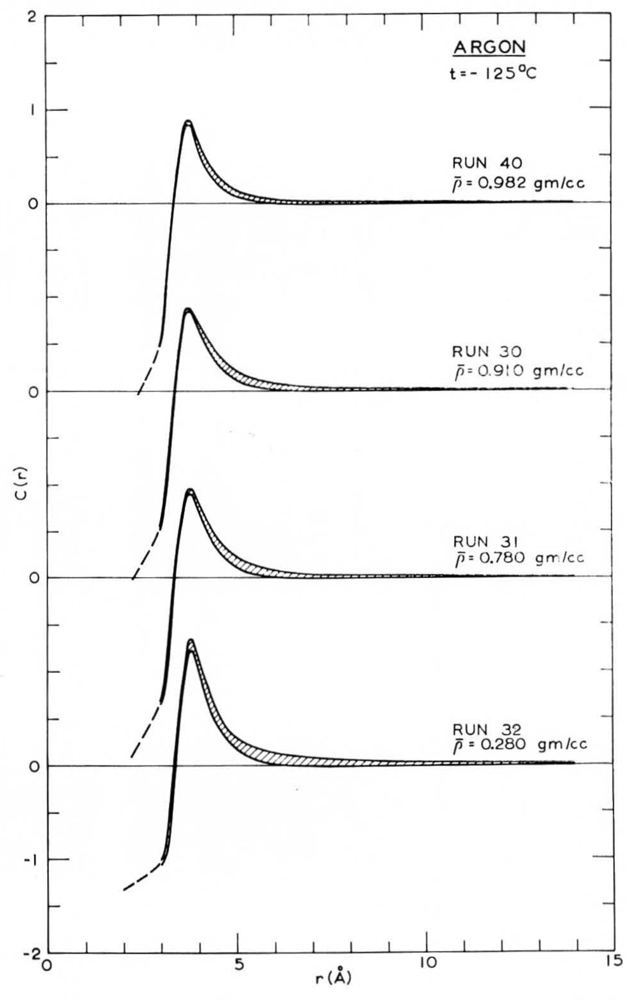


Fig. 5. — The direct correlation function for argon at $t = -125°C$. Run 40, $\rho = 0.982$ g/cc; Run 30, $\rho = 0.910$ g/cc; Run 31, $\rho = 0.780$ g/cc; Run 32, $\rho = 0.280$ g/cc.

multiple occupancy of a point in space leads to the result that g(r) must be essentially zero for $r<d$, where d is some characteristic hard-core diameter.

For monatomic fluids C(r) may also be directly related to the observable intensity of scattered radiation, as was the case with G(r):

$$C(r) = (2\pi^2 r\rho)^{-1} \int_0^\infty si(s)[1 + i(s)]^{-1} \sin(sr)ds \qquad (9)$$

Equation 9 relating C(r) to i(s) is not an independent expression, but is obtained by solving Equations 4 and 8.

The i(s) data obtained in the author's laboratory have been used in Equation 9 to compute C(r) at 19 different states of argon. Figure 5 shows a typical set of data, which might be compared state by state with the g(r) computations shown in Figure 4. It is quite apparent that, even with the uncertainties in both cases, C(r) is definitely more short range than is G(r). Particularly for high-density states there are identifiable second, and even third, peaks in G(r); no such peaks are apparent in C(r), at least not at the level of reliability posed by our uncertainty bands.

USE OF STRUCTURAL DATA TO TEST INTEGRAL EQUATIONS[6]

Of the many existing theories for predicting molecular distribution functions of fluids, two that have gained recent prominence are the Percus-Yevick (PY) approximation[7, 8], and the convoluted-hypernetted-chain (CHNC) approximation[9, 10]. Both of these approximate theories have shown moderately good agreement between predicted thermodynamic properties and experimental values[10, 11]. Most of the methods used to test these theories fall into two groups. In the first group are computations based on relatively simple potential functions, e.g., the hard-sphere model, in which predicted virial coefficients are compared with exact theoretical values[12, 13] or for slightly more complicated potentials, with Monte Carlo results[14]. In the second grouping, more realistic potentials are used, e.g., the Lennard-Jones 6-12, and the results are tested by comparing predicted distribution functions or thermodynamic properties with available experimental data[15]. As far as a test of the basic PY or CHNC theory is concerned, the first grouping suffers because, although the equations may be rigorously tested, the results do not conform to the behavior of any real fluid. In the second group any definite conclusion regarding the applicability of these equations is clouded by uncertainties in the potential function used in the computations. We are suggesting here that it is possible to utilize G(r) and C(r) functions obtained from interpretations of experimental diffraction data to test directly the basic hypotheses underlying these two approximate theories[16].

Liquids often exist at densities comparable to solids, the fluid state lacks the well-defined long-range order of a crystalline solid.

THE PY AND CHNC equations may be derived very simply by considering the Ornstein-Zernike direct correlation function as defined by Equation 8. The derivation of the integral equations is then initiated by introduction of fundamental assumptions regarding the relationship of C(r), G(r), and the intermolecular potential function, u(r). These assumptions are [8, 17].

$$\text{PY:} \quad C(r) = [1 + G(r)]\{1 - \exp[u(r)/kT]\} \qquad (10)$$

$$\text{CHNC:} \quad C(r) = G(r) - \ln[1 + G(r)] - [u(r)/kT] \qquad (11)$$

The usual form of the PY approximation is then obtained by eliminating C(r) from Equations 8 and 10, and the CHNC approximation from a similar treatment of Equations 8 and 11.

If the direct correlation function and the net radial distribution function are known, Equations 10 and 11 provide the most direct test regarding

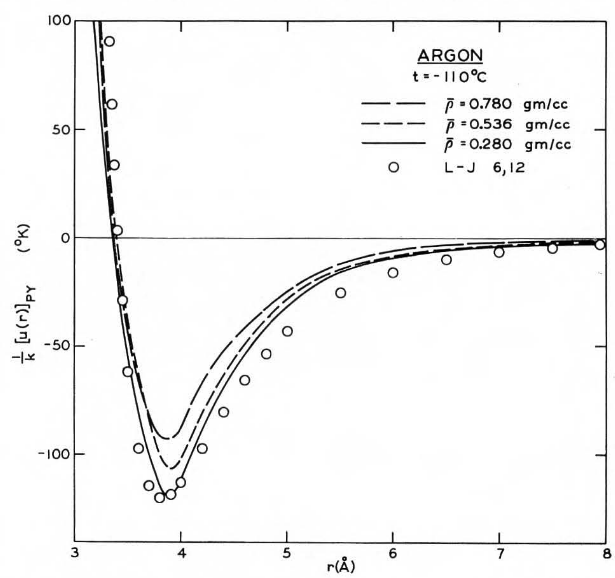


Fig. 6. — Potential-energy functions of argon predicted by the PY hypothesis of Equation 13 for three densities along the −110°C isotherm. The open circles represent the Lennard-Jones 6-12 potential with parameters σ = 3.405° A and ϵ/k = 119.8°K.

Although the dynamic chaos associated with dilute gasses is manifest in dense fluids, the movement of a molecule in a liquid is correlated with the location of its neighbors.

the applicability of these two theories. Moreover, this test is unique in that no further assumptions are required regarding the detailed nature of the potential function. This becomes evident by solving the equations for u(r):

$$[u(r)]_{CHNC} = kT\{G(r;\rho,T) - C(r;\rho,T) - \ln[1 + G(r;\rho,T)]\} \quad (12)$$

$$[u(r)]_{PY} = kT \ln\left[\frac{1 + G(r;\rho,T) - C(r;\rho,T)}{1 + G(r;\rho,T)}\right] \quad (13)$$

If the fundamental PY and CHNC assumptions are correct, these predicted potential functions are required to be independent of temperature and density even though both G(r) and C(r) are state-dependent. This test is direct in the sense that it uses only experimental data and that no assumptions or approximations need be made concerning the nature or the shape of the potential function. The essence of the test is to establish whether or not the predicted potential functions are state-independent.

Using our values of G(r) and C(r) reported in the preceding papers[2, 3], we have performed the indicated computations according to Equations 12 and 13. Figure 6 shows the predictions along the −110°C isotherm. Contrary to the fundamental PY hypothesis, the predicted potential function is not independent of state. As the argon density is increased at constant temperature, the depth of the well does not remain constant, but decreases significantly. On the other hand, at constant density there is no conclusive temperature effect within our experimental uncertainty. This same behavior is observed for the other isotherms and isochors of this study. For comparison, the Lennard-Jones 6-12 potential function with parameters $\sigma = 3.405$ A and $\epsilon/k = 120°K$ is also shown on the figure. Very similar behavior is revealed for the CHNC approximation.

THIS SIGNIFICANT DENSITY effect on the predicted PY potential function, along with the negligible temperature effect over the range studied, is shown more convincingly in Figure 7, where the depth of the well of $[u(r)]_{PY}$ is plotted against the argon density for all 13 states of our investigation. The symbols on the graph are slightly displaced from the five measured isochors in order to show our estimate of the experimental uncertainty at each state. This plot clearly shows

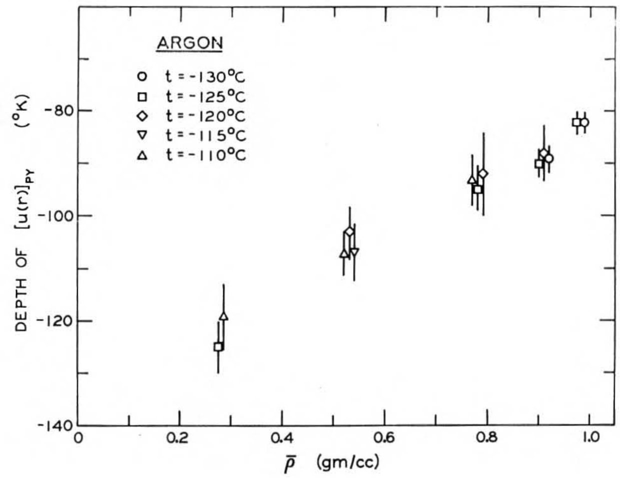
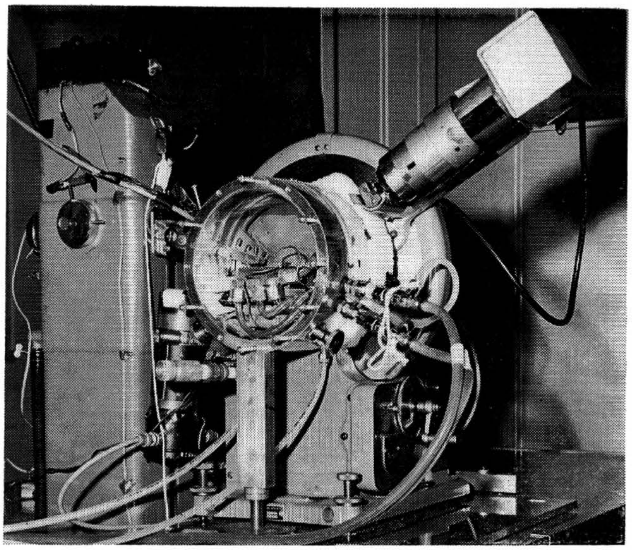


Fig. 7. — Depth of the argon potential well as predicted by the PY hypothesis of Equation 13 as a function of density and temperature.

the failure of the fundamental PY hypothesis to produce a potential function which is independent of state.

In light of these results, we conclude that the original PY and CHNC approximations are in contradiction with experimental facts for argon. In seeking to interpret these facts, we offer the following suggestions: in order to satisfy the PY and CHNC approximations, and also to predict a distribution function that agrees with experiment, apparently a pair-potential function is required which varies with state, primarily with density. Accepting for the moment the validity of these underlying hypotheses, one may conclude that there is a significant nonadditive contribution to the true intermolecular potential. As the atomic packing becomes more congested by increasing the density, the many-body interactions become increasingly important with a net result of decreasing the effective two-body potential energy. This nonadditive contribution has been estimated to be as high as 15% to 23%, and in the same direction as we observe here[18, 19].

On the other hand, if the nonadditive forces are strictly negligible, the results of our test show that the PY and CHNC approximations require additional terms in order to produce results which are more nearly in agreement with experiment. This approach has been taken in the development of the so-called PY2 and CHNC2 approximations [20, 21], and most recently by Rowlinson[17], who incorporates an empirical state-dependent factor in the original PY and CHNC hypotheses.



Equipment for X-ray diffraction studies of liquids.

Since the PY approximation is known to be valid in the low-density limit, the data plotted in Figure 7 suggest that the experimental results presented here can be used to obtain a "true" two-particle intermolecular potential function. To accomplish this, we make the pragmatic assumption that the effective PY u(r), as shown in Figure 6, is in reality the product of the true zero-density potential $u_0(r)$ and a state-dependent function $\Phi(T,\rho)$. From the data shown in Figure 7, this state-dependent function has been estimated by neglecting any temperature effiects and fitting a least-squares straight line to the data points. The zero density u(r) was then obtained from the following equation, with ρ in grams per cubic centimeter:

$$u_0(r) = [u(r)]_{PY}(1 - 0.394\rho)^{-1} \quad (14)$$

The results of these computations are shown in Figure 8. The band shown in this plot was constructed so that it encompasses the estimated $u_0(r)$ function for all of the 13 states. The parameters of this potential function are $\sigma = 3.38 \pm 0.06$ A, $r_0 = 3.86 \pm 0.03$A, and $\epsilon/k = 134 \pm 10°$K. Considering the nature of the assumptions involved, these results are in reasonable agreement with current estimates of the potential-energy function of argon.

