CEE

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CHEMICAL ENGINEERING DIVISION OF AMERICAN SOCIETY FOR ENGINEERING EDUCATION

1977 Award Lecture

SUPERHEATED LIQUIDS: A Laboratory Curiosity and, Possibly, an Industrial Curse

Part I - Lab Studies & Theory

Robert C. Reid

Pittsburgh's
ALAN J. BRAINARD

The Graduate Program
INSTITUTE OF PAPER CHEMISTRY

RANKING ChE DEPARTMENTS - **GRISKEY**

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FEATURES

DEPARTMENTS

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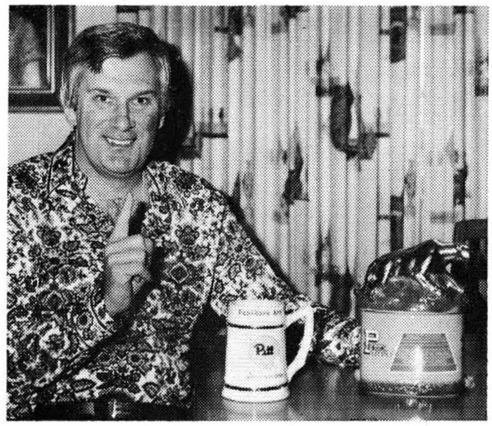
Alan J. Brainard

OF PITTSBURGH

PREPARED BY BARBARA DIPPOLD
University of Pittsburgh
Pittsburgh, Pennsylvania 15261



Dr. Brainard with Pitt Football mementos.

WHEN ALAN BRAINARD LEFT his job at the Esso Research Laboratories in Baton Rouge, Louisiana, to become a professor of chemical engineering at the University of Pittsburgh, he felt confident his decision was sound. Positive learning experiences at Fenn College (now Cleveland State University) and the University of Michigan and early teaching experiences as a teaching fellow in chemistry at Michigan and as an instructor of engineering science at Oakland University, Rochester, Michigan, no doubt had much to do with his return to the classroom. Now, ten years and approximately two thousand students later, his faculty colleagues, former and present students, and most of those he has met along the way will attest to the wisdom of that 1967 decision.

"My major responsibility as an educator," he says, "is to structure the learning experience for each student such that the student perceives it as valuable—hard work, perhaps—but valuable to him."

Shelves of neatly sectioned books cover one wall of his small, twelfth-floor office in Benedum Engineering Hall. Texts in heat, mass, and momentum transfer, process design, kinetics, thermodynamics, applied mathematics, physics, and chemistry rest beside those in creativity and creative design, educational psychology, and educational approaches to teaching. How man learns, teaching methods, the capacity for understanding, and creativity are as much a part of the educational process as the subject matter Brainard presents.

In working with both faculty and students to achieve a more effective teaching-learning experience, Brainard emphasizes the need for the development of social responsibilities in today's engineering students.

The author of many papers on teaching methodologies and the creative processes, he practices what he preaches. One of his early successes in effective teaching involved the development of a series of 35mm colored slides used in an introductory course in thermodynamics. He prepared the slides by using pressure-sensitive letters (Tactype©) on white posterboard superimposed on colorful designs, i.e., op-art posters, vivid gift-wrapping papers, etc., and photographed the resulting format. The "text" material of each slide was reproduced and given to the students in the form of an "active-involvement" book, greatly reducing student note-taking in class. Space on the bottom of each page permitted the individual student to add material from the lectures of

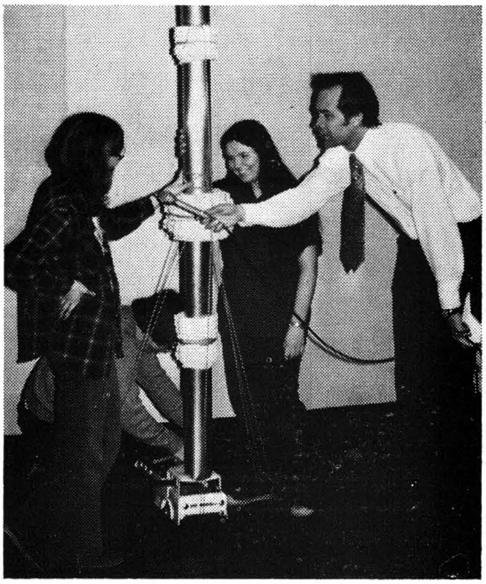
Because educating the educator is as much a part of Brainard's activities as teaching undergraduates, a portion of his efforts at Pitt has been directed toward a year-and-a-half study of ways to improve teaching at the University of Pittsburgh.

particular importance to him. After several experiences with this format, Brainard finds that more comment is necessary for the students to tie the slides together and to elaborate on some of the steps in the derivations presented in some slides. At one point, he experimented by playing tapes of classical music in the background to supplement his lecture comments, but since he was unable to determine if the background music was conducive to learning thermodynamics he abandoned the practice. Now, even without music, students attest to the fact that his thermo course is truly a colorful learning experience.

The initial success of the thermo course caused the "young and naive" Dr. Brainard to assume that the mere existence and proper use of the slides could be enough to result in a significant improvement in student problem-solving abilities in thermodynamics. Such was not the case. For while the use of the slides did provide a great deal of structure to the course and did enable the students to cover the elements of the theory in the course in a shorter time than usual, it did little to enhance student problem-solving skills. Recognizing this, he developed a set of self-study examples to supplement the materials used in the lectures. These self-study examples followed the format: problem statement, statement of educational objectives the student will gain from the solution, and a very detailed solution to the problem. In several self-study examples, he omitted some of the steps in the solutions, leaving these steps for the students to complete, as he realized that without these missing steps too many students would simply read the solutions and not try to establish the correctness or source of each portion of a given solution. The utilization of the self-study examples coupled with the slides and their companion book have been a significant benefit to promote student learning in thermodynamics. It is not uncommon for forty percent of the students in this course to earn A grades. (A more extensive description of this approach is published in an article by A. J. Brainard and H. T. Cullinan, Jr., "New Instructional Media for Teaching Large Classes," *Engineering Education*, 62, No. 8, 930, 1972).

FORTRAN FOR FRESHMEN

HIS INTEREST IN HELPING students learn prompted him, in January of 1973, to accept the assignment as director of Pitt's Freshman Engineering Program—a program which, in a period of peak enrollments, reduced attrition of first-year students from about thirty percent to a low of eight percent. Under his direction, Pitt's unique freshman program came to full development. It departs from the traditional freshman studies of chemistry, mathematics, physics, and English to include a series of half-term two-credit courses in FORTRAN programming, automatic control, manufacturing, measurements, creative design, energy, materials, biomedical engineering, microprocessors, and transportation. Only the computer programming course is mandatory; students may choose three of the remaining courses to complete first-year requirements.



Local TV personality interviewing students in the Creative Design Class.