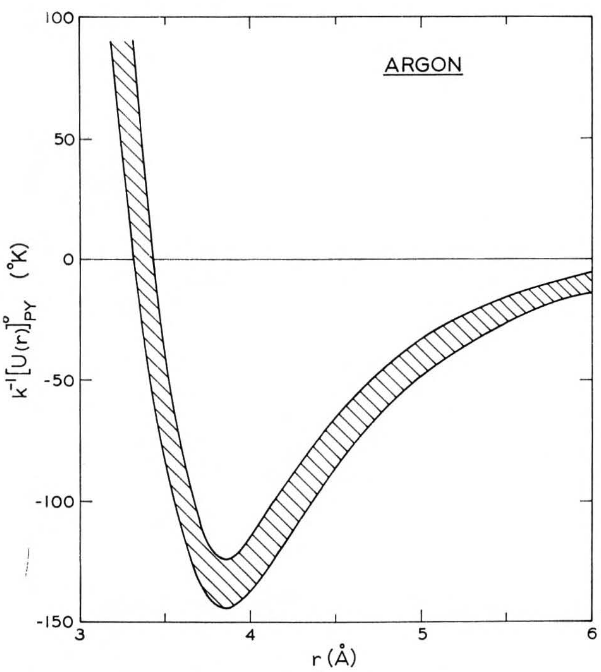


Fig. 8. — The extrapolation zero-density potential-energy function of argon as computed from Equation 14.

The second part of Professor Pings lecture will be published in a later issue.

REFERENCES

1. T. L. Hill, Statistical Mechanics, (McGraw-Hill Book Co., New York, 1956.
2. P. G. Mikolaj and C. J. Pings, *J. Chem. Phys.* **46**, 1401 (1967).
3. P. G. Mikolaj and C. J. Pings, *J. Chem Phys.* **46**, 1412 (1967).
4. L. S. Ornstein and F. Zernike, *Proc. Acad. Sci.* (Amsterdam) **17**, 793 (1914).
5. M. E. Fisher, *J. Math. Phys.* **5**, 944 (1964).
6. Much of this section has been reported in Reference 3.
7. J. K. Percus and G. J. Yevick, *Phys. Rev.* **110**, 1 (1958).
8. J. K. Percus, in *The Equilibrium Theory of Classical Fluids*, H. L. Frisch and J. L. Lebowitz, Eds. W. A. Benjamin, Inc., New York, 1964, p. II-33.
9. E. Meeron, *J. Math. Phys.* **1**, 192 (1960).
10. J. M. J. Van Leeuwen, J. Groeneveld, and J. de Boer, *Physica* **25**, 792 (1959).
11. D. Henderson, *Ann. Rev. Phys. Chem.* **15**, 31 (1964).
12. E. Thiele, *J. Chem. Phys.* **39**, 474 (1963).
13. P. Hutchinson and G. S. Rushbrooke, *Physica* **29**, 675 (1963).
14. A. A. Broyles, S. U. Chung, and H. L. Sahlin, *J. Chem. Phys.* **37**, 2462 (1962).
15. A. A. Khan, *Phys. Rev.* **134**, A367 (1964); A1260 (1964).
16. P. G. Mikolaj and C. J. Pings, *Phys. Rev. Letters* **15**, 849 (1965).
17. J. S. Rowlinson, *Mol. Phys.* **9**, 217 (1965).
18. L. Jansen, *Phil Mag.* 8, 1305 (1963).
19. N. R. Kestner and O. Sinanoglu, *J. Chem. Phys.* **38**, 1730 (1963).
20. J. K. Percus, *Phys. Rev. Letters* 8, 462 (1962).
21. L. Verlet, *Physica* **30**, 95 (1964).

ATTRITION OF CHE UNDERGRADS

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Oran L. Culberson received the BSChE from Texas A&M and, after service as an infantry officer in WW II, received the MS and PhD (1950) from the University of Texas. He spent three years with Gulf Research and Development Company in process design and economic analysis. In 1953, he joined Celanese Corporation in the same capacity, subsequently moving into managerial positions in computing and operations research. Dr. Culberson is Professor of Chemical Engineering at the University of Tennessee.

Attrition of chemical engineering undergraduates is a continuing problem at most institutions. If attrition of students could be reduced, the number of chemical engineers graduating and entering industry could be significantly increased. For this reason, the Council of AIChE asked the Education Projects Committee to identify the causes of high attrition and to review techniques that have been used to increase retention of undergraduate engineering students.

Any in-depth study would require personal interviews with dropouts over a period of time to determine the basis for their decision. Instead of attacking this formidable task directly, the Committee chose to seek better information about current attrition rates and prospects for improvement by surveying all chemical engineering departments in the United States by means of a questionnaire. There were responses from 85 schools.

The first item on the questionnaire asked for current retention rate as the percentage of entering freshmen who achieve the Bachlor's degree. It must be recognized immediately that there is much "noise" in such a number. At many schools, students do not identify their major to be chemical engineering until their sophomore or even junior years. At almost all schools, students transfer from other universities and junior colleges and, to a small extent, from other colleges of the same university. Some students take more than four years to complete the BS. Despite the inaccuracies inherent in these reported retention rates, they were presented in Figure 1. Nine schools reported their rate as "unknown." The mean rate for the 76 other schools is about 53%.

The department heads were also asked to give opinions as to whether their rate "could be" or "need be" improved. Their responses to each of these items took three forms": "Yes," blank, and "No" in the five combinations shown in Table 1. As one would expect, the schools with the better retention rates feel less need or possibility for improvement. It should be noted that some schools with low retention rates (e.g., 30% and 45%) replied in the "Not" categories; these were state universities who felt they were primarily at the mercy of having to accept all applicants.

The data from the questionnaire were processed in an analysis of variance to determine the dependency of retention rate on:

TABLE I — RESPONSES TO WHETHER RETENTION RATE "COULD BE" AND/OR "NEED BE" IMPROVED

	Number Respondirg	Range of Rates, %	Mean Rate, %
Could be	30	25 - 80	53
Need be	12	25 - 74	47
Could be and Need be	19	18 - 77	46
Could not be	2	45 - 85	65
Could not be and Need not be	7	30 - 90	61

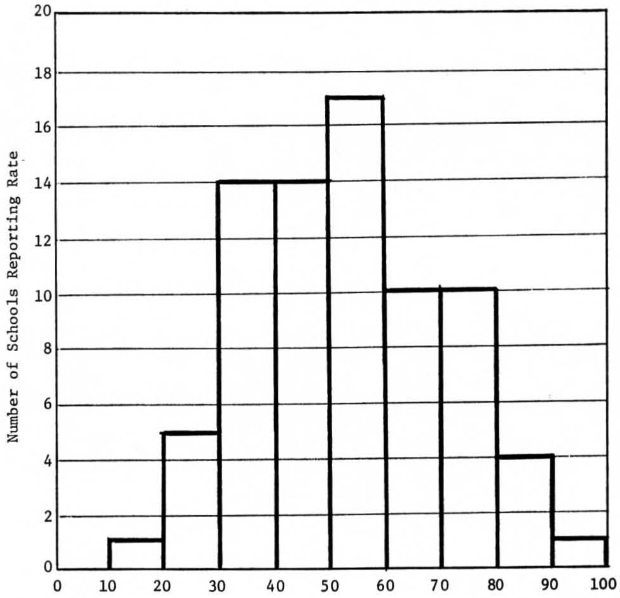
(A) The nature of the school with respect to its being public or private.
(B) The year in which the student takes his first course in the chemical engineering department.
(C) Interaction between factors (A) and (B).

The analysis showed a very strong relationship between retention rate and nature of the school, with private schools having a significantly higher retention rate. There is a probability of only about 0.001 that the observed difference in rates between public and private schools could have occurred by chance alone. No significant relationship existed for retention rate and year of first chemical engineering course, nor for the interaction. This lack of relationship to first course is some what at odds with other information to be presented later.

Some additional comment is probably in order regarding the data. First, it should again be noted that accurate retention rate data are extremely difficult to compile. Undergraduates come and go almost continuously, and few departments have adequate means of keeping such records. Even though this be so, it is reasonable to

FIGURE 1

DISTRIBUTION OF RETENTION RATES AMONG REPORTING SCHOOLS



As % entering freshmen achieving B.S. in Ch.E.

expect that the figures reported on the questionnaires have some relative validity. For example, one would expect a department reporting a 35 percent retention rate to be experiencing a de facto rate which is less than that of a department reporting a 75 percent rate. The data item of most dubious accuracy is the year the first chemical engineering course. These data were compiled from school catalogs. The question arises as to whether the catalog information is in phase with and applicable to reported retention rate. A school which has just instituted a freshman ChE course will probably not observe any possible consequences for some years hence.

Figures reported by University of California at Berkeley and Bucknell University indicate that those departments attempt accurate records on undergraduate flows:

	Berkeley	Bucknell
Achieved BSChE	58%	45%
Transferred to other majors	12%	32%
Withdrew for academic reasons	18%	14%
Withdrew for other reason	12%	9%

We shall see later that considerable additional information of this kind is available for engineering undergraduates as a whole.

The questionnaire also contained a "Comments" section, to which there was substantial but not universal response. The comments dealt primarily with causes for students' dropping out, and actions which might be or have been taken to improve the situation. Table II summarizes the responses, where it can be seen that the dominant causes of dropping out are:

- **Inadequate college counselling and early contact with the ChE faculty.**
- **Inadequate pre-college orientation leading to wrong choice of major field of study.**
- Quality of students.

The actions cited by the respondents as having been found effective in improving retention correlate very strongly to removing the causes in order of importance given in Table II. That is, the most effective means of improving retention have been found to be improved college counselling and contact with ChE faculty, improved precollege orientation, etc. A majority of the comments confirmed the Berkeley and Bucknell observations that many or most ChE dropouts transfer to other disciplines and graduate. (It is most interesting to note the high degree of correspondence between the comments offered by the department heads and the observations of Professor J. C. R. Turner of Cambridge University on his year of teaching at the University of Texas.[1]

TABLE II
CAUSES OF ATTRITION STATED BY RESPONDENTS

Item	Number Citing
Quality of students	12
Lack of funds	1
Family background and problems	1
Inadequate pre-college orientation leading to wrong choice of major	13
Inadequate reading ability	2
Changed career goals	1
Inadequate college counselling and early contact with ChE.	17
Nature of chemistry courses	7
Nature of math courses	3
Raiding by core repartments in early years	2
Inflexibility of ChE curriculum	1
Inadequate interest and self-discipline	8
Poor image of chemical engineering:	
a) Financially	1
b) Social mindedly	3
c) As a profession	2

The department heads were asked whether the undergraduate attrition problem had been studied quantitatively at their schools. Six identified studies for which some kind of report was available: Carnegie-Mellon, Cornell, Michigan State, New York University, Purdue, and the University of Washington. These will be summarized here.

Professor Lebold observes that first semester performance is the best single predictor of an engineering students' performance.

Michigan State Study

Probably the most exhaustive of the six studies is the one performed at Michigan State, and which also included students at Northwestern and Wisconsin.[4] All male students who entered engineering in 1963 at the three universities formed the study population. A sample was created comprised of two groups: persisters and non-persisters. The non-persisters were students who canged majors to non-engineering curricula during the freshman or sophomore year while earning at least a "C" cumulative grade point average. The persisters were students from the population whose academic potential individually match that of a non-persister but who persevered in the pursuit of their engineering degree. Questionnaires and taped interviews were used to elecit information.

Statistical analysis of the questionnaire data revealed the following significant relationships between the two groups:

- The non-persisters tended more to have come from lower middle class homes and to have graduated from central city or non-metropolitan homes.
- Non-persisters attached more importance to social status and prestige and the opportunity to work with people rather than with things.
- Non-persisters selected engineering as a career at a later age than did the persisters.

The interviews led to the following most noteworthy findings:

- Students chose engineering majors for a wide variety of reasons, the most common of which were:
  a. Success and interest in high school science and mathematics courses.
  b. Encouragement towards engineering received from fathers, brothers, relatives and friends.
  c. Interest developed while pursuing mechanical or scientific hobbies and leisure-time activities.
  d. Extrinsic features such as monetary benefits, prestige and glamor of the field.
  e. Belief that an undergraduate engineering program would provide a sound background for a career in some other field.
- High school students, teachers, guidance counselors and parents evidently know little about the work of the professional engineer or the nature of the educational programs leading to such careers.
- Persisters and non-persisters are frequently dissatisfied with the highly structured, inflexible engineering curricula.
- Certain required courses, especially mathematics, antagonize many students and reinforce misconceptions of the nature of engineering work.
- Sophomore engineering courses are welcomed and enjoyed by most students.
- Friends and acquaintances of respondents play important roles in their decisions to continue their engineering studies or change to other curricula.
- Large proportions of both persisters and non-persisters report passive, procedural relationships with their academic advisers as being typical throughout their college years.
- Non-persisters cite a variety of reasons for changing out of engineering. Those most frequently mentioned include:

  a Students had mistaken impressions of the engineering field.
  b. Students were dissatisfied with the content of the required courses.
  c. The student's scholastic performance did not meet his expectations.
  d. Students adopted new career goals.
  e. Students felt they could find more appropriate routes to the non-engineering goals they had originally established.
  f. Students wanted to explore other career opportunities.

Eight recommendations were offered as a result of this study, concentrating on better communication of the nature of engineering work to high schools and to university undergraduates, and on better contact between engineering professors and students, particularly freshmen. Professor M. H. Chetrick stated on his questionnaire that Michigan State has invested considerable time and effort in the study of attrition and in the establishment of programs for its reduction, but that while they are pleased with these programs in general, they continue to be frustrated in not having been able to influence attrition significantly.

New York University Study

A brighter note comes from New York University where it is felt that significant reduction in the loss of freshman engineers is being achieved[5,6]. Four programs seem to be responsible. First, all prospective engineering freshmen are interviewed before admission, apparently by engineering faculty or engineering alumni. Second, all freshmen take an examination in mathematics before classes begin and are placed accordingly in one of four plans. Third, treatment of freshmen has been personalized and an atmosphere created wherein freshmen become confident that they can easily reach a ready and sympa-

(Continued on page 50)

ChE laboratory

A SYSTEMS APPROACH

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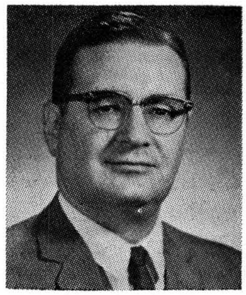

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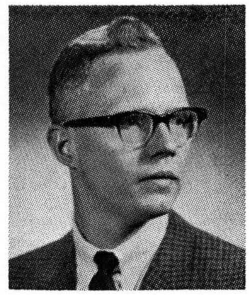

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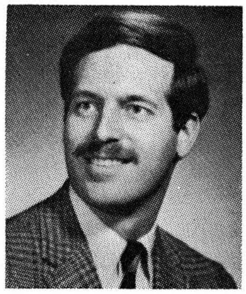

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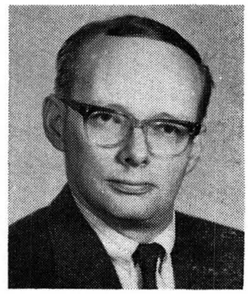


. . . Thygeson

Chemical Engineering Laboratories have proved traditionally less "cookbook" than other engineering laboratories, but they have tended to suffer none the less from becoming stereotyped as to their objectives and the types of experiments run. Mostly laboratories have been used to complement traditional textbook material by attempting to illustrate the application of theory to experiment. In the course of a major curriculum revision at Drexel we had the unique opportunity, and the strong support of our administration, of NSF and of industry, to make a break with the past and to develop a new approach to chemical engineering laboratories.

We have changed the objective of the laboratory from one of complementing lectures to one of supplementing them. We believe that the students in their junior and senior years are sufficiently mature to apply principles already learned to the analysis of laboratory data and to forge beyond what they had received in class to develop new ideas so as to deepen that analysis. We feel that if the student understands that he has certain specific responsibilities in the course to educate himself, laboratories might be approached with more curiosity and enthusiasm than in the past. Our goals were to develop a laboratory which would require the students to (1) study and apply principles not taught in class as well as to use those previously learned; (2) analyze problems such as might arise in pilot plant studies, i.e., a realistic engineering situation, (3) be challenged sufficiently that the experience would be enjoyed rather than endured.

From our early discussions evolved the idea of having the student approach chemical engineering from a systems viewpoint. This was consistent with an earlier decision to introduce to the elementary stoichiometry course use of flow sheets as teaching tools. We want students to learn early that material and energy balances around units are related to other sections of a process flow sheet. Consequently, it was logical to design a laboratory in which units could be run as an integrated system or as small subsystems, and thus provide an opportunity for students to study the interrelationships. With such a system both dynamic and steady-state studies are possible. We felt that the student would be able to progress from running individual units to running combinations of units to eventually running the entire line. The line not only had to meet our educational objectives but also had to remain within the constraints of our budget.

THE LABORATORY FLOW SHEET

What evolved for our first processing system is the flow sheet of Figure 1. This is an inorganic processing line in which a mixture of soluble and insoluble salts is separated and the products refined in units under automatic control.

The mixture is fed from an automatically controlled, vibrated feed-hopper to a mixing tank where it is slurried. The mixing tank is provided with density, level, and temperature controllers. The tank contents are mixed by means of a side-entering agitator. This is the one feature of the subsystem which is not under automatic control. Agitation rate, however, can be manually varied. The water for the mixer comes from two heat exchangers which are automatically controlled.

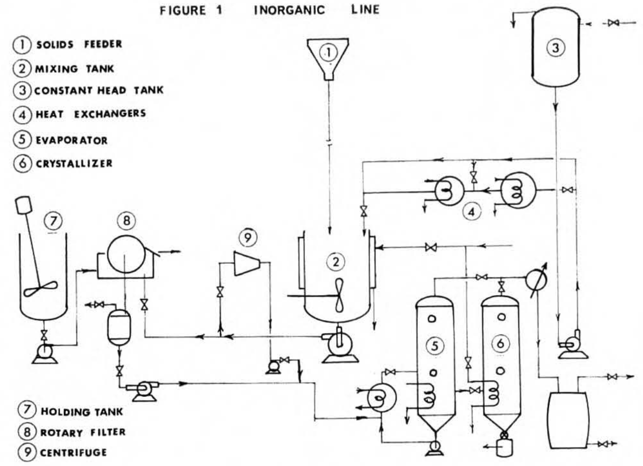
John R. Thygeson did his graduate work at Drexel. After a stint in industry, he returned to graduate school at the University of Pennsylvania where he obtained his MS in ME and PhD in Chemical Engineering. Thereupon, he joined the Chemical Engineering Department at Drexel where he is currently an associate professor. His research interests are in separation theory and applied optimization.

Dr. Elihu D. Grossman has his PhD from the University of Pennsylvania and his BSChE and MS from Drexel. Research interests are in thermodynamics and transport properties of mixtures, drying theory and applications, and agricultural pollution problems. He is currently Associate Professor of Chemical Engineering at Drexel.

Dr. Robert Heidemann is a graduate of Washington University. He joined the Chemical Engineering faculty at Drexel in 1963. He is currently Associate Professor of Chemical Engineering at the University of Calgary. His research interests are largely in the area of automatic control.

Lester Kershenbaum did his undergraduate work at Cooper Union and his graduate work at The University of Michigan where he received his PhD in 1964. He is currently Assistant Professor of Chemical Engineering at Drexel. His research interests are in the areas of kinetics and thermodynamics.

FIGURE 1 INORGANIC LINE



The slurry can be pumped to either a rotary vacuum filter, or to a continuous centrifuge, or it can be fed to an intermediate holding tank for future processing. The rotary filter is designed for washing of the insoluble cake as well as for removal of filtrate. The solid cake can be manually transferred to either a tray drier or to a fluidized bed drier. The cake may be pretreated before drying if the students decide that such treatment is necessary. The filtrate or centrifugate can be pumped either to intermediate storage or directly to a double effect evaporator. The first effect is for concentrating the solution and the second effect is an evaporator-crystallizer. Both effects have temperature, level, flow, and pressure control. As crystals of the salt build

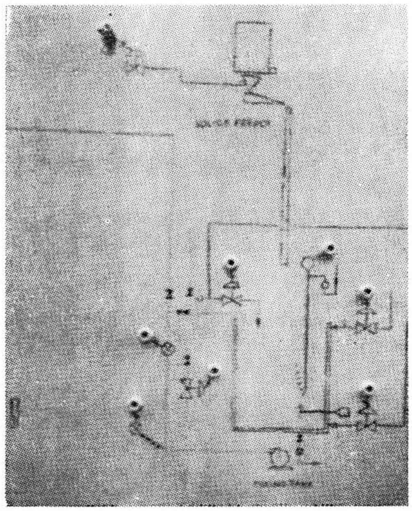


Figure 2. Graphic Panel View

up within the conical bottom of the crystallizer they can be manually dropped into a salt catch for later removal and drying.

We have, for reasons of economy as well as for educational value, designed the panel board (Figure 2) for maximum flexibility in the use of equipment. Sensing elements can be plugged into any of several controllers, which in turn can be connected through flexible tubing to stations on the graphic panel which represent — and are connected to — the final control element. Recording equipment for temperatures, flows, levels, pressures, etc. is at the right of the panel board; controllers at the left. Our control elements are mostly pneumatic. In addition there is a magnetic flow meter in the line, some thermocouple elements, and some electrical to pneumatic conversion units. We also have available, when dynamics experiments dictate their use, either a two channel or a six channel oscillograph for more detailed study of transients.

Figure 3 illustrates how flexibility was attained in the instrument installation for the Inorganic Line. The equipment sketched is the jacketed mixing tank. In the processing scheme, it is the unit where the solids are introduced, the soluble salt is dissolved, and the insoluble one is slurried. The equipment of Figure 3 is used in the intermediate laboratory course for heat transfer experiments. It is piped to permit hot water, steam, or cold water to enter the jacket and to use either hot or cold water as the processed fluid. A filled-bulb temperature transmitter is installed in the pumped recycle line and diaphragm motor control valves are installed in the jacket inlet water and steam lines.

The level control instruments are useful for steady-state experiments on heat transfer (during the second laboratory course) and for studying the dynamics of level control (during the third course). A bubbling-type level transmitter is employed as the source of the level signal for control, and control valves are installed in both inlet and outlet process fluid lines. The control valves can be used in flow control studies of liquid to and from the tank. (Flow transmitters are not shown in Figure 3.)

OPERATION OF THE LABORATORY COURSES

We realized that students would not be able to operate and analyze the overall system unless they first had some understanding of its subsystems. Consequently, the first lab in the three term sequence is devoted to experiments which develop skill in manipulation of equipment and analysis of data. Students learn how to use measuring equipment, how to safely operate pumps, heat exchangers, mixers, etc. There are a few bench scale transport experiments interspersed with an introduction to larger scale experimentation on the equipment in the line, e.g. conduction in rods, determination of diffusivities.

During the second laboratory, students investigate both the dynamic and steady-state behavior of individual processing units. Use is made of the instrumentation and control equipment so that the students learn of the interactions of the controls and the process.

With the wide variation possible in experiments, no two student groups need be asked to study the same phenomenon. As a consequence, the lab has more of the character of small scale research projects, forcing the students to rely more on themselves than they would in a conventional setting. They gain confidence in their ability to analyze and solve new problems. Control of a double-effect evaporator, and interrelationship of variables such as level control and throughput have real meaning to them so that when they advance to the final laboratory in the last term of their senior year, the students are ready to meet the more challenging problems presented there.

Since one purpose of the final laboratory course is to involve the student in a relatively large scale project which requires some ingenuity and originality on his part, we have avoided establishing a specific set of experiments. Rather we have some interrelated units of processing equipment and their associated instruments for study. The student has the responsibility to specify the control loop or loops he will study. He then is expected to analyze the various components of the control loop to obtain the appropriate differential and algebraic equations, to linearize the equations if necessary, to predict, using linear control theory, the transient behavior of the equipment under control, and to prove his model and mathematics by experimentation on the equipment. He is expected to have a full understanding of the control hardware involved including valves, sensing elements, and controllers.

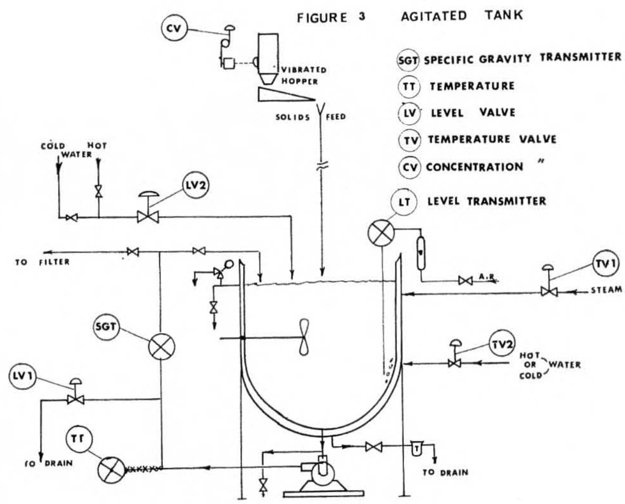


FIGURE 3 AGITATED TANK

As an example a group might be asked to determine the system control characteristics for the water preheat exchanger operating under proportional control. The group would be expected to prepare an experimental plan, a mathematical model, and to decide what measurements were needed to test their model. They must explain any discrepancies between their idealized description and their experimental results.

Every effort has been made to keep instrument application flexible so the equipment could be run in a variety of ways. Initially the student may not wish to operate under closed-loop control at all. In that case, control loops need not be closed and sensing instruments, transmitters, and recorders are still available for steady-state measurements. Certainly the availability of these instruments makes steady-state operation easier. It has proved, for example, especially useful to have level control instruments available for operating the rotary filter and the evaporator. The level of drum submergence in the rotary filter is an important parameter in the equipment opera-

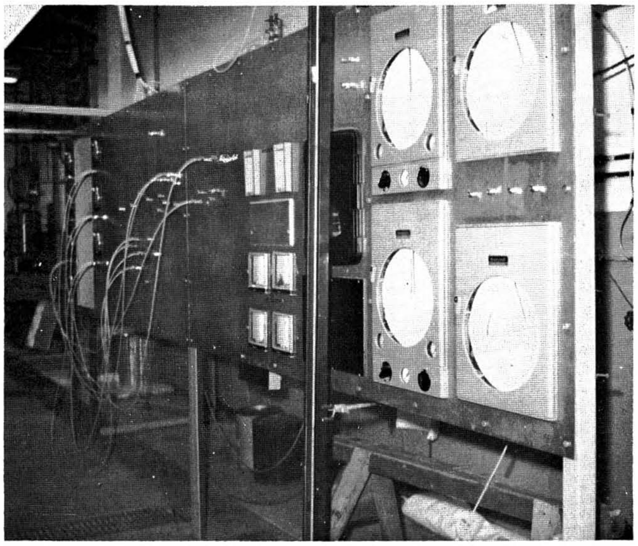


Figure 4. Panel Board View

tion and it is difficult to maintain it fixed without the controls. In the evaporator level is only a secondary variable, but matching inlet flow to evaporation rate is essential for accurate mass and energy balances to be performed. The equipment responds so slowly that manual rate adjustment cannot be relied upon; effects of changes can be observed only after long times. To use the controls in these cases, the students need have only a minimal understanding of the hardware and no real knowledge of theory.