Brainard's own course, Creative Design, is by far the most popular of these with registration of at least 150 students each time it is offered. Continual revision and experimentation keep the course basic with respect to engineering skills and dynamic in the area of creativity. Students develop their own thinking patterns with exercises from brainstorming to studying such engineering projects as the Sydney, Australia, opera house, off-shore oil storage vessels in the North Sea, the stadium in Honolulu, and designs in nature. A particularly interesting feature of this course is the five-week student project which requires student teams to design and construct prototypes of various special-purpose vehicles. An example of one of these projects is the egg-delivery problem: A pine board eight inches high and eight feet long is placed eight feet from a starting line. A target having a bull's-eye of five inches in diameter is then placed with the center of the target eight feet from the board. The starting line, board, and target are all in a smooth horizontal plane. Each team of students is given a raw hen's egg and asked to construct a "vehicle" which will travel either over or around the barrier to deliver the egg unbroken to the target. An acceptable solution includes either depositing the egg on the target or having the vehicle stop with the egg above the bull's-eye.

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These projects have proved to be beneficial in introducing engineering skills and stimulating interest in what engineers do. Students particularly like the hands-on experience they provide. Locally, the media, too, have expressed interest in the students' demonstrations of their team-built prototypes. Not only have the projects received coverage in the student newspaper, but city newspapers and television stations have covered the demonstrations as well. Also, one project, the design of an improved bicycle developed by two freshman women, was mentioned in *Family Circle*, a nationally distributed women's magazine.

RETURN TO RESEARCH

THIS FALL, WITH THE FRESHMAN engineering program firmly established, Dr. Brainard resigned as its director to return to full-time teaching and research in chemical engineering. He finds his work in the department a dramatic change from the days when he served as adviser, or, in his words, "father figure of the Western World," to 450 new freshman students each year. He considered these advising sessions as very important in the development of the engineering students and never hesitated to tell an unhappy student to forget engineering and study music if that's what the student really wanted or to advise a failing student that "not making it" in engineering can be turned into a positive experience by adjusting goals toward a more comfortable and rewarding career. Since returning to chemical engineering he is able to provide more specialized advising with more attention and concern for the individual student.

At the present time he is involved as a senior scientist with two of his departmental colleagues, Professors S. H. Chiang and G. E. Klinzing, in research on hydrogen distribution and transfer in coal hydrogenation systems.

Creative design project—Improved Bicycle Design.

While Dr. Brainard's own research activities in chemical engineering were necessarily limited during the four-year period he served as director of the Freshman Engineering Program, he did manage to keep abreast of the contributions of his contemporaries. In particular, he was general conference chairman and program co-chairman for the international Twelfth Biennial Conference on Carbon, held at the University of Pittsburgh in July, 1975. This five-day conference attracted participants from eighteen countries including Japan, USSR, and Australia. Later that same year, he presented the results of one of his student's work "Liquid Crystal Thermography—A Tool for the Calibration of Numerical Solutions of the Unsteady State Thermal Diffusional Equation for an Anisotropic Solid" at the Fifth International Congress of Chemical Engineering, Chemical Equipment Design and Automation, CHISA'75, in Prague, Czechoslovakia. Having attended the earlier conference, CHISA'72, this was his second visit to Prague. He admired the many beautiful churches and other buildings and agrees with those who say Czech crystal is the finest in the world and proclaims that when it comes to Czech Pilsen pivo (beer) there is no equal —at least in his experience. An avid photographer, he shot all the film the law would allow and came back with many picture-postcard scenes. Also, flying Icelandic Airlines on the trip provided a stop at Reykjavik, Iceland, and an opportunity to expose a bit more film.

TURTLES AND MORE TURTLES

ALTHOUGH HE HAS CHOSEN not to exhibit his photography in his office, he does display a portion of his turtle collection—metal ones, ceramic ones, and one on a note pad proclaiming "Turtles get ahead only by sticking their necks out." He explains he became interested in turtles, reptiles, dinosaurs, and snakes as a child, and, while this interest waned during his teens, it resurfaced toward the completion of his graduate work, when he acquired a small midlands painted turtle (*chrysemys picta marginata*) as a gift from a friend. Shortly thereafter, he found a mate for his lone turtle, and, by the time he completed his Ph.D. and took a job with Esso (now EXXON) in Baton Rouge, had eight turtles to take along. (He may have been one of the few people to ever import turtles into the state of Louisiana). While living there, his live turtle collection reached twenty-six, and, when he came to Pittsburgh, he imported turtles to yet another state. But despite heat lamps and heaters he couldn't keep his pets from a host of respiratory problems and many died. In recent years his avocation has been directed to a collection of turtle figurines, now numbering 172, which are displayed in an attractive walnut-and-glass lighted case he constructed to house them. Although some of his turtles are virtually priceless, many of the more precious are simple, inexpensive ones given to him by his students and friends.

Aside from the figurine case in his den, turtles can be found in many other places in the Brainard's split-level suburban home. There are turtle planters, napkin rings, candlesticks, drawings, jewelry, belt buckles, shirts and neckties—even a bathroom done completely in turtle decor.

In 1975-76 he received the Western Electric Fund Award for Excellence in Engineering Education in recognition of his teaching accomplishments and contributions.

Dr. Brainard examining his turtle collection.

He is so well identified with the turtle, he often uses it as his signature. On at least one occasion, this unique signature caused a bit of a problem. For the past eight years he has been very active in the Educational Research and Methods Division (ERM) of the American Association for Engineering Education (ASEE) and for six of these years has served as back-cover artist for *ERM* magazine. Turtle signatures have been included in the majority of his back cover designs. In a recent back cover advertising the annual ASEE conference in Grand Forks, North Dakota, a new printer interpreted the turtle as a blob and deleted it from the design. Recognizing this terrible error, Brainard's contrite ERM colleagues presented him with the "Deleted Turtle of the Year Award," which hangs, duly framed, on his office wall.

A member of the ERM Board of Directors since 1972, he serves this year as program chairman for ERM events at the annual ASEE conference in Vancouver, British Columbia, and, in 1975, was editor of the "effective teaching" issue of *Engineering Education.*

In 1975-76 he received the Western Electric Fund Award for Excellence in Engineering Education in recognition of his teaching accomplishments and contributions.

EDUCATING THE EDUCATOR

HE HAS GIVEN numerous presentations on the subject of effective teaching and motivation at both regional and national ASEE and AIChE meetings and has been an invited lecturer on creativity at several universities. Recently, at an Effective Teaching Workshop which he conducted at Notre Dame University, he told the participants, "The importance of writing educational objectives and making them available to the student is central to any effective-teaching approach. Further, a study of various teaching methods—lecture-recitation, proctorial system of instruction (PSI), and audio-tutorial—has led me to believe that no single approach is necessarily to be preferred over any other. In addition to the constraints which local resources may place on the selection, the personality of the professor plays an essential role."

Although he has chosen not to exhibit his photography in his office, he does display a portion of his turtle collection— metal ones, ceramic ones, and one on a note pad proclaiming "Turtles get ahead only by sticking their necks out."