From the study of single units the student groups progress to operation of linked units. They quickly discover, for two or more pieces of equipment to be operated in sequence, that control devices are essential. There are too many interrelated variables to be adjusted for the students to obtain steady-state in a reasonable time without the aid of instruments. Suppose that the filter and evaporator are to be operated in series so that the filtrate, which contains a soluble salt, is to be fed to the evaporator-crystallizer where the salt will be removed. In steady-state, the filtrate production rate has to match the evaporation rate and all levels will be constant. The students have three or more variables to manipulate; typically, slurry rate to the filter, filtrate feed rate to the evaporator, and the evaporator steam valve position. Achieving steady-state in this situation without controls would be very difficult and time consuming.

Most groups also do steady-state analyses of their processing units in order to obtain necessary data and understanding for running the processing line.

Once the students have reached the point where they are able to handle the operation and analysis of two units in sequence, meshing of their projects begins. One group, for example, may have been collecting operating information on the feeding of mixed salts to the slurrying tank (data such as feed rates, specific gravity, agitation requirements, pumping, etc), Another group would have been collecting information on the rotary filter, its efficiency, cake moisture, residual solubles, drum immersion, filtrate rate, drum speed, etc. A third would have been studying the influence of level, flow rate, vacuum level, temperature difference, steam rate, etc. on evaporator operation. From the data obtained from two or three weeks of experimentation and analysis, the individual groups would have determined feasible operating limits for the unit which was their responsibility. The student groups then meet with each other and decide on the operating details for running the entire line to manufacture product.

It is worth noting here some special features of the mixture of salts which are both the raw material and the products of our processing line. The insoluble is calcium carbonate, chosen because it has good filtering characteristics, is relatively non-abrasive, and is cheap. The soluble salt is sodium sulfate, chosen on the basis of its relatively low corrosive effects on the equipment and its low price. It has the added educational benefit, however, of forming a series of hydrates which complicate its handling when removing it from the crystallizer. In our system the crystallizer is operated around 90°F which, the student soon finds out by consulting the phase diagram, results in anhydrous sodium sulfate as product. However, if the product is not immediately centrifuged upon removal from the salt catch and dried, the mother liquor provides enough water for decahydrate to form as the temperature lowers. The result is a very hard lump that can only be broken by a hammer.

It requires about one week of joint operation before the groups learn how to coordinate the operation of the individual process units so as to make product. The line has been run for several hours at steady-state. Once the salt catch fills it is very difficult to remove product without severe upset to the system so that steady operation is limited by this factor. Perturbations of feed flow rate, steam flow, level in the evaporator have all been carried out and the response of the system determined. The large capacitance of the equipment relative to the upsets imposed showed the processing line to be very stable.

Since our senior classes tend to be large (40-50 students), we allow some groups with the inclination to do so to study complex control problems rather than to run the line. This is possible because of the flexibility built into our instrumentation scheme. We deliberately purchased some additional control equipment whose main function was to make available automatic control loops beyond those needed simply to study the equipment. The heat exchangers, for example, have such capacity.

While the groups studying advanced control problems may not be operating more than a subsystem of the processing line, they are constantly aware that their experimentation is being done on operating equipment and in that sense they are making a contribution to a better understanding of how the line operates and how that operation might be improved.

DESCRIPTION OF CONTROL EQUIPMENT

All of the installed instruments either generate or are operated by 3-15 psi pneumatic signals. The leads from transmitters and to control valves are all brought to a panel board where a schematic of the equipment is drawn. A photograph of a portion of this panel board is attached as Figure 4. Connection can be made to any of the instruments at the front of the panel board through quick-disconnect pneumatic fittings.

The transmitter outputs are, in addition, connected permanently to strip chart recorders mounted in the panel board. A continuous record of the transmitted signals is thus available to students for their analysis. Some channels on the recorders are left free for students to trace intermediate signals in control loop, such as valve position.

As the equipment confronts the students, there are no completed control loops (e.g., as indicated by the schematic of Figure 3,), Controllers are installed so that adjustment of proportional band, reset rate, or derivative time can be made from the front of the panel. Several manufacturers are represented. All the controllers have indicating control stations and all have a 3-15 psi signal. Each, therefore, is compatible with each instrument installed with the equipment. Access to the controller receiver and to its output signal is available at the front of the panel board through quick-disconnect fittings.

The student is able to complete the control loop he wishes to study by connecting, at the front of the panel board, the appropriate transmitter output to the specific controller desired and by connecting the controller output to the control valve that is to be manipulated. Any controller may be used in any control loop; any transmitter may be employed in manipulating any valve.

STUDENT RESPONSE

The response of our students even in the early stages when the line had to be made operable has been gratifying. The first classes, whose task it was to make things work, had the attitude that they were pioneers in a new approach to chemical engineering and worked long hours to carry out their assignments, to find out what the difficulties were, and to make suggestions on how to correct them. The next group of students who ran the line as individual units were enthusiastic about their laboratory work. They approached it with an enthusiasm not seen in a more routine course. They did the job and they are doing the job of digging out those things they have not been taught but which they need to know.

In general the students are finding the laboratory a real learning experience and not just a routine chore to be endured and gotten out of the way with a minimum amount of effort. Those students who have run the system as a complete line have had a sense of accomplishment that usually most students do not get from chemical engineering or any other undergraduate laboratory. They have had the opportunity, the excitement, and the satisfaction of running a purposeful operating system and of learning how the parts of it interact, and how they can make a product. The students look upon the lab as a challenge to be met instead of an affliction to be suffered.

PROBLEMS

Of course, we had some problems which arose during the design, construction and debugging phases of the laboratory, as well as some which have appeared with operations. For example, during design many changes were made in the flow sheet in order to match our ideas with our budget.

Another problem which caused some concern was to minimize hold-up in pipelines and to have pipe runs as short as possible consistent with the scale equipment available to us (50 to 100 gallons) and still have a realistic system. Another constraint is having enough space between equipment units for students to move and do their jobs safely. The spacing is largely controlled by the floor plan of a building already erected. We were able to overcome these difficulties without significant sacrifice to the educational concepts.

During the initial phase some final control elements had to be relocated because system response was too slow. Some minor piping changes had to be made in order to accomodate flow rate and pumping requirements.

CONCLUSIONS

- A systems approach to laboratory can be made to work successfully even under the constraints of curriculum limitations and available time.
- Student acceptance has been excellent and the levels of learning high.
- The cost in faculty time has been great but the benefit to the undergraduate student has been worth it.
- As a consequence of this faculty investment in time and the student enthusiasm for the concept, overall student morale within the department has improved.
- Response from both visiting educators and industrial people has been universally favorable.

The results have encouraged us to complete and to improve our original concept for an organic processing line. The students will study different interacting operations including those involved with chemical reactors and kinetics.

We believe that the students participating in Drexel's laboratory will graduate with a firm appreciation of the problems of running an entire processing system. We especially feel that those students who go into design and research will have benefitted by knowing something about systems problems and the interactions of subsystems with each other and with the men who must run them.

ACKNOWLEDGMENTS

The plan for the laboratory was an outgrowth of the philosophy of Dr. Charles E. Huckaba who was at the time department chairman. With his basic ideas, enthusiasm and assistance the support of the National Science Foundation and of the Institute administration was enlisted in the project.

ChE curriculum

CHEMICAL ENGINEERING EDUCATION IN WESTERN EUROPE

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Charles Barron received his chemical engineering education at Clemson University and the University of Virginia. He taught at Tulane University for five years, and he spent the academic year, 1967-68, as a Fulbright-Hays lecturer at the Catholic University of Louvain, Belgium. The following year he joined the faculty of the University of Virginia. His research interests are in the area of homogeneous catalysis and chemical reactor analysis.

In thinking of curricular reform, which seems to be a never-ending chore, it is worth attending to trends that arise and evolve in circle other than our own. With this in mind an attempt will be made to discern directions in which chemical engineering education in western Europe is moving. Many ideas on this subject were presented and discussed at a meeting held in Churchill College, University of Cambridge, early in July, 1968, under the sponsorship of The European Federation of Chemical Engineers. Several of the key points presented at that meeting will be cited, and implications and conclusions will be drawn as they are relevant to the educational scene in the United States. No attempt will be made to review all of the discussion from this meeting. The teaching of chemical engineering within the educational structure of the western European university has developed from a different tradition than that in the United States. If this difference can be identified at all, it is in a stronger affiliation with industrial chemistry.

CURRICULAR CONCERNS

The tone of the curricular considerations was set in the meeting to which reference was made earlier by comments from Professor Sorgato of the University of Padua, Professor Le Goff of the University of Nancy, and Professor Danckwerts of the University of Cambridge.

Professor Sorgato emphasized the importance of minimizing over-specialization and descriptive subjects in the curriculum and went on to add, "One characteristic of our time which will have more and more importance in the future is the fact that on the one hand the technician must often commit himself entirely to the resolution of very particular problems, understood only by a restricted circle of specialists, while on the other hand, he must just as often concern himself with complex problems that involve disciplines that are far from the field of his specific interest." His conclusion was that any form of education that tends to give the student encyclopedic knowledge must be avoided. Following the same line of reasoning Professor Le Goff pointed out that from a pedagogical view the point has long since been passed of arguing about what subjects will be added to the curriculum and in fact the serious problems are now in the choice of which subjects can be omitted. He seemed to have no doubt that a solid mathematical foundation was required for all engineers, and beyond that emphasis should be placed either on the social-economic side *or* on the physical-chemical side of his education. Implementing these ideas in terms of a particular university program Professor Danckwerts made the following remarks relative to curriculum plans at Cambridge University.

"We shall probably be forced to recognize that in the general process of specialization the chemical engineer has ceased to be responsible for the structural or electrical aspects of chemical, or process, plants, and we shall therefore cut out such topics as the mechanical and structural aspects of plant design, mechanical drawing and applied electricity. As for materials science the choice of materials is of course fundamentally important in the practice of chemical engineering, but can one learn enough about the science of the matter in a few lectures to influence one's choice in this to the slightest degree. Is not the choice going to be the product of experience and expert advice"

American faculties might consider electives in applied chemistry such as catalysis, polymers, biochemistry, surface chemistry and electrochemistry.

These ideas from Cambridge are in accord with those from the University of Minnesota, as described by Professor Neil Amundson before an AIChE annual meeting in December, 1966. He expressed the belief that courses in mechanics, strength of materials, electrical engineering, and drafting were on a steady decline and were expected to vanish or at least be reduced to a very minor level.

In discussing the place of economics and social sciences in the chemical engineering curriculum, Professor Danckwerts noted that, "Due to the limitations of time, such subjects as social sciences and economics will necessarily be developed somewhat superficially. The requirements of the normal chemical engineering course simply preclude the development of such subjects from first principles, as we might do in fluid mechanics or thermodynamics. Such superficial development forces these studies to appear somewhat shallow relative to their counterparts in the physical sciences of engineering. For this and other less important reasons, such studies will never contribute as significantly to the education of the chemical engineering student as may be desired by his more mature predecessors." In this subject area Professor LeGoff offered the following comments which support the position given above, "My personal opinion is that economics should be practically absent from the curriculum of engineering and that preference should be given to the physical chemical sciences, for these branches of science are only assimilated with ease before the age of 25. A reconversion to quantum mechanics cannot take place at the age of 40 whereas the taste for economics and human science comes with maturity. The evolution from science to administration is a well known phenomenon in nearly all professions. Furthermore, a conscientious student is much more likely to participate in social and humanizing activities outside the classroom and so can be expected of his own accord to educate himself in these areas. (The student's) prospective mind and his creative imagination must be developed by banishing all kinds of descriptive and passive teaching in favor of an active formation in comprehension. In other words, we ought to strive more to teach the mechanism necessary for familiarization with new subjects and a certain attitude towards new problems rather than the inculcation of pure fact. This is the one single condition necessary in the student's training if it is to remain valid ten years hence."

As is to be expected, the chemistry content of the curriculum always gets more than passing consideration. Although there was some discussion of chemistry content in the curriculum, none of the authors at the EFChE meeting specifically addressed this question. Professor Amundson did offer his ideas on the subject with the following remarks:

> **"Most curricula contain little in applied chemistry and this, of course, is the greatest departure from the past, since once chemical engineering meant applied chemistry. I believe the future of chemical engineering is intimately tied to chemistry, and we should find ways to reinforce these two fields to each other in some other context than thermodynamics, chemical kinetics, and molecular transport."**

Of course, the normal European program of study in chemical engineering includes more supporting courses in chemistry. In answer to the challenge posed by Professor Amundson, some consideration might be given by American faculties to such courses as polymer chemistry, biochemistry, surface chemistry, catalysis, and electrochemistry, which are often a part of European study programs in chemical engineering. These areas of applied chemistry have certainly develepend to the point that substantial courses of study could be devised, and they might be offered on an elective basis to allow students to specialize their own interests.

There was in Europe an undercurrent of belief, both expressed and silent, that the failure of engineering to attract the best students was focing the American universities to turn increasingly to pure science in their engineering courses. The feeling also seemed to be that this change was not good for engineering as a profession. By way of contrast to this position, Professor Le Goff asked the question, "To what extent must the training of engineers be different from that of research scientists?" In developing his answer to this question he cited the impact of the "physical-mathematical revolution" of the 1950's on the education of chemical engineers. "During this period," he said, "chemical engineering evolved

There is increasing throughout Europe a closer communication between the university and industrial practitioners.

rapidly and fundamentally, producing a far greater scientific rigor in the study of industrial processing. Ceasing to be the simple addition of chemistry and mechanics, chemical engineering became an autonomous science resulting from the direct application of physics and mathematics, according to its own method, to what had previously been a field of process chemistry." With this introduction, Le Goff then went on to answer his own question,

> **"Freed from materialistic tasks by automation, the engineer can now be considered as a researcher: research into improvements, research into the optimal functioning of his plant, research into the material and human means of obtaining results. Thus, his behavior is analogue with that of his colleague in the laboratory, even though his objectives may be different."**

By such reasoning, he argued that the research scientist and the engineer should receive similar education, the same foundation based on physics, mathematics, and chemistry, with the engineer receiving an introduction to the synthesis concepts which are so important in his subsequent career.