Because educating the educator is as much a part of Brainard's activities as teaching undergraduates, a portion of his efforts at Pitt has been directed toward a year-and-a-half study of ways to improve teaching at the University of Pittsburgh. The Provost-appointed study committee on which he served recommended, in addition to a required yearly review of each faculty member's performance, the establishment of an Office of Faculty Development. Strongly supporting these recommendations, he is firmly convinced that some recourse must be provided for faculty members to improve their teaching inasmuch as demonstrated abilities in this area will now have a more significant impact on decisions concerning promotion and tenure.

For one who spends so much time teaching, Alan Brainard is constantly learning. Yet he does make an attempt to occasionally draw away from the academic in favor of more casual pursuits. This fall he started jogging—in royal blue New Balance shoes, sweat pants, and a shirt which proudly proclaims "Pitt Is It." He likes to golf but seldom finds time for it. Judy, his wife of thirteen years, threatens to use his golf cart to carry her groceries if he doesn't soon put it to proper use. But there is always a paper to write, a book to read, a study to follow-up, a student who needs a little extra help. As a result, most of his sports are spectator, played with intense enthusiasm. Originally from Cleveland, Ohio, he favors the Browns in pro football and cheers for Michigan and Pitt on the college gridiron. He is particularly proud of the fact that Pitt won the National Football Championship in 1976.

In working with both faculty and students to achieve a more effective teaching-learning experience, Brainard emphasizes the need for the development of social responsibilities in today's engineering students. A quote from an article he wrote for *Pitt Magazine* expresses his deep concern: "The responsibilities of an engineering educator include the development of a sensitivity to our environment in each of our students. We want them to question the prevailing philosophies present in our society. Design topics that are addressed to cosmetic needs should receive little attention. Rather, socially-constructive designs must serve as the focal point of our teaching efforts. . . . Engineers must design for society's needs rather than its wants."

Brainard's concern is particularly personal as he worries about the world his sons, John (age 11) and Paul (age 8) will inherit. The complexities of the problems of population, various forms of pollution, the dwindling amounts of natural resources including known forms of energy, will force their generation to make many difficult decisions. He believes that people must interact with their environment in order to have some control over it. "It is not necessary," he says, "that we sacrifice all of the comforts that we have managed to introduce in the last several thousand years. We must recognize that the degree of this interaction cannot extend without limit, however."

He likes to conclude all of his presentations with a "Thought of the Day," which today will be, *"People are the greatest resource that we have; may we all provide opportunities for each of them to demonstrate their contributions."*

Alan Brainard has certainly demonstrated his. □

ChE book reviews

Biomedical Engineering Principles: An Introduction to Fluid, Heat and Mass Transport Process (Biomedical Engineering and Instrumentation Volume 2)

by David O. Cooney
Marcel Dekker, Inc., 448 pp., $36.50.

Reviewed by E. F. Leonard, Columbia University

The cover of this new text calls it "a fundamentally unique introductory *textbook* in biomedical engineering" (sic), and claims for its clientele students of biomedical and chemical engineering, physiology, internal medicine and medical instrumentation. Its author is a professor of chemical engineering and, as I shall discuss further below, there is considerable interest in teaching material for the phenomenal number of chemical engineering students with biomedical interests. The book will be reviewed here from this perspective.

Prof. Cooney's book can be considered to have three parts: (1) a selection of quantitative information about human structure and function as developed by physiologists and other biological scientists, apparently intended to be complete enough that no prior acquaintance with biology is needed to follow the rest of the text, (2) treatment of the biomedical "fluid, heat, and mass transport processes" (quote from the text's subtitle) selected by the author: blood rheology and the mechanics of blood circulation; internal and external heat transfer; drug and indicator distributions; and solvent and solute transport across cell walls and (3) consideration of current understanding of transport processes in the natural kidney followed by analysis of various artificial kidneys, then, in the same manner, natural and artificial heart-lung circuits. Each chapter of the text contains about 6 problems (with answers) plus a few discussion questions. (A solution manual for the problems is available to instructors.) The problems generally corroborate what is in the text, occasionally offering minor extensions; the problem statements often include comments about the credibility of the numerical answer.

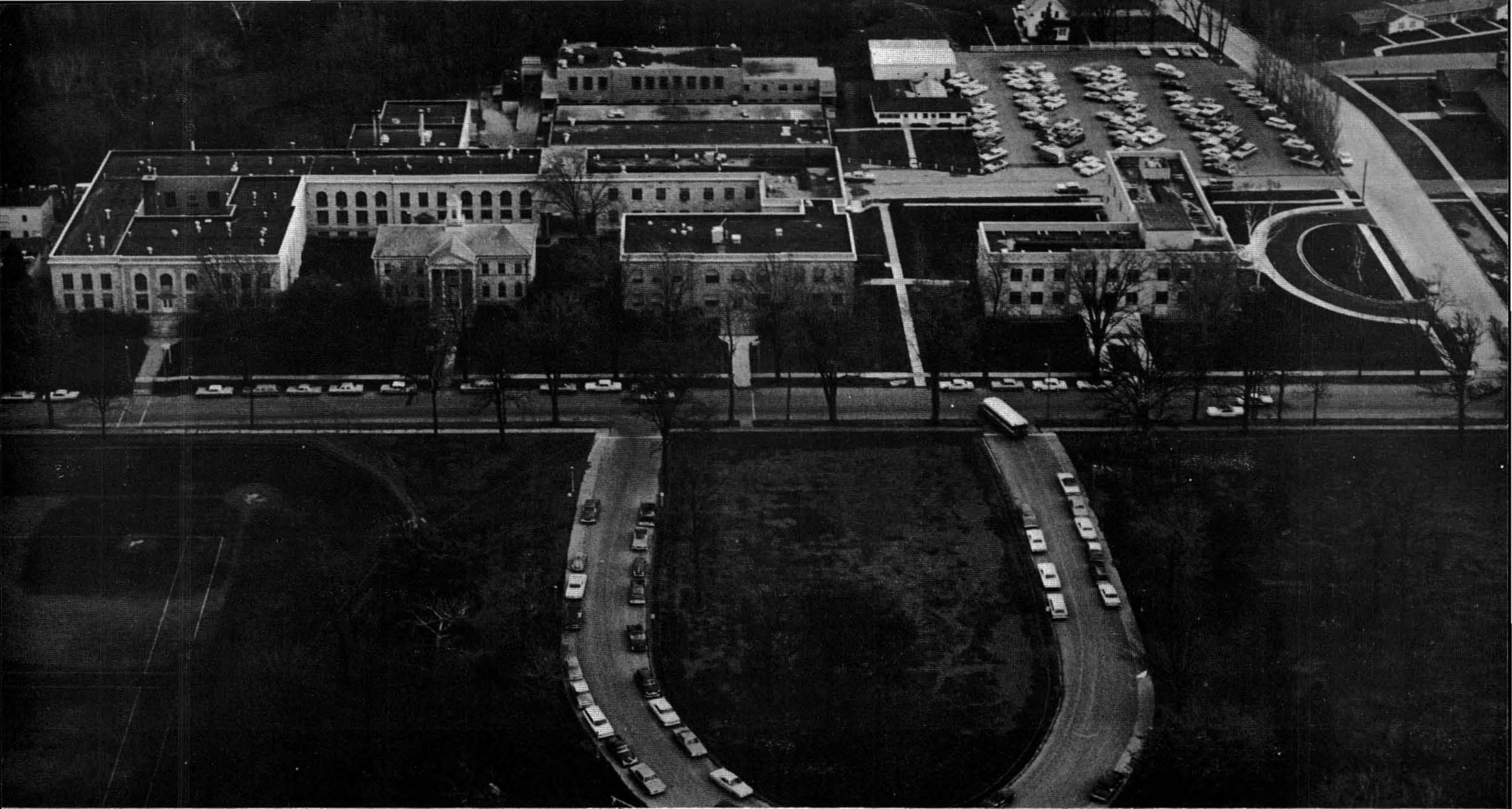
Thus this book represents a sincere and largely successful effort to make available a text in this area. Its claim to uniqueness is largely justified: Lightfoot's book is brilliant but uneven and more in the form of a monograph. Seagrave's important early effort is very elementary, limited both in scope and in ability to be interfaced with other courses. Middleman's book is the *journee* of a fine mind in a new territory, forming sound judgments but lacking detail and exercises needed by the immature student. Prof. Cooney's prose is clear and unpretentious; his development is careful and generally well-sequenced. While no biological background seems to be required, elementary fluid mechanics and either physical chemistry or chemical thermodynamics in addition to the usual engineering mathematics seems to be necessary. The text shows care in proofreading and assembly. Reference citations are complete and the index has been carefully constructed. The book is well outlined in its introduction and has a detailed table of contents. Thus the book is the best currently available text for undergraduate, and perhaps for beginning graduate, students in chemical engineering who have biomedical interests.

In my judgment this text does have serious faults, some particular and technical, others of a more general nature touching on fundamental questions about biomedical and chemical engineering. The first chapter of the book takes up a formidable task: summarizing the history and accumulated knowledge of 400 years of medical research. The response seems inadequate; what is significant for engineers and the developing specialty of biomedical engineering in the history and achievement of medicine might have been emphasized, and an effort to make particular points might have been mounted, but the absence of a relevantly critical attitude gets the text off

Continued on page 73.

CORRECTION

In the paper "Thermodynamic Heresies" by M. V. Sussman published in the Winter 1978 issue of *CEE*, the superscript ° was omitted from the free energy change $\Delta G_{reaction}$ and ΔG_r in the first three paragraphs of Heresy II page 35. In the last sentence on page 35, the word "than" should be inserted between "less" and "that." Also RdV in mid-page 36 should be PdV. *CEE* regrets these errors even though they were probably obvious to most of our erudite readers.



THE GRADUATE PROGRAM AT THE INSTITUTE OF PAPER CHEMISTRY

ROY P. WHITNEY AND
HARRY T. CULLINAN, JR.
Institute of Paper Chemistry
Appleton, Wisconsin 54911

THE INSTITUTE OF Paper Chemistry was established in Appleton, Wisconsin, in October, 1929. The concepts which led to its founding were developed by a small group of men within the Board of Trustees of Lawrence College (now Lawrence University), a liberal arts institution of distinction in Appleton. Prominent among them was Dr. Ernst Mahler, an executive of the Kimberly-Clark Corporation and a chemical engineering graduate of the Technische Hochschule in Darmstadt, Germany, who was undoubtedly influenced by the excellent work in the pulp and paper field at that institution.

It was the aim of the founders that the Institute become a unique partnership between industry and education, with three specific objectives. First, it was to undertake graduate education, "to train men in the basic sciences and technologies applicable to the pulp and paper industry, to a point where these men can assume technical positions applying science to the industry, do research on the development of new principles, and prepare for higher executive or coordinating positions." Second, the Institute was to be a research center, where both staff and students could engage in a broad program of pure and applied studies in areas and disciplines pertinent to the present and future interests of the industry. The third objective, was to develop a comprehensive library, not only serving the academic and research activities of the Institute, but also providing a central source of information for the pulp and paper industry as a whole.

The new Institute started operation early in 1930, in close affiliation with Lawrence College, with one full-time staff member and three students. Many of the classes were taught by Lawrence professors, who divided their time between the two institutions. Several staff additions were made during the first year, and more students were admitted in September. The Master of Science degree was first awarded in June, 1931, and the degree of Doctor of Philosophy in June, 1933.

It is evident that the Institute has grown and developed considerably in the forty-eight years since its establishment. Growth always brings change, of course, but there has been remarkably little change in the guiding principles laid down by the founders. The academic affiliation with Lawrence University continues, although the relationship has become more tenuous in the structural sense, and the Institute functions essentially as a separate institution. Educational activities are still concentrated at the graduate level. The academic approach continues to be aimed at breadth with competence, rather than narrow specialization. The existence of a true research environment at the Institute is important since only in such an environment can graduate study be meaningful.

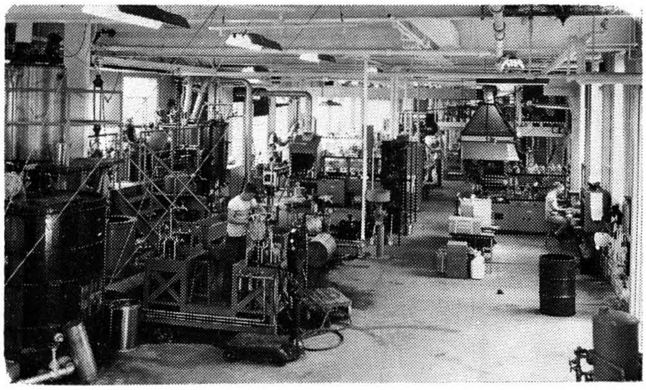
The Institute of Paper Chemistry is a private institution. In a very real sense, it belongs to the pulp and paper industry of the United States. Basic support is accomplished through the mechanism of "member companies"; any company manufacturing pulp, paper, or paperboard in the United States is eligible for membership in the Institute. The members support the Institute through membership dues, which vary in amount depending on the size of the company. That the support of the Institute is widespread is indicated by the fact that its member companies produce a majority of the pulp, paper, and board manufactured in the United States.

The buildings and equipment of the Institute have a replacement value of about $17.9 million, and the functional area for education and research is about 225,000 square feet. It is interesting to note that major capital outlays for new buildings and special equipment have been financed separately from operating expenses, and that the Institute has been the recipient of many gifts for such purposes from companies, foundations, and individuals. The total staff numbers about 225, of whom about 95 are professional scientists or engineers. This does not include the graduate students, and the research fellows and visiting scientists usually in residence. The operating budget for the current year is approximately $6 million.

At the Ph.D. level, all of the work is on an individual basis. The students' first requirement is to develop and demonstrate the capacity for independent investigation by satisfactorily completing a program called "Preparation for Research."