In the implimentation of curricula to achieve the many objectives previously alluded to, Professor Danckwerts underlined his belief that there was three basic ingredients in a university education—the first of which is *vocational training*. He included in his example of this type of training lawyers, doctors, scientists, and engineers. His second ingredient is *intellectual discipline* or the study of some particular subject in depth. This ingredient is required in order that the student develop habits of rigorous thought and penetrating analysis. Certain parts of every curriculum are to be included for their value as intellectual disciplines and not necessarily for their vocational value. "The final ingredient in a university education is that it should *broaden the mind.* The university graduate should not only be trained in the practices of his professor and in rigorous habits of thought, he should also be aware of the relationship of his subject to other subjects and its significance in human affairs as a whole." In discussing the implementation of curricular objectives Professor Le Goff strongly advocated the increased use of laboratory teaching in order to keep the future engineer in touch with physico-chemical phenomena and the natural imprecision of experimentation.

There seems to be little doubt that the European chemical engineering student has a broader laboratory experience than does his American counterpart. We might find that increased laboratory teaching would be desirable to supplement offerings in some areas of applied chemistry.

Finally in order to accomplish these various requirements, there seems to be increasing interest in several quarters throughout Europe in closer communication between the university and industrial practitioners. This process is occurring at the same time that academic emphasis is shifting more and more in the direction of science and away from technology.

INDUSTRIAL INTERACTIONS

Quite a lot of discussion at the EFChE meeting centered about the cooperation of practicing chemical engineers with educators in certain phases of university programs, and the reciprocal cooperation of educators was called for in some aspects of industrial professional development programs. Mr. H. M. Miller, of duPont de Nemours International S. A., Geneva, keynoted these ideas by citing the advantages from the industrial side of the cooperative, or "sandwich", courses which seem to be flourishing in England. In his opinion such courses effectively create a flow of continuing education into the domain of the practicing engineer. Quoting, "Let me emphasize that these engineering education-industry programs are in no sense charity. Their proponents realize full well that altruism—on either side—will not carry any program past the initial stages of success. They must be joint ventures in fact, validated by perceptive recognition of the waste of going separate ways, of the mutuality of objectives, and of the synergistic results of co-action." He mentioned also that similar advantages accrue to the participants in the so-called partnership programs which certain American universities use in their design courses in association with local practicing engineers.

The need for significant interaction of the university and industry was also recognized to exist in the area of career development. In this activity as well, the advantages were expected to flow in both directions, contrary to the popular view in the United States. The career development of the young engineering professor demands the stimulating influx of interesting ideas and problems from the industrial environment, and similarly the engineering practitioner needs and wants the stimulation of new developments in theoretical understanding. In this way both parties to any cooperative venture can maintain a healthier perspective.

POSTSCRIPT

The American observer of chemical engineering education in western Europe finds several recognizable benchmarks for comparison, but also he finds several trends which are not so obvious in his own situation. A similar optimistic opinion was expressed by Professor H. Blenke of the Technische Ho Hochschule, Stuttgart:

"The development of chemical engineering started and proceeded in the USA and Great Britain on the one hand, and in continental Europe on the other, under different conditions. Thus, the development temporarily moved in opposing directions but with resultant converging trends which lead in our opinion to a considerable agreement between the two concepts. This is not surprising because under the hard criteria of free industrial competition objective, realistic conceptions sooner or later gain the upper hand. Therefore, concepts of science and engineering do not differ more between highly industrialized countries than they do within each country. This is encouraging for it promotes and facilitates the exchange of experiences and cooperation — not only across borders of discipline but also across borders of nations."

On reflection of the many similarities observed, it was surprising to note how little concern there was with the ability of engineers to communicate either in written or spoken words. It is difficult to imagine that this is a problem unique to the United States, but in the EFChE conference confronting problems in the education of chemical engineers not a word was said about this particular problem.

Finally, if any single conclusion could be drawn from the experience of observing the chemical engineering education scene in western Europe, it is that such an activity is extremely educational and is one to be strongly recommended to others.

ACKNOWLEDGMENT

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ChE classroom

PROGRAMMED GAS ABSORBER CALCULATIONS

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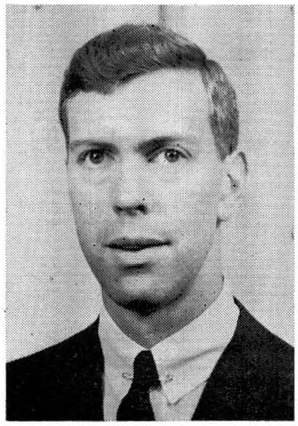

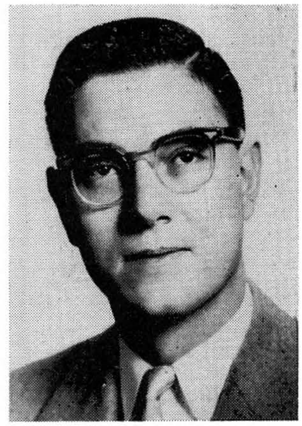

Norman F. Brockmeier began teaching at The University of Texas in Austin in 1966 after receiving his PhD at the MIT the same year. He has had industrial experience with Minnesota Mining, Dow Chemical, and Chevron Research, and is a registered proessional engineer in Texas. Since his coming to Texas, he has taught the unit operations lecture and laboratory courses and continued his research work in the area of microwave plasma chemistry. (left).

David M. Himmelblau is a graduate of MIT, Northwestern University, and the University of Washington (PhD '57). His interests include process cost analysis, machine computation, and process simulation. (right)

Sophisticated systems for computer-aided design can make an important contribution in the teaching of design. The bulk of the design programs in the area of chemical process design have been prepared by large companies or IBM[1]. These programs simulate the steady-state performance of large, integrated plants consisting of many interconnected processing units with considerable recycle.

In order to use such comprehensive executive programs, it is necessary that the component subroutines which represent individual process units are adequately formulated. Practically all of the subsystem models are of the macroscopic type, i.e., they consist of well mixed systems whose output is equal to the value of the dependent variables within the system. However, there is one characteristic type of process in which a plug flow distributed parameter model of equipment is required, namely, in processes such as absorption, ion exchange, and chemical reactors. Treatment of these types of processes form a substantial part of the unit operations and design phase of current chemical engineering curricula.

A rather flexible digital computer program is described here for absorbers which can be incorporated in any large executive program. It also can be used independently as a separate routine to enable students to gain some insight into the design of processes in which the plug flow distributed model is applicable.

There are certain basic requisites which must be met before an instructor can use such an approach to design.

- The physical process must be realistically desirable in mathematical terms.
- The students must be receptive to this approach to design, and they must be slightly familiar with computer programming. It is not necessary that they actually be able to program the original problem. Rather, they must be able to introduce data into the program and perhaps in some cases make very slight modifications in the program as it stands.
- Suitable computer facilities must be available at reasonable cost. The introduction of time sharing at many university facilities makes the use of a digital routine rather simple.

Our experience has been that student enthusiasm is high in using such an approach to design because the approach is novel, it relieves drudgery, and it seems to be professionally oriented. Students are able to work in a more creative and stimulating climate, which is all to the good, especially when economics are involved in an optimal design, for the digital program substantially reduces the tedium of repetitive calculations.

USE OF THE PROGRAM

The approach used in preparing the students to work with the computer program is to first give a sound description of the mathematical foundations of the program. The basic equations are described and their methods of solution presented. Next, methods of obtaining the param-

The students seek out their own data, cost information, and physical parameters and carry out the assigned design.

eters in the model are discussed in detail, inasmuch as the students are expected to provide these themselves. Most of the available parameters come from literature sources or handbooks, but in the case of tabulated or graphical material, it is necessary to convert the available information into the form of functions or equations.

A few very simple problems are solved by hand, using both graphical and analytical techniques. These problems are posed so that all the information the student needs is provided, and he merely introduces the available information and solves for the requested answer.

Design a packed column that will recover all but 0.5% of the carbon disulfide contained in a nitrogen carrier. The CS_2-N_2 mixture has a partial pressure of CS_2 equal to 50 mm Hg at 75°F and is blown into the absorber at atmospheric pressure at the rate of 50,000 cu ft/hr. The absorption oil has an average molecular weight of 180, viscosity 2 centipoises, and specific gravity 0.81 at 75°F The oil enters the absorber stripped of essentially all CS_2 and solutions of oil and CS_2 are ideal. The vapor pressure of CS_2 at 75°F is 346 mm Hg. The column is packed with 2-inch Raschig rings and operates isothermally. For a liquid/gas ratio of twice the minimum, determine the required oil feed rate, the diameter of the column, and the packed height[2]

Note that the problem statement provides all the details required to obtain a unique solution.

The last phase of the instruction prior to the actual use of the program is to describe the logic of the program and the sequence in which the calculations are actually made. Then, the students are given the prepunched program deck and instructions for its use. They are assigned one of the simple problems previously solved by hand to execute using the program deck. This stage of the instruction ensures that the student's program deck will work and that he understands how to introduce the data required to solve a problem.

Finally, the student is assigned a rather general problem in which he is asked to design some particular piece of equipment either using the program deck or not using it as he sees fit. In most cases the problem involves a simple economic balance of operating, fixed, and overhead costs, and thus requires a case study analysis to achieve some type of economic design. It would be possible to use the program in conjunction with a general nonlinear programming optimization routine. However, the case study method is more intuitively appreciated by the student than a more formal optimization routine.

The students seek out their own data and carry out the assigned design. They are required to obtain their own cost information as well as the physical parameters involved in the problem.

Such a problem assignment overwhelms many of the students at the start, inasmuch as practically all of their prior experience has been with canned problems in which all the information was available and the known solution variable specifically assigned. However, as they enmesh themselves in the problem, many of them find for the first time that they become interested in solving a problem, primarily for one of two reasons. Either the problem appears very realistic to them, whereas most previous problems were rather insipid, or else they are challenged by the computer programming aspects of the problem and feel that they are now working with one of man's most modern tools.

From the instructional viewpoint, the digital computer program makes it possible to assign much more comprehensive and realistic design problems. Many more variables can be allowed to change, the various parameters in the process model can be varied, and, as mentioned above, the factor of economic analysis can be introduced on a modest scale.

GAS ABSORBER COMPUTATIONS

Packed column gas absorber calculations are based on a continuous contact model in which the interphase transfer is given by the product of an overall mass transfer coefficient, K_ya, and a difference in gas phase compositions

$$d(y \cdot GY')/dZ = K_y a(y - y_e) \qquad (1)$$

where y = mole fraction of solute in gas phase
y_e = solute mole fraction in equilibrium with liquid
GY' = total gas rate in moles/hr-ft^2

Let us consider the mass transfer in a packed zone of a differential height, dZ. In order to integrate eq. 1 over the packed height, Z, the total gas rate is replaced by the solute-free gas rate, GY, which is a constant. For the designer's convenience in making graphical calculations, the mole fraction, y, is replaced by the mole ratio, $Y = y/(1-y)$. The intergation of eq. 1 over the whole column[3] leads to the following approximate expressions:

Computer-aided design enables students to work in a more creative and stimulating climate especially when economics is involved in an optimal design.

$$\int_{Y_a}^{Y_b} \frac{\phi dY}{(1 - Y)(Y - Y_e)} = \frac{K_y a(1 - Y)_{LM}}{GY} \int_0^Z dZ \tag{2a}$$

$$NTU = \frac{1}{HTU}(Z) \tag{2b}$$

The left hand side of equ. 2a is commonly called the number of transfer units, NTU, and the reciprocal of the group in front of the integral sign on the right hand side is called the height of a transfer unit, HTU. The relative velocity factor, Φ, is the transfer velocity in the gas phase relative to the interface. The quantity $(1 - Y)_{LM}$ is the log mean of the concentration difference of the non-diffusing species.

The value of NTU may be calculated analytically using the left hand side of equ. 2, or it may be calculated by numerical integration as in the computer program. The value of the HTU must be obtained from empirical correlations, many of which are available in the literature. Because the basis for the values of the NTU and the HTU is the *overall gas phase* resistance, the following equation gives the HTU, hereafter called HOY:

$$HOY = HY + HX(mGY/GX\phi) \tag{3}$$

where m = slope o fthe equilibrium solubility line
HY = individual gas-phase resistance in feet
HX = individual liquid-phase resistance in feet
GX = solute-free liquid rate in moles/hr-ft^2

The individual resistances can be calculated from the following empirical relations :

$$HX = \frac{1}{\alpha}(GXAV/\mu)^n Sc^{0.5} \tag{4}$$

$$HY = (1.01)GYAV^{0.31}/GXAV^{0.33} \tag{5}$$

where α,n = constants characteristic of the type of packing
μ = liquid viscosity in lb/ft-hr.
Sc = Schmidt group, μ/ρ_xDVX, dimensionless

GXAV, GYAV = average rates for liquid and gas, resp., in lb/hr-ft^2 Equ. 4 and 5 are valid for systems in which the liquid is either water or light hydrocarbons.[4] Furthermore, equ. 5 is accurate only for estimating the HY of 1-inch and 2-inch Raschig rings[5]. The Wilke[6] equation is used to calculate the liquid diffusivity, DVX, that is needed in the Schmidt group in equ. 4.