THE ACADEMIC PROGRAM

TURNING NOW TO the academic program, it has been noted that the Institute is primarily a graduate school in engineering and the sciences. The teaching faculty numbers 45 members, organized into five academic departments (Chemistry, Physics and Mathematics, Biology, Engineering, and General Studies). Since the opening of the Institute, 780 regular students have matriculated from 187 colleges and universities located in 44 states and 16 foreign countries. The great majority of these students have taken their undergraduate degrees in chemical engineering or chemistry; some did their previous work in biology, physics, or mechanical engineering, and in recent years students have been admitted from undergraduate pulp and paper science and engineering departments.



A general view of the pulping and papermaking laboratory.

It is worth noting that the educational philosophy of the Institute, while no longer unique, is still unusual among graduate schools. The objective is to develop the "scientific generalist," or the industrial scientist who is well versed in several disciplines within the physical sciences and engineering; but who is specialist in none. The belief is that people with a broad viewpoint, who understand the inter-relationships among scientific fields, and can range across the boundaries of disciplines in their pursuit of knowledge and insight, will be the key people in guiding this industry to new vistas and new accomplishments. This concept evolved directly from the desires of the founders for competent breadth in the graduates, and has characterized the academic approach ever since.

.... the educational philosophy of the Institute, while no longer unique, is still unusual among graduate schools. The objective is to develop the "scientific generalist," or the industrial scientist who is well versed in several disciplines within the physical sciences and engineering; but who is specialist in none.

Although it is possible to proceed directly to the Ph.D., most students who enter the Institute for graduate study first undertake the Master of Science program. This comprises a sequence of lecture, laboratory, and classroom studies, with a limited research requirement. While any student's specific program may vary somewhat with background and interests, the major requirement lies in a series of courses undertaken by all students. These are designed to insure that each student develops an adequate background in chemistry, physics, biology, mathematics, and ChE, so that the student has ample opportunity to apply learned principles to real problems in pulp and paper technology.

The basis of the program is an interdisciplinary core of courses in thermodynamics, surface chemistry, chemistry of natural products, mechanics of deformable media, and structural plant science. In addition, a sequence in applied science and engineering is required which covers pulping and bleaching processes, dynamics of papermaking, chemical recovery technology, colloid chemistry of papermaking materials, and physical properties of fibrous structures. Courses in mathematics are provided for those who need to enhance their backgrounds in this area. Students who have not previously studied ChE are required to complete elementary courses in this field.

INTEGRATION OF DISCIPLINES

ONCE THIS BASIC foundation is laid, much emphasis is placed upon the inter-relationships among fields and the integration of disciplines. Where possible, emphasis is given to systems and situations pertinent to the pulp and paper industry. Students elect one set of areas of concentration. These include process engineering, environmental technology, applied chemistry, fiber resources and materials science.

Advanced seminars are offered in cellulose and lignin chemistry. Courses in biochemistry and genetics are offered. Advanced ChE courses in process control, kinetics, applied mathematics, fluid mechanics, and heat and mass transfer continue the work in this area. Other general studies and optional courses are available. In addition, each student is required to spend a modest amount of time on an individual research problem of limited scope.

At the Ph.D. level, all of the work is on an individual basis. The student's first requirement is to develop and demonstrate the capacity for independent investigation by satisfactorily completing a program called "Preparation for Research." This approach was developed at the Institute some years ago to replace the former written and oral qualifying examinations for doctoral study. In "Preparation for Research," the student is assigned a series of complex problems, each of which may be in a different area of science or technology. The student is required to analyze the problem, search the literature, plan a research program aimed at its solution, and defend the efforts before a faculty committee. The student is not required to undertake the research or to solve the problem. The faculty members evaluate the student's performance, and attempt to help develop capacities for research planning. Normally, about one month is spent on each problem, and a student may be required to complete two or three, depending upon performance. Successful completion of this requirement results in the student's admission to doctoral candidacy, and clears the way for the one remaining task, the doctoral thesis.

The doctoral thesis must of course be specific, and an excursion in depth. The thesis is left as much as possible in the hands of the student, so that he or she derives the maximum educational benefit. The student may work in any area of faculty interest and must choose the thesis topic, (subject, of course, to faculty approval). A faculty advisory committee guides the work and reviews quarterly progress reports but leaves the initiative with the student as he or she is capable of accepting it. On completion of the research, the student presents the thesis and defends it before an examining committee appointed to represent the faculty. Students spend an average of two calendar years on their thesis research.

M.S. candidates must complete one summer of work experience in the pulp and paper industry in order to gain practical experience. Requirements for the Ph.D. include two summers of work experience. Usually, this requirement is met as early as possible in the program, so that full time can be devoted to the thesis in the latter stages.

At the beginning of the academic year, normally about 100 regular graduate students are in residence, including an entering class of about 35 new members. This decreases gradually during the year, as students complete their work. About one third of the student body are Doctoral candidates, engaged in thesis research. After Commencement in June 1977, the Institute had awarded about 554 Master's degrees and about 351 Ph.D.'s.

The great majority of regular students receive financial support in the form of a fellowship and tuition scholarship. The amount of the grant depends upon the student's marital and family status, and generally is adequate to provide essential living expenses in addition to tuition and fees. The graduates are free agents. They have no obligation to seek employment in the pulp and paper industry, although a high fraction of them do so.

OTHER ACADEMIC ACTIVITIES

IN ADDITION TO THE regular graduate program, other academic activities are worthy of note. There are the special students, for example, who are not candidates for an advanced degree, but who are sent to the Institute by their sponsors for intensive study, (usually for a period of one academic year). Special students elect courses appropriate to their interests and study with the regular graduate students.

Each year, the several Postdoctoral Research Fellows in residence at the Institute, engage in research under some member of the faculty. The Institute frequently plays host to visiting scientists who may be in residence for specific purposes.

Research at the Institute is directed toward the long range needs of the industry and spans a broad spectrum of engineering and science. Faculty participate in a large number of funded research projects. Examples are the investigation of a new O_2-alkali pulping process, laser Raman and x-ray diffraction studies on cellulose, development of methods to eliminate scaling in black liquor evaporators, structural analyses of the performance of corrugated containers, studies of retention and drainage in the papermaking process, environmental investigations of trace contaminants, and cell fusion and plant tissue culture applications.

Student research provides a significant complement to the overall research program. Examples of current M.S. research projects include the investigation of the hydrodynamics of pulp suspensions, development of computer models for waste treatment processes, studies of the enzymatic degradation of starch in whitewater systems, and determination of the rheological behavior of corrugating adhesives. Current Ph.D. theses include studies of the degradation of carbohydrates in alkaline systems, investigations of the surface properties of cellulosic materials and analysis of fiber-fiber bond strength.

The basis of the program is an interdisciplinary core of the courses in thermodynamics, surface chemistry, chemistry of natural products, mechanics of deformable media, and structural plant science. In addition, a sequence in applied science and engineering is required which covers pulping and bleaching processes, dynamics of paper-making, chemical recovery technology, colloid chemistry of papermaking materials, and physical properties of fibrous structures.

This research activity is evidence that the unique academic-industry partnership produces a setting particularly conducive to graduate student research. The Institute of Paper Chemistry, created in response to the needs of one of the largest industries in this country, continues to develop, with the support of the industry, to meet its requirements. The interdisciplinary graduate program is a product of this special relationship with the pulp and paper industry. The academic mission of the Institute continues to be the integration of a broad spectrum of disciplines and the application of the integrated whole to the solution of the problems of this industry. □

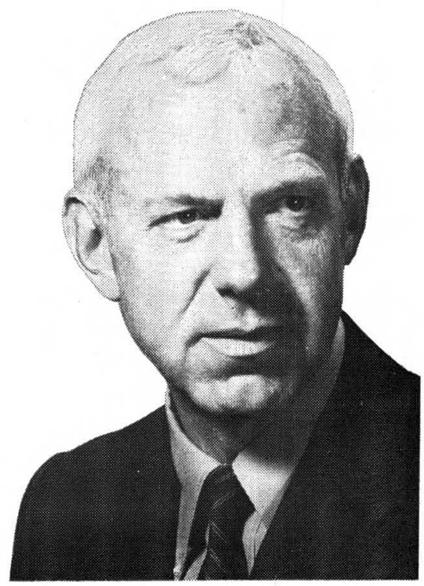
1977 Award Lecture

SUPERHEATED LIQUIDS A LABORATORY CURIOSITY AND, POSSIBLY, AN INDUSTRIAL CURSE

Part 1: Laboratory Studies and Theory

The 1977 ASEE ChE Division Lecturer is Dr. Robert Reid of Massachusetts Institute of Technology. Bestowed annually on a distinguished engineering educator who delivers the Annual Lecture of the Chemical Engineering Division, the award consists of $1,000 and an engraved certificate. These were presented to Dr. Reid at the ASEE Summer School for Chemical Engineering Faculty held July 31 - August 5, 1977 at Snowmass, Colorado. During the 1977-78 academic year, Dr. Reid will visit three universities to speak on topics related to the subject matter of his award lecture. The 3M Company is supporting this activity in addition to the award itself.

Professor Reid spent his youth in Denver, Colorado and attended the Colorado School of Mines. After a four-year interruption during the second world war, he transferred to Purdue University where he obtained both a B.S. and M.S. in chemical engineering. His doctoral studies were carried out at M.I.T. after which he joined the faculty as Director of the Engineering Practice School at Oak Ridge, Tennessee. He has been active in the AIChE and served as a Director from 1969-71 and as editor of the AIChE Journal from 1970 to 1976. He was the Institute Lecturer in 1968 and received the Warren K. Lewis award in 1976. His research interests have covered a wide range of subjects including kinetics, boiling heat transfer, life support systems, crystallization, properties of materials, cryogenics and thermodynamics. Books include texts on crystallization growth rates from solution, thermodynamics and the estimation and correlation of the properties of gasses and liquids.



ROBERT C. REID
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

WHAT IS A SUPERHEATED LIQUID? HOW ARE THEY PREPARED?

IF WE PLAN TO DISCUSS superheated liquids, we first need to define them. On Figure 1, there is shown a simple pressure-temperature graph for a pure substance. The area below the saturation curve and above the zero-pressure isobar is normally a stable gas region. If, however, a substance could be maintained as a liquid but still remain in this (shaded) region, it would then be called a superheated liquid; note that, in this case, there is no restriction to positive pressure. Super-

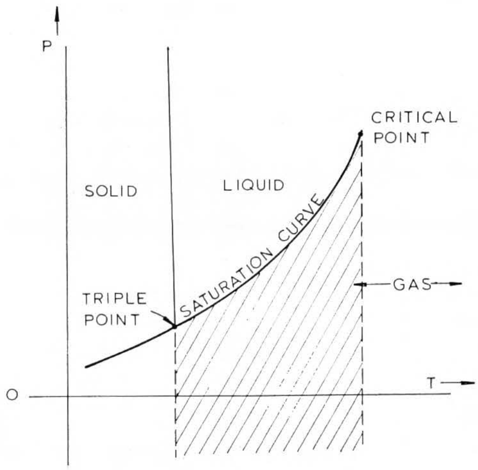


Figure 1

Domain of Superheated Liquids (Cross-hatched) For a Pure Substance

heated liquids at negative pressures (i.e., in tension) are quite common.

In Figure 2, we show the domain of superheated liquids in a different manner. Here we have isothermal sections of a P-V-T surface for a pure substance. The saturated liquid and saturated vapor curves join at the critical point where the critical temperature is shown as T_3. Tracing an isotherm, say T_1, beginning in the upper-left corner, subcooled liquid exists until the pressure equals P_1. This point represents a saturated liquid at a vapor pressure P_1. If one tries to reduce the pressure further, vaporization normally occurs and the vapor phase is represented by the intersection of T_1 with the saturated vapor curve. If, however, boiling could be suppressed, then by lowering the pressure, while keeping the system at T_1, one enters the two-phase dome as noted by the dashed curve. As will be described later, there is a limit to how far one can continue this process, and this limit is shown by the spinodal curve where the pressure is P_1'. Thus superheated liquids lie in the region between the saturated liquid curve and the spinodal curve. (A similar phenomenon could be described on the vapor side, but this then would involve us in subcooled vapors—a fascinating subject, but not pertinent to the topic under consideration).

Figure 2 is also useful in pointing out possible experimental techniques to obtain superheated liquids. The process described involved an isothermal depressurization. Alternatively, starting, say at T_1, P_2', the liquid could be heated in an isobaric manner at P_2'. The limit, in this case, would be the state at T_2, P_2'.

Before learning how one might prepare a superheated liquid, there are several fundamental concepts in boiling that need emphasis. Normally, boiling is carried out on a hot, solid surface whose temperature exceeds the bubble point of the liquid.

Referring to Figure 3, when the solid temperature is only slightly greater than the boiling point, convection currents carry away energy; no bubbles are visable and evaporation occurs at the free surface of the liquid. At somewhat higher solid temperatures, a thin film of liquid becomes slightly superheated and bubbles appear at specific sites on the solid. Irregularities on the surface, such as microcavities, have trapped a small vapor embryo; the superheated liquid film vaporizes into these preformed vapor embryos until bubbles grow large enough to detach and start the cycle again. Increasing further the solid's temperature increases the degree of superheat in the liquid and "acti-

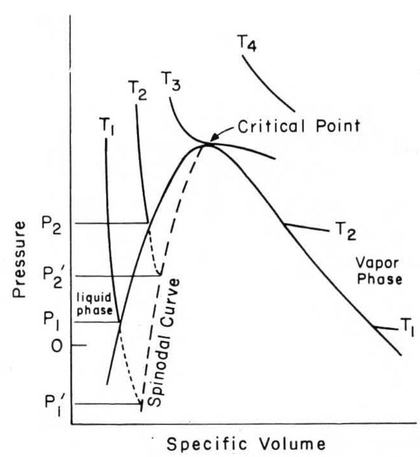


FIGURE 2 SUPERHEATED LIQUIDS LIE BETWEEN THE SATURATED LIQUID CURVE AND THE SPINODAL CURVE

Significant superheating of the liquid is then possible. The drops of the test liquid may begin to vaporize while heating if there is contact with a solid mote or if improperly degassed, but if one attains a sufficiently high temperature, there is spontaneous nucleation. With a sharp noise, a vapor bubble suddenly appears. This event resembles a miniature explosion.