Because the values of m, Φ, and $(Y - Y_e)$ in equs. 2a and 3 generally change with distance in a packed column, the computer program employs the following technique to calculate the NTU and HOY. The packed section is divided into small increments of variable height in which the change in gas composition, $(Y_{n+1} - Y_n)$, is arbitrarily set at $^-0.005$. A loop in the program makes a mass balance around each incremental section, solves for the liquid composition change, and then uses eq. 2a to calculate the NTU. This technique has been described elsewhere.[7]

An equilibrium equation of the following form has been used to relate the gas and liquid compositions,

$$y = (PVP/P)x \tag{6}$$

where P is the total pressure, PVP is the Henry's Law solubility constant for the system, and x is mole fraction in the liquid. The slope, m, is the coefficient of x in equ. 6. For those systems that approach ideal solubility, PVP becomes the vapor pressure of the solute at the design temperature.

The gas rate, GY, which appears in equ. 3, is the product of the gas flooding rate, GYF, and the fraction of flooding, FF, at which the column is operated. The value of GYF is calculated from the following equation:

$$CYF = \left[\frac{1890/C_f^{0.33}}{4.85\bar{\mu}^{0.04}(1/\rho_x\rho_y)^{0.33} + 4.1\bar{\mu}^{0.1}(GY/GX\rho_x)^{0.67}}\right]^{1.5} \tag{7}$$

where C_f = packing factor in ft^{-1}
$\bar{\mu}$ = liquid viscosity in cp.
ρ_y, ρ_x = gas and liquid density, respectively, in lb/ft^3

Equ. 7 has been redived from an appropriate rearrangement of Bertetti's equation[8], which is an analytical form of the well-known graphical flooding relationship[9]. The numerical constant in the numerator of equ. 7 has been increased by a factor of 1.258 and th packing factor, C_f, replaces the ratio a_v/ϵ^3 where
a_v = packing surface area per unit volume in ft^{-1}
ϵ = void fraction.

These two changes bring the GYF predicted by equ. 7 into closer agreement with the GYF obtained from the latest graphical correlation[10].

A set of oscilloscope subroutines is added to the program to give a visual display of the results.

from the latest graphical correlation[10].

The input data that the student must introduce into the computer are those data that are typically known to the designer: the column operating temperature, the gas pressure, the volumetric gas feed rate, and the compositions (mole fraction) of the entering gas and liquid and the effluent gas. A number of other required parameters related to the physical and chemical properties of the gas and liquid must also be introduced, such as the molecular weights of the solute, liquid, and gas; the viscosity and density of the liquid; and the molar volume and equilibrium relationship for the solute. Several parameters related to the packing are also required inputs: the packing factor, the packing cost per cubic foot, and the constants α and n in eqn. (4). The user specifies a certain multiple (called FACTR) of the minimum liquid-to-gas ratio at which to operate. Also, the operating gas rate is set at a certain fraction (called FF) of the flooding rate.

The computer obtains the following results: column diameter, liquid feed rate, packed height, and effluent liquid composition. These results may be used directly to compute and minimize those costs that are significant. Often these will be the yearly depreciation (TC) on the installation and two or more operating costs, such as the cost of operating the gas blower (BC) and the cost of recovering the solute (DC) from the more or less dilute solvent liquid[11, 12]. The student is expected to calculate these costs or to insert into the program appropriate equations to calculate them. Note that the user must specify the cost in dollars per pound to recover the solute from the liquid stream.

All of the design variables can easily be changed by the user, either separately or in combination, to simulate the column operation and allow him to observe the changes in column, diameter, packed height, and liquid rate and composition. There are four groups of variables, corresponding to four separate loops in the program. The first group (NDES) contains the parameters that are held constant for a single design, such as the molecular weights of the solute, liquid, and gas, the density of the liquid, the molar volume of the solute, the feed compositions, and the gas feed rate. The other parameters are placed in three groups to allow for variations on a single design. The second group of variables (NTEMP) permits the user to vary the operating temperature (PVP in the equilibrium eqn. 6 and viscosity must be changed together with temperature) and the pressure. The third group (NPACK) contains the parameters for each kind or size of packing to be tested. The fourth group (NFACT) contains each set of FACTR and FF at which the column is to be operated. The four loops in the program thus will compute a design variation for each set of data in each group, or a product of the numbers (NFACT) (NPACK) (NTEMP) (NDES).

There are some limitations in this program as it stands. One limitation is that the designer must check the computed column diameter to be sure that it is at least eight times the characteristic length of the packing selected. The choice of eqns. 4 and 5 restricts this program to systems in which the liquid is water or light hydrocarbons and the packing is Raschig rings, but other correlations can be substituted for these. Finally, the form of eqn. 3 provides an accurate estimate of the HOY only for those systems which do not have a large liquid composition difference between the bulk and the interfacial values.

STUDENT RESULTS

This absorber design program has been used for three semesters as an instruction aid in teaching junior chemical engineering students. Toward the end of the first semester, an informal survey was made to determine the program's effectiveness. The results of the survey and the unsolicited remarks to the instructor indicate that the students derived a lot of benefit from using the program. Some of the students generated a noticeable enthusiasm for the design problem and program. Several students eagerly modified the program to make it compatible with the IBM 1620 (it was written for the CDC 6600) and others executed it on the teletype time sharing system.

The students found the original program, which had only two "do loops," inconvenient, so they added two more loops and thus contributed much to the final form of the program. In answer to the question, "What aspect of the design method seems most difficult to understand?" a large majority indicated that the concept of the height of a transfer unit (HTU) was the greatest problem. The students estimated that they needed about 30 minutes to look up the required parameters, punch the data cards, submit their deck, and then pick up the output. This was in contrast to about four hours to do a single design by hand.

It was interesting to discover that only eight out of thirty-four students had taken a computer science course. Nearly all of the class had a working knowledge of how to submit a deck with data and get the results from the computer. Some had learned this from using the computer in physical chemistry laboratory and from a fluid flow and heat transfer course.

A set of oscilloscope subroutines has been added to the original program so that the results can be displayed visually as the student operates the computer (an SDS 930) from a keyboard. The display on the cathode ray tube includes the Y-X coordinates, the equilibrium line, and the operating line. The transfer units are constructed between the operating and equilibrium lines using the approximate method of White and Baker[2]. The numerical answers are also displayed on the oscilloscope. In this way, the operator can explore the effects of numerous variations in just a few minutes time. The student response to this modified program has been even more enthusiastic than it was with the printed output only.

The authors wish to emphasize that the program should not be made available to the students until they first have learned to complete a full design by hand calculation. The program is such a timesaver that one is tempted to use it before it is understood. Readers may obtain copies of the program notation, flowchart, and Fortran listing from the authors.

LITERATURE CITED

1. Steward, D. G., "A Survey of Computer-aided Chemical Process Design," Electronic Systems Laboratory Report ESL-R-304, M.I.T., April, 1967.
2. Treybal, R. E., "Mass-Transfer Operations," 1st Ed., p. 230, McGraw-Hill, New York, 1955.
3. McCabe, W. L., and J. C. Smith, "Unit Operations of Chemical Engineering," 2nd ed., p. 653, McGraw-Hill, New York, 1967.
4. Sherwood, T. K., and F. A. L. Holloway, *Trans. AIChE*, **36**, 39, 1940.
5. Sherwood, T. K., and R. L. Pigford, "Absorption and Extraction," p. 228, McGraw-Hill, New York, 1952.
6. Wilke, C. R., *Chem. Eng. Prog.*, **45**, 218, 1949.
7. Koelsch, B. N., AIChE Student Members Bulletin, **7**, 39, Fall, 1966.
8. Bertetti, J. W., *Trans. AIChE*, **38**, 1023, 1942.
9. Leva, M., "Tower Packings and Packed Tower Design," 2nd ed., p. 40, U. S. Stoneware Co., Akron, Ohio, 1953.
10. Treybal, R. E., "Mass Transfer Operations," 2nd Ed., McGraw-Hill, New York, 1968.
11. Wroth, W. F., *Chem. Eng.*, **68**, 166, July 10, 1961.
12. Van Winkle, M., Personal Communication, Dec., 1968.

PROGRAMS IN WATER POLLUTION CONTROL

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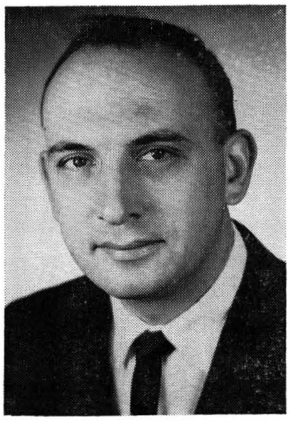
During the last three years, the University of Connecticut ChE Department has offered a program of study in water pollution control. The treatment of industrial and municipal wastes requires a variety of techniques and processes involving unit operations, transfer processes, reaction kinetics, and process control. Thus, the chemical engineer has substantial background that is applicable to pollution problems. To contribute effectively to a broad range of pollution problems, the chemical engineer needs additional training in biological processes and sanitary engineering.

Training programs are offered on both the undergraduate and graduate level. Students in these programs are educated as chemical engineers with specialized background in environmental engineering. Graduates from these programs meet all requirements for a degree in chemical engineering. In addition, they take a sequence of courses and conduct research in water pollution control.

Undergraduate Program

Although the major emphasis is on graduate activities, we feel industry needs BS degree chemical engineers with a background in pollution control. These engineers would be of special value to smaller chemical firms that could not justify a full-time pollution engineer.

Donald W. Sundstrom is Associate Professor of Chemical Engineering at The University of Connecticut. He received BS and MS degrees from Worcester Polytechnic Institute and a PhD degree from The University of Michigan. Before starting his teaching career, he had several years of industrial experience with Union Carbide and Allied Chemical Corporation. (left)

Herbert E. Klei is an Assistant Professor in Chemical Engineering at The University of Connecticut. He received a BS degree from MIT in 1957 and an MS from the University of Michigan in 1958. After four years with Chas Pfizer & Co., he received his PhD from The University of Connecticut in 1965. Presently he is studying the application of automatic control to activated sludge reactors under an FWPCA grant. (right)

The undergraduate program is incorporated into the present chemical engineering curriculum by simply choosing the recommended courses as electives. These courses give the student background in microbiology, sanitary engineering, and the separation methods developed primarily by chemical engineers. All students, both undergraduate and graduate, are expected to conduct research in the waste management field. We feel that research experience is important to the student in developing his ability to analyze and solve problems in the pollution field.

Table 1. Recommended Electives for Undergraduate Program

SEMESTER	COURSE
Second, Junior Year	Introduction to Microbiology
First, Senior Year	Water and Sewage Treatment (Sanitary Engineering Course)
	Introduction to Research
Second, Senior Year	Rate Processes in Water Treatment Systems, ChE 281
	Introduction to Research

Graduate Program

The MS program consists of 27 to 33 credit hours of work, including 6 to 9 hours of thesis research. Students in this program are required to take chemical engineering graduate courses in thermodynamics, reaction kinetics, and transfer processes. For electives, they are expected to take courses in microbiology, sanitary engineering, and environmental chemical engineering. The electives outside of chemical engineering provide the students with needed scientific material in the biological field and acquaint them with the current procedures of sanitary engineering. For an entering graduate student with no previous background in the area of pollution control, ChE 281 is also required.

The program at the doctorate level is flexible and is designed to meet the needs and interests of the individual student. Although there are no specific course requirements for the PhD degree, courses are usually selected in biochemistry, microbiology, process control, optimization, and systems analysis.

Table 2. Recommended MS Curriculum

First Semester
- Advanced Chemical Engineering Thermodynamics
- Advanced Transfer Operations I
- Fundamentals of Microbiology
- Research

Second Semester
- Reaction Kinetics
- Environmental Elective
- Sanitary Engineering Elective
- Research

Summer
- Environmental Systems Analysis, ChE 381
- Research

Chemical Engineering Courses

The major contribution of chemical engineers to water pollution control has been in the areas of rate processes and systems analysis. Classically, the water pollution field has been dominated by civil and sanitary engineers, who are more concerned with flow and structural aspects. The basic course in our program, "Rate Processes in Water Treatment Systems" (ChE 281), applies chemical engineering principles to sanitary engineering problems. As mentioned previously, this course is normally taken by seniors or first year graduate students. Material for this course is drawn from the fields of microbiology, chemistry, sanitary engineering. Since no completely satisfactory textbook exists and since the literature is expanding rapidly, the course is based mainly on recent published articles. An outline

The chemical engineer has a background that is applicable to pollution problems.

of the course and some selected references are listed in Table 3.

Systems analysis is introduced into the program in a project type graduate level course. In this course, we emphasize dynamics, control, and optimization of environmental systems. Typical project topics have included "Response and Stability of an Activated Sludge Reactor" and "Design and Control of an Activated Carbon Recovery Process."

Unfortunately, our water resources have only recently received the attention which they deserve. Since the quantity of fresh water in many areas is severely limited, we will have to do a better job in managing the available supply. The quality of our water in the future will be determined by the extent to which chemical engineers and others succeed in their effort to improve our water purification technology.

Table 3. Course Outline for Rate Processes in Water Treatment Systems

I. Fundamental Principles
- A. Nature of aqueous solutions
  1. Eisenberg, D., Kauzmann, W., The Structure and Properties of Water, Oxford Univ. Press, 1969.
  2. Gould, R. F., ed., Equilibrium Concepts in Natural Water Systems, American Chemical Society, 1967.
- B. Mass transfer and chemical reaction in heterogeneous systems
  1. Astarita, G., Mass Transfer with Chemical Reaction, American Elsevier, 1967.
  2. Den Hartog, H. J., and Beek, W. J., Local Mass Transfer with Chemical Reaction, *Appl. Sci. Res.*, **19**, 338 (1968).
  3. Wen, C. Y., Noncatalytic Heterogeneous Solid-Fluid Reaction Models, *Ind. Eng. Chem.*, **60** (9), 34 (1968).