vates" more cavities. The heat flux increases with the temperature difference between the solid and the bubble point of the liquid to some maximum value (peak nucleate flux) where a further increase in temperature actually causes a decrease in heat flux since the bubbles on the surface become effective insulators. This initiates the transitional region, and it continues until the entire

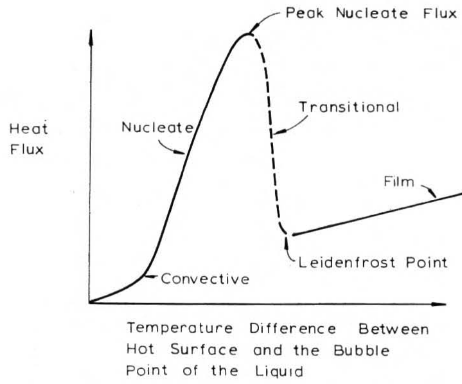


Figure 3
Boiling Regimes

surface is effectively blanketed by vapor. A minimum in heat flux is then attained and is often called the Leidenfrost point. Finally, further increases in the solid temperature increases the heat flux slowly as energy must be driven across a vapor film; i.e., the system is in film boiling.

Returning to the nucleate and transitional region, suppose the hot surface could be made microscopically smooth so as to eliminate any preexisting vapor embryos. This barrier to "nucleation" would then allow the liquid to superheat. Using a hot, very clean, immiscible liquid as a heat source is the most common way to prepare a superheated liquid.

Consider the apparatus in Figure 4 (Moore, 1959; Wakeshima and Takata, 1958). A dense, hot liquid fills the vertical column. Heating wires are wrapped about this tube in such a way as to insure that there is a temperature gradient with the hottest liquid on top. The bottom of the column is kept cool (below the bubble point of the test liquid). Small drops of this test liquid are injected and rise into the warmer zones. Heat transfer is rapid and the bulk temperature of a drop (circa 0.5 mm or less) is close to the "host" fluid temperature at any height. Significant superheating of the liquid is then possible. The drops of the test liquid

The prediction of the SLT from the thermodynamics is, in essence, a problem of predicting stability limits. Gibbs (1876, 1878) first discussed stability in a paper published a century ago.

may begin to vaporize while heating if there is contact with a solid mote or if improperly degassed, but if one attains a sufficiently high temperature, there is spontaneous nucleation. With a sharp noise, a vapor bubble suddenly appears. This event resembles a miniature explosion.

A logical question to ask is why carry out such an experiment? What is learned? At best, after many trials, we learn just how high we can heat a liquid before it undergoes a phase transition to vapor. This temperature is important because we associate it with a point on the spinodal curve (Figure 2). We also believe that this limit (often termed the superheat limit temperature or SLT) represents the temperature where extremely rapid homogeneous nucleation occurs, i.e., when vapor bubbles appear spontaneously in the bulk liquid.

There have been numerous modifications to the basic "bubble column" just described. Apfel (1971) levitated his test drops in an acoustic field while Forest and Ward (1977) held their test drops in a flow field and varied the temperature of the host liquid. Besides the bubble column there are other ways to measure the superheat limit

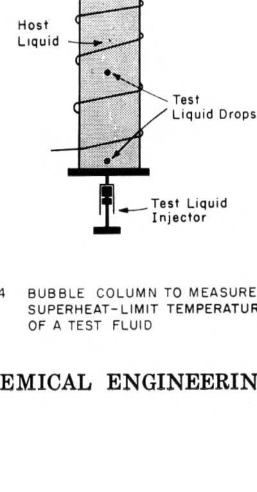


FIGURE 4 BUBBLE COLUMN TO MEASURE THE SUPERHEAT-LIMIT TEMPERATURE OF A TEST FLUID

temperature. Heating may be accomplished using very clean, very smooth glass surfaces (Briggs, 1955; Wismer, 1922; Kendrick et al., 1924; Field, 1977), but it is difficult to attain temperatures as high as found in bubble columns. Skripov (1974) and Skripov et al. (1977) describe a pulse-heating

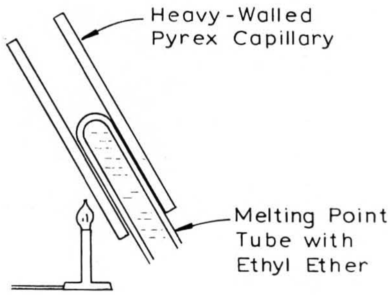


FIGURE 5
WOODBRIDGE MICRO (SUPERHEAT-) ROCKET

technique which shows promise. A programmed current is imposed across a platinum wire in the liquid. The voltage drop is monitored and the calculated resistance is related to the surface temperature of the wire. A thin film of liquid is very rapidly heated. Spontaneous nucleation is recognized by a sharp rise in voltage. The key is to heat the liquid so fast that surface nucleation on the wire surface occurs slowly relative to bulk heating and nucleation in the adjacent liquid film.

A most unusual demonstration of the rapidity of homogeneous nucleation was described by Woodbridge (1952). He selected fresh melting-point capillary tubes about 1.5 mm in diameter and 6-7 cm in length. These were filled about 3/4 full with ethyl ether. The ether tubes were placed loosely within a 15 cm, heavy-walled Pyrex capillary tube as shown in Figure 5. When heated gently, the ether expanded until liquid reached the open end when "with a noise like a pistol shot, the rocket takes off. . . ." Flights of 40-50 feet were obtained.

Typical data showing measured superheat limit temperatures are shown in Table 1 (Blander and Katz, 1975; Patrick, 1977). Note the rather amazing constancy of the ratio of the SLT to the critical temperature.

Most data for mixtures have been limited to binary systems of hydrocarbons; Figure 6 from Blander and Katz's review paper shows some typical data for the *n*-pentane—*n*-hexadecane system. In our laboratory, we are beginning to measure the SLT for polar mixtures.

THERMODYNAMIC APPROACH

THE PREDICTION OF the SLT from thermodynamics is, in essence, a problem of predicting stability limits. Gibbs (1876, 1878) first discussed stability in a paper published a century ago. Considerably more recently Beegle et al. (1974) reconsidered the problem from Legendre transform theory and derived a very general criterion to indicate the limit at which a superheated liquid becomes unstable.

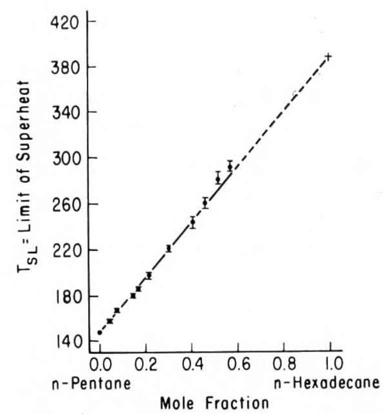


FIGURE 6 SUPERHEAT-LIMIT TEMPERATURES FOR THE BINARY SYSTEM N-PENTANE -- N-HEXADECANE AT ONE BAR

[M. BLANDER AND J.L. KATZ, AIChE J. 21, 833 (1975).]