II. Biological Phenomena
- A. Mass transport to the biological floc
  1. Calderbank, P. H., Mass Transfer in Fermentation Equipment, Ch. 5 in Blakebrough, N., ed., Biochemical and Biological Engineering Science, Vol. 1, Academic Press, 1967.
  2. Gulevich, W., Renn, C. E., and Liebman, J. C., Role of Diffusion in Biological Waste Treatment, *Environ. Sci. Technol.*, **2**, 113 (1968).
  3. Swilley, E. L., et al., Significance of Transport Phenomena in Biological Oxidation Processes, *Purdue Univ. Eng. Bull., Ext. Ser.* **117**, 821 (1964).
- B. Reaction kinetics in aerobic and anaerobic systems
  1. Aiba, S., et al., Biochemical Engineering, Academic Press, 1965.
  2. Gates, W. E., et al., A Rational Model for the Anaerobic Contact Precess, *J. Water Pollut. Cont. Fed.*, **39**, 1951 (1967).
  3. Luedeking, R., Fermentation Process Kinetics, Ch. 6 in Blakebrough, N., ed., Biochemical and Biological Engineering Science, Vol. 1, Academic Press, 1967.
- C. Design of biological reactors
  1. Bischoff, K. B., Optimal Continuous Fermentation Reactor Design, *Can. J. Chem. Eng.*, **44**, 281 (1966).
  2. Eckenfelder, W. W., Ford, D. L., Economics of Wastewater Treatment, *Chem. Eng.* **76** (19), 109, (1969).
  3. Erickson, L. E., et al., Modeling and Optimization of Biological Waste Treatment Systems, *Chem. Eng. Prog. Symp. Ser.*, **64** (90), 97 (1968).

III. Physical Methods of Separation
- A. Adsorption
  1. Weber, W. J., Morris, J. C., Kinetics of Adsorption on Carbon from Solution, *Am. Soc. Civil Eng. Proc., San. Eng. Div.*, **89**, 31, Apr. 1963.
  2. Weber, W. J., Morris, J. C., Equilibria and Capacities for Adsorption on Carbon, *Am. Soc. Civil Eng. Proc., San. Eng. Div.*, **90**, 79, June 1964
- B. Foam fractionation
  1. Lemlich, R., Principles of Foam Fractionation, in E. S. Perry, ed., Process in Separation and Purification, Vol. 1, Interscience, 1968.
  2. Rubin, E., Gaden, E. L., Foam Separation, Ch. 5 in H. M. Schoen, ed., New Chemical Engineering Separation Techniques, Interscience, 1962.
- C. Membranes
  1. Merten, U., Desalination by Reverse Osmosis, MIT Press, 1968.
  2. Michaels, A. S., and Bixler, J. J., Membrane Permeation: Theory and Practice, in E. S. Perry, ed., Progress in Separation and Purification, Vol. 1, Interscience, 1968.

IV. Chemical Methods of Separation
- A. Coagulation
  1. Packham, R. F., Polyelectrolytes in Water Clarification, *Proc. Soc. Water Treat, Exam.*, **16** (2), 88 (1967).
  2. Stumm, W., and O'Melia, C. R., Stoichiometry of Coagulation, *J. Amer. Water Works Assn.*, **60**, 514 (1968).
- B. Combustion
  1. Corey, R. C., Principles and Practices of Incineration, Wiley, 1969.
  2. Spalding, D. B., Some Fundamentals of Combustion, Butterworths, 1955.
- C. Ion Exchange
  1. Applebaum, S. B. Demineralization by Ion Exchange, Academic Press, 1968.
  2. Arden, T. V., Water Purification by Ion Exchange, Plenum Press, 1968.

INNOVATION AND MOTIVATION -- A FRESHMAN DESIGN COURSE

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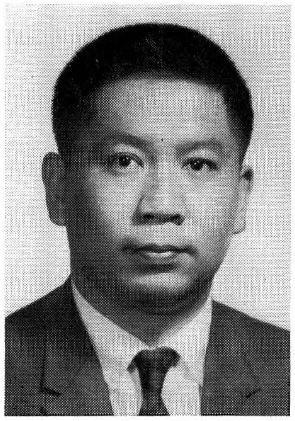
Suppose we were to organize a football team and we had a unique training program aimed at giving the players good fundamentals: the first year we do nothing but calisthenics; the second year we add dummy drills to our program; the third year we let them run patterns; then, finally, in the fourth year we let them scrimmage and play. Do yo uthink that we would be successful?

The answer, as everybody can imagine, is an emphatic NO because no one would join our team in the first place since there would simply be no fun to play on such a team. All training and no play makes the team dull.

And yet this is precisely an exact image of the conventional engineering program, chemical engineering included. During the first three years the student learns nothing but humanities, pure and applied sciences which are no doubt of prime importance in his future career. But he has no opportunity to see how knowledge learned in these subjects can be put together in a meaningful way in solving engineering problems until perhaps the fourth year when a semi-realistic and fairly well-defined problem is presented to him in the traditional design course. By this time the knowledge he is supposed to use will have become vague because of the lack of immediate opportunity to utilize it before. The present engineering program, especially the freshman portion, is not one which will greatly enthuse the student because he simply cannot see why he should be an engineer rather than a scientist. Even many of those who started out in engineering have lost their interest, thus constituting the major cause of the engineering mortality rate (50%[1] and manpower shortage[2] .

Secondly, **solving an engineering problem is quite different from solving a scientific one both in their natures and the methods of attack.** If during the fourth year an engineering student finds that he does not like to solve the open-ended type of problems usually found in engineering work, then it will be too late for him to change to a different field.

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Therefore, *early in the engineering curriculum we need to show the student the difference between science and engineering.** We want to demonstrate to him how an engineer actually looks at things, how he approaches a problem, and what economical, sociological and human factors he has to consider in addition to his technical problems. That is exactly why at the Catholic University we offer an introductory engineering course, ChE 198 Fundamentals of Creative Design, to give the student a chance to be personally involved in engineering and to create new tools for mankind.

*Our favorite quote for the students is: "Scientists discover what is; engineers create what has never been."—by Theodore von Kármán.

Furthermore, our course is vastly different from the conventional introductory course which usually deals with the slide rule, computer, measurement, etc. because we want to give the students a chance to accomplish something on their own. Despite all the advancement in science and the upgrading of requirements in the curriculum, we are probably not producing graduates with creativity commensurate with their scientific knowledge. In fact, with the courses becoming increasingly highly specialized and structured, we suspect that their inductive problem-solving skills have yielded places to deductive skills. We are not claiming that creativity has actually "degenerated"; we merely suspect that the development of creativity has not kept pace with the advancement of scientific knowledge. The student should know that there is a *design process* by which he can most effectively use his imagination.

COURSE OBJECTIVES AND DEVELOPMENT

Based on the foregoing premises, our ChE 198 is designed to **(1) Give the beginning student a preview of engineering——its mission, objective, viewpoint and methodology. (2) Motivate the beginning student by giving him an opportunity to innovate, to unlimber his imagination before he enters a highly structured, analysis-oriented educational program.**

Freshman design courses have in recent years been rapidly increasing in number due to realization of such considerations as those set forth above.

In the summer of 1965, six institutions: The University of California at Berkeley and Los Angeles, Carnegie Institute of Technology, Case Institute of Technology, Dartmouth College, and Massachusetts Institute of Technology, under the auspices of the Commission on Engineering Education and with NSF funding hosted six Design Education Workshops across the country, aimed at sharing their experience with selected design teachers from other institutions. These Workshops advocated different approaches which were designed for students of different levels, according to the interests and experience of the host institutions. One of the authors (MML) was fortunate enough to participate in the one at Dartmouth whose ES-21 Introduction to Engineering[3] was a sophomore course. The experience of the summer was extremely enlightening. Based on his report and recommendations made upon his return, a new experimental course, ChE 198 Fundamentals of Creative Design, was put into effect in the Spring of 1966. It was a resounding success. The second year our enrollment included students from Mechanical Engineering and Space Science and Applied Physics Departments. Students and staff members from different disciplines worked well together. Now in its third year, the course is also taken by non-engineering majors, including girls* from such departments as Sociology, Economics, and Psychology. Perhaps with the exception of the computer course, this is the first time that the Engineering School offers a service course to arts and sciences students!

LECTURE PROGRAM

Activities of the course can be divided into two main components, lectures and project, which are intimately related. The lectures supply knowledge needed in the project while the project complements and illustrates the lectures. To put it differently, the lectures are given on need-to-know basis while the project creates the need to know.

Designed to acquaint the student will all aspects of engineering, the lecture program includes such topics as the following:

Patents and Noteboook Keeping • Project Planning and Control • Computers—Analog and Digital • Professional Ethics • Creativity and Methods of Innovation • Information Storage and Retrieval • Decision-making • Marketing • Engineering Economics • Contracts and Legal Aspects of Engineering • Technical Communication (oral and written) • Art of Leadership and Group Psychology • Sociological Impact of Engineering • Safety in Industry • Optimization • Engineering Materials • Case History • Instrumentation • Management of Engineering • Human Factors in Engineering • Conference Leadership • Mathematical Modeling.

This list does *not* include technical subjects which are directly related to the project itself. For example, in the dental project two years ago, special seminars were given by and field trips arranged through the courtesy of responsible professional people in government and industry.

These general and seemingly "trivial" topics become a living experience to the students as they proceed through their projects. Highly idealistic, many of them are extremely interested in professional ethics ("shall I tell my roommate what we're doing?") and sociological impace (such as

*The problem with girls is that we have to keep an eye on them so that the boys will not employ them exclusively for secretarial duties.

machines replacing men). The importance of technical communication is never so real as when one has to stand up to convince a group of experts and to defend his design. Cost accounting, market and financial analysis, patent regulations, project planning and control, creative methods, information retrieval, human engineering and conference leadership have been found no less useful.

DESIGN PROJECT

The other main ingredient of the course is an open-ended, comprehensive project which the students, working in teams of approximately six each, are required to complete in one semester. Each "company," as we prefer to call it to create a more realistic atmosphere, is assigned an instructor who is referred to as the "company consultant." In the "game" we play, he acts as the "coach"; but when the emphasis is on the project as a course, he assumes the teacher's role which includes amplifying the lecturer's point and applying it to the specific project on hand, critiquing student's work and reports and the pleasant (or unpleasant?) job of grading them. In our experience, the rank and age of the instructor are immaterial as long as he takes an active interest in the students and has reasonable industrial and design experience of which, of course, the more the better.

Each company has its own student officers (President or Chief Engineer, and others) who take active leadership roles. Currently we are experimenting with a system whereby each student is responsible for one of the approximately six phases of the project.

The companies are contracted by a manufacture company* which feels a certain need, or has a general idea, for a new product or process. It asks for a more specific design, complete with technical and economic analysis, market survey, drawings and/or prototype to show that it will be a product that will benefit the society as well as earn the client company monetary return should it go into the fanufacture of this product or adopt this process. The problem statement is contained in a business-like communication to the student companies, who then submit a written proposal and orally present it to a panel of expert judges retained by the client company. After the project is accepted for "funding," each company is required to submit a progress report to the client at the end of each phase. A final design report is submitted and public presentation made at the end of the term to a panel of experts who, instead of electing a winner or giving out prizes, critique the student's work—product and procedure. (That is why internally we like to call them "evaluators" instead of "judges.") Intro-company individual reports are required by the company leadership according to the general guidelines for the entire course. Among the project themes we have chosen, "Project I-Cube" two years ago, was to design something to help people in developing countries. This "something" must be affordable by the local populace and utilize local resources. The four Companies work in four different areas, namely: solar-powered water lifting device, a public water supply system for the Barriadas in Peru, sanitation and public health system in Nicaragua and profitable utilization of lumber resources in Chile. The projects are full of international flavor. For example, in addition to having instructors from four different countries, the Vice President of Nicaragua, on his visit to Washington, assigned one of his Embassy staff to regularly help out a particular student group. We have also corresponded with agencies of foreign countries to obtain their experience.

*This company used to be a fictitious one consisting of faculty members. But this year, with "Project I-Cube" (International Innovations and Inventions), a real organization, VITA (Volunteers for International Technical Assistance), is the client.

The other main ingredient of the course is an open-ended, comprehensive project

Last year we asked the students to design something to facilitate the conversion to the metric system. (Have you heard of a dual-thread British-Metric screw? It really works!) This coming spring we are going to work on our environment!

The students are required to budget their time and money which consists of the real and "paper" categories. Via this they are led to the concept of planned invention and are made aware of the cost of time, man-power and such things as overhead cost contingency allowance, profit allowance, etc.

Three textbooks[4, 5, 8] have been tried in the course so far. They are used more or less as source books or guides with suggested reading assigned for each week as the project progresses. Other books[6-17] have been considered and recommended as references.

SPECIAL FEATURES

One great feature of our program is the extensive contribution made by outside experts holding responsible positions in industry and government. For this we are extremely fortunate and thankful. Most of them are guest lecturers. They have come very willingly, offering more help than we ever expected to trouble them with. The students gain tremendously from listening to and discussing problems with these real-life experts.

... Why should not liberal arts majors not take at least one engineering course? ...

To many the mere experience of sitting in a relatively small group with a prominent person is the greatest thing that has happened in their lives. After the lecture they can "hire" the lecturer as a special consultant to help them with their own specific problems. The client company also hires them occasionally to act as judges for the presentations.

The second outstanding feature is the realistic environment we provide. Ninety percent of the time we treat them as business associates or counterparts rather than students. We address them as such in our "contracts," in intercompany communications and in presentations which range from the formal auditorium-type to informal conference-room get-togethers. The judges are urged to give them as realistic a going-over as possible, from such things as wrong definitions of the problem, design contradicting physical laws to such things as unsatisfactory items in the budget.

The students answer this challenge with an equally, if not more so, impressive and realistic effort. Their footprints cover such places as the patent office, government and industrial laboratories and libraries, the dentist's office, barber shops and union. They make both telephone and mail surveys. They phone and write *real* manufacturers for technical and market information. And, to the judges scrutinization, they offer mature answers, even occasional rebuttals. After serving as one of the judges, one of our colleagues volunteered: "This is the greatest thing that has happened around here." This is typical of the comments we have received from both "insiders" and "outsiders."

Being chemical engineers offering this course, we have deliberately chosen projects which have potential chemical solutions. Admittedly the students' background in chemistry is not very strong at this point and the development of a suitable chemical requires time and the tenacity to endure government food and regulations, they are nevertheless made to study some of the existing and related chemical products.

An innovative feature of this program is that, with gratifying cooperation from our liberal arts colleagues, we have begun to enroll non-engineering students in our course. **We feel that our present-day technology is so encompassing that mutual understanding, cooperation and cross-fertilization among various technical and non-technical disciplines are indispensible.** After all, engineering students do take a number of liberal arts courses. Why should liberal arts majors not take at least one engineering course? Among some of our enthusiastic course alumni are economists, psychologists and sociologists who have perceived the need to know some engineering—not necessarily the technical aspect, but at least the engineering process—in order to work with engineers in the future.

Our success with this course and our experience in doing international technical assistance projects have attracted the personal attention of Dr. John A. Hannah, AID Administrator, and won us the unusual opportunities of conducting similar workshops for chosen foreign students these past two summers, under the sponsorship of AID and the African-American Institute. This is a particularly relevant part of their training since a little creativity could go a long way in utilizing local resources to develop the economy of their respective home countries.

DISCUSSION

Our experience in offering our own program and in participating elsewhere has shown that the student can be led to better utilize his creativity. *By providing him with an atmosphere where free expression of ideas is encouraged and properly guided, his imagination can be made more productive. This is the innovation aspect of this program.*

Secondly, the motivation aspect has also been achieved. We do not necessarily mean that students come out with better grades in subsequent courses. But to the best of our observation, they have in general become more enthusiastic and responsive. They now take a more active interest in their chosen profession.

Moreover, this course also serves as a bridge to bring students and faculty closer together early in their education. Because of this early contact with engineering, the student feels more at home with the engineering school, his department and faculty. He feels that he belongs. Now his advisor is literally an advisor, not just the Professor What's-His-Name who only signs the registration card. He is the person whom the student can bring his problems to, whether academic or social.

At the end of each year's course, we ask each student to fill out an extensive, anonymous ques-

. . . This course also serves as a bridge to bring students and faculty closer together early . . .

tionnaire rating every aspect of this course. An outstanding conclusion from these cumulative data is the supreme importance of the company consultant (instructor). Not only his personal reputation is on the line, but the student's impression of the entire course (even the guest lectures his company consultant has nothing to do with) depends on the latter's ability to interest and inspire. The company consultant is the one who could make this course demanding and rewarding, or simply a drag.

Other significant reactions of students are that they rate very highly the major reports and presentations, opportunity to create, stimulating their interest in engineering, quality of effort required, sense of accomplishment and the value of this course in their overall education. They said that they could do without tougher judges.

Problem selection is extremely important. It should be one that all instructors are reasonably enthused about, though not necessarily in the special areas of competence of everyone. It should be one with great local interest or appeal so that guest speakers and consultants can be obtained easily. Other local cooperations are also essential.

We hope to involve more and more liberal arts students in this course, even if this only serves "cultural" purposes, just as liberal arts courses do for engineering students. For engineering is at the heart of 20th Century culture. It is in everyone's daily life. If a housewife understands some basic engineering principles, she may become a better cook by more properly utilizing her stove and oven, and the life expectancy of the family car may be prolonged. Unfortunately, instead, we see, week after week, students (mostly liberal arts majors) fumbling on the simplest technical questions on the "College Bowl" TV program while recalling down to the last detail titles of literary works and names of authors, artists and composers. It is common to find the engineer a better conversationalist among arts and humanities majors than one of them in a group of engineers. *The engineer is, therefore, perhaps the most cultural of all people, if culture is properly defined to include all of the main ingredients of our civilization.*

We also feel that a modified version of this course to service high-school students can be of great value as a career guidance device

REFERENCES

1. Beakley, G. C., Address to the University of Texas, College of Engineering, Teaching Effectiveness Colloquium, November 17, 1966.
2. Beller, W. S., "Long Term Engineering Shortage Seen," Technology Week, p. 28, March 20, 1967.
3. "Teaching the Realities of Engineering," *Chem Eng.* 71 (3) 106 (February 3, 1964).
4. Buhl, H. R., "Creative Engineering Design," Iowa State U. Press, Ames (1960).
5. Krick, E. V., "An Introduction to Engineering and Engineering and Engineering Design" Wiley and Sons, New York (1965).
6. Alger, J. R. M. and Hays, C. V., "Creative Synthesis in Design," Prentice-Hall, Englewood Cliffs, N. J. (1964).
7. Asimov, M., "Introduction to Design," Prentice-Hall, Englewood Cliffs, N. J. (1962).
8. Liston, J. and Stanley, P. E., "Creative Product Evolvement," Balt, W. Lafayette, Ind. (1964).
9. Osborn, A. F., "Applied Imagination," Scribner's Sons, New York.
10. Starr, M. K., "Product Design and Decision Theory," Prentice-Hall, Englewood Cliffs, N. J. (1963).
11. Arnold, J. E. "The Creative Engineer," ASME, New York.
12. Easton, W. H., "Creative Thinking and How to Develop It," ASME, N. Y.
13. Randsepp, E., "30 Attributes of the Creative Engineer," *Machine Design,* May 28, June 11 and 25, 1959.
14. Woodson, W. S., "Creative Techniques—A Comparative Analysis," *J. of Ind. Eng. X V* (2) 60 (Mar.-Apr. 1964).
15. Taylor and Barron, "Scientific Creativity: Its Recognition and Development," Wiley and Sons, New York (1963).
16. Smith, Ralph J., "Engineering as a Career',, 2nd ed., McGraw-Hill, New York (1962).
17. Wilson, W. E., "Concepts of Engineering System Design," McGraw-Hill New York (1965).
18. Edel, D. H. et al. "Introduction to Creative Design," Prentice-Hall Englewood Cliffs, New Jersey (1967).

CULBERSON ON ATTRITION

(Continued from page 27)

thetic "Establishment" ear for their problems. Fourth, a specially-tailored course for the second semester of the freshman year was developed as a result of interviews of freshmen by an ad hoc faculty committee. The freshmen lamented "Where is the engineering?" in a curriculum then consisting of mathematics, physics, chemistry, English and physical education or ROTC. There also seemed a definite need to answer the question "What is engineering?" The course meets once a week for two hours under supervision of senior faculty, and is devoted to the conduct and data analysis of experiments from all fields of engineering.

Purdue University Study

It appears that Purdue University, and particularly its Department of Freshman Engineering, has made more studies of the attrition problem than any other school or organization. Some 50 studies are said to have been made. Two reports of this work will be reviewed here.

The first is a study of the relationship between social class background and success in the freshman engineering program.[7] Social class was dichotomized into a higher level and a lower level based on fathers' source of income and educational level. Students' performance was found to be quite dependent on social class, with the likelihood of success in the engineering program increasing in the higher social class. A number of non-intellectual factors were evaluated:

- The greater the amount of his educational expenses provided by a student (rather than coming from his parents), the more likely he is to succeed in the engineering program. This effect appears independently of social class.
- Students who live in fraternity houses are more likely to withdraw from engineering than are students who lived in dormitories or off campus.
- Factors found to be not significant to performance when controlled to social class where: mothers' brothers' and sisters' education, geographical origin and type of community (urban-rural).

Several other evaluations resulted from the study. Both the successful and unsuccessful students felt that the amount of work required in the courses was reasonable. The unsuccessful students were more likely to rate the freshman counselling services as being helpful. The unsuccessful students also were more likely to have taken an aptitude test.

Professor William LeBold of Purdue has been conducting research for 10 years in the characteristics of engineering and science students and graduates.[8] He states that practically no correlation has been found between non-cognitive factors and achievement in engineering studies. However, he finds that the first semester, and even more so the second semester, performance of an engineering frshman is a very good predictor of the student's cumulative undergraduate performance. In fact, first semester performance is three times as effective in predicting undergraduates' final grade point average as is high school class standing, and twice as effective as class standing and entrance examination score taken together. This strong correlation has been demonstrated to hold for students who transfer to major universities from junior college or their equivalent.

Carnegie-Mellon, Cornell and Washington Studies

Carnegie-Mellon has studied the performance of the class which entered in 1962, and the following judgments were made upon the members of that class who entered the College of Engineering and Science.[2] The best single predictor of academic performance is college board score, but there is no obvious college board score to select as the minimum for admission. They suggest that a prospective student having a marginal college board score be further evaluated by "plusses" and "minuses" awarded from a derived matrix of values for number of high school activities, parents' educational level, and other factors. Student performance was also recognized as being dependent on other and unmeasured variables such as dorm living conditions, teacher-student relationships, etc.

The Registrar at Cornell produces an "Undergraduate Attrition Report" biennially in which the status of matriculants is reported for each college as numbers: graduated on schedule in (a) college of matriculation or (b) another college, still pursuing degree past scheduled graduation, and non-graduates no longer at Cornell. These reports in general do not seek out criteria for successful performance. However, the 1966 report notes a large increase in the percentage of engineers graduating on schedule.[3] This increase is attributed to two factors: a change from a five-year to a four-year Bachelor's program, and the establishment of a basic engineering program providing excellent counselling to beginning engineers.

In 1962, the University of Washington (Seattle) began keeping close records of students entering engineering there directly from high school. The accumulated data for the classes entering in 1962, 1963, 1964 and 1965 were recently reported.[9] Further correlation and study of the data are to be pursued, but some very interesting information already has been identifield. First, the high school grade point average (GPA) of entering engineering students has held fairly constant from year to year, and does not differ significantly from the GPA of all freshmen entering the University. Mathematical proficiency of the entering engineering students has increased markedly during the period. The year-by-year performance of each class is broken down in the report by those continuing in engineering, voluntarily withdrawing, transferring to other studies, or dropped for low scholarship. Following are the average retention figures as percentages of entering freshmen:

At the End of Year	Still in Engineering
Freshman	70%
Sophomore	48%
Junior	43%
Senior	40%
Graduated on Schedule	15%
Graduated during Fifth Year	20%

There was very little variation in the year-by-year performance of the four classes. For 86% of the students, their University of Washington cumulative GPA changed by less than 0.5 of a grade point. This seems to support Professor LeBold's observation that first semester performance is the best single predictor of success. Ten percent of the students who persisted through four years of engineering studies earned a better cumulative GPA than they had in high school. Many statistics are contained in this report dealing with the destinations of students who left engineering, high school and university grade point comparisons, etc.

Other Studies

An ASEE study of engineering enrollment and attrition,[10] and an EJC Manpower Commission report[11] have also come to the attention of the writer. The EJC report shows that retention rates of freshmen engineering classes have declined fairly uniformly from a figure of about 65 percent in 1952 to 50 percent in 1962. The report also recommends remedial measures quite similar to those given in the Michigan State study.

There is some evidence that this long-term decline in engineering undergraduate retention rate may to some extent be caused by continually increasing expectations of students by educators, who in turn may be reflecting industry expectations. The Learning Resources Center of the University of Tennessee recently published material suggesting such a cause.[12] Following are some items from that publication:

- **In a four-year study at the University of Georgia, college GPA's declined eight percent for successive classes of entering freshmen while their class SAT verbal scores had been increasing ten percent.**
- **At Berkeley, 30 percent of a freshman class had GPA's below C even though all members of the class graduated in the top one-eighth of their high school class.**
- A professor of calculus, not knowing he had been assigned a class of superior students who had received only A's in all previous mathematics courses, gave the usual distribution of A through F grades on the first examination. The students made the situation known to him, he relented at the end of the term to a distribution of 40 percent A's, 50 percent B's and 10 percent C's.
- A survey of 300 institutions showed overall grade-point-average distributions to be quite similar in those institutions which admitted only superior students and those that had no selective admissions policies.
- In a five-year period at the University of Tennessee, college GPA's declined ten percent for successive classes of entering freshmen while their mean composite ACT scores were increasing ten percent.

These seem to constitute evidence that our standards for the Bachelor's degree are being raised at a pace which can be matched by an ever smaller proportion of our students.

Hopefully, the foregoing material on attrition will provide an ample base from which the Education Projects Committee and interested members of Council can map a suitable next action. Sincere appreciation is extended to the questionnaire-plagued department heads who completed the one sent out in this study, and particularly to Professors H. L. Toor, Robert York, M. H. Chetrick, John Happel, R. A. Greenkorn and R. W. Moulton who provided the reports on pertinent work at their schools.

LITERATURE CITED

1. Turner, J. C. R., *British Chemical Engineering*, 12, 630-632 (1967).
2. Abel, W. H., Part II, Research Note No. 6, Office of Institutional Studies, Carnegie-Mellon U., March 1968.
3. Registrar's Office Undergraduate Attrition Report, Cornell U., Nov. 1, 1966.
4. Augustine, R. D., "Persistence and Attrition of Engineering Students," Office of Dean of Engineering, Michigan State U., Aug. 1966.
5. Klein, W. J., New York University Alumni News, March 1965.
6. Rabins, M. J., *Engineering Education*, 345-6, May 1966.
7. Kallas, G. J., M. S. Thesis in Sociology, Purdue U., June 1961.
8. *Backgrounder*, Schools of Engineering, Purdue U., April 1966.
9. McNeese, D. C., "Engineering Students' Performance, 1962-67," College of Engineering, U. of Washington (Seattle), January 1968.
10. "Factors Influencing Engineering Enrollment," American Society of Engineering Education, 1965.
11. "Engineering Student Attrition," Engineering Manpower Commission, Engineers Joint Council, April 1963.
12. "Grades and Grading,"," Learning Resources Center, U. of Tennessee, Fall 1966.

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