The derivation is quite straight-forward and is based on the Gibbs criterion that, for an isolated system in a stable equilibrium state, the total entropy is a maximum. With this simple statement, and with Legendre transform theory to vary the independent variables in the system, one arrives at the result for a *n*-component system,

$$y^{(n)}_{(n+1)(n+1)} > 0 \quad \text{for a stable system} \tag{1}$$

Here, $y^{(n)}$ is the *n*th Legendre transform of the system energy and $y^{(n)}_{(n+1)(n+1)}$ represents second-order partial derivative of $y^{(n)}$ with respect to the $(n + 1)$ variable.

Continued on page 83.

Editorial

THE RANKING OF DEPARTMENTS: IS PRODUCTIVITY THE SAME AS QUALITY?

In this issue *CEE* presents the second paper by Professor Richard Griskey on the ranking of chemical engineering departments by means of an average productivity index. We suspect it will be an even more controversial paper than his previous article which was published in *CEE* in the Summer, 1976, issue. The editor of *CEE* and many of the reviewers of this paper do not agree with Professor Griskey's system of ranking departments or with the method used to obtain the results. However, rather than reject the paper on this basis, it was felt to be preferable to publish the paper along with the critical comments of its reviewers in order that our readers would have the chance to draw their own conclusions. *CEE* invites further comment on this important matter.

As in the previous paper, the criteria used by Professor Griskey were 1) refereed papers published during the past year per faculty member, 2) dollars extramural research funds expended during the past year per faculty member, 3) number of masters degrees awarded during the past year per faculty member, and 4) number of doctoral degrees awarded during the past year per faculty member.

One criticism of this paper is that the data used to obtain the indices are not reliable because they are based on only one year rather than on an average over several years and are thus subject to large fluctuations. Furthermore, much of the information came from replies to questionnaires which may be completed with varying degrees of accuracy by busy departmental chairmen and their secretaries.

Another criticism is that the results are not meaningful. But Professor Griskey argues that his criteria are meaningful because 1) they are normalized in terms of the number of faculty and 2) they can be quantitatively measured and are therefore "objective." But while normalization on the basis of the number of faculty members may seem reasonable as a measure of productivity, this may not be the case if one is trying to measure quality. For this implies that departmental size offers no advantages to the student or professor. Actually, some students could benefit from a large department because the larger faculty could provide them with more opportunities to select course work and research in their area of interest and some may profit from the atmosphere of a small department. So it is basically a subjective opinion as to whether quality can be measured by a normalized index.

Furthermore, Professor Griskey's rankings are not truly objective because they are based upon the subjective opinions that the four indices he uses actually measure quality (either individually or collectively), that they alone should be used, and that each of them should have equal weight.

But do Griskey's quantitative criteria really measure quality?

As one reviewer points out, his productivity index has shown a correlation coefficient of 0.5 to 0.73 with large sample peer evaluations (such as used in the American Council on Education reports). Thus, his method "accounts for only 25 to 50 per cent of the quality variations indicated . . ." and his index fails to include some variables which many educators consider important.

Another of our reviewers, whose department ranked high, is even more emphatic. He says that if he were to "push for a substantial increase in any or all of Griskey's categories next year . . ." he would "necessarily *lower* the quality of graduate education" in his department. "The faculty" he says, "would divert more time away from students and into dealing with government agencies and would have less time to spend on *each* student because of the higher enrollments required to produce more degrees and because of the greater time they would need to spend "writing papers they shouldn't have" to get more publications.

As he points out, "simply counting degrees says nothing about the quality of the degree or the worth of the educational experience to the student." In fact, contrary to traditional concepts of educational quality, Professor Griskey has made a *high* student-faculty ratio a desirable goal, rather than a low one. Such emphasis on productivity is thus somewhat like ranking all composers (whether classical, country or rock) on the basis of their annual output. Or, on a more down-to-earth level, it is like ranking the nation's restaurants on the basis of the number of hamburgers they produce per employee per year. Both the quality of composers and the quality of restaurants are matters that are much too subjective and too complex to be determined by productivity indices, no matter how accurate the data.

Of course, the above comment is not meant to state that a *low* average productivity index should be the goal of every department either. Instead, each department and each university must have some latitude in setting its *own* goals. Rankings such as those of Professor Griskey's tend to promote conformity, as some departments, in striving for a higher ranking, might tend to lose sight of their own unique mission. As Professor King points out, "All departments should not have similar goals and variety should be encouraged."

The editor feels that the ultimate goal of a department should be to serve society in its own unique way rather than to rank high on someone's list. For some departments, this may very well involve providing the largest possible number of students with graduate degrees; for others it may instead involve providing a small number of students with what it feels is a quality education. For some it may involve doing currently-fundable research; for others, it may involve doing exploratory or pioneering research for which extramural funding may not be available. For some departments, a large undergraduate program may be desirable to serve the needs of the citizens of the state government that supports it and to provide justification for a large faculty; for others it may be better to have some faculty who primarily do undergraduate teaching and others who primarily do research; for still others it may be desirable that they all do research. Each department and each situation in time and space is different and it is detrimental to the ideal of service to society that, through such a system of rankings, departments are tacitly encouraged to produce more Ph.D.s of dubious ability, and their faculties are driven to write more papers of questionable value, and to seek more contracts to do research of little long-term significance—all in a vain drive for high institutional rank and prestige.

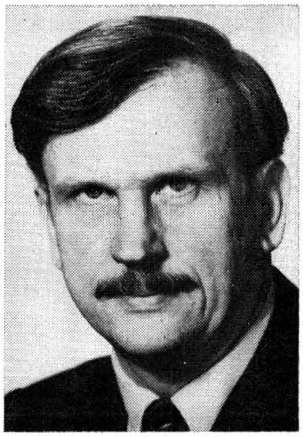
In essence, the Griskey set of rankings not only stimulates the setting of false goals but also implies that a complex, multidimensional and subjective matter, educational quality, can be reduced to a single number. That does not work when dealing with restaurants and hamburgers, and it certainly does not work when dealing with departments and human beings. □ **RWF**

RANKING ChE DEPARTMENTS IN TERMS OF PRODUCTIVITY INDICES

RICHARD G. GRISKEY
University of Wisconsin-Milwaukee
Milwaukee, Wisconsin 53201

THE RANKING OR ordering of chemical engineering departments is an important aspect of information for those in industry, government, and academia. In an earlier paper [1] a method of attempting to do this in an objective fashion was presented. The method involving statistical data published for four indices of performance was used to generate an overall index of performance. In contrast to earlier studies the ranking reflected overall graduate and research productivity and not just doctoral program effectiveness. The four indices of performance were: 1) masters and 2) doctoral degrees awarded per faculty member per year, 3) thousands of dollars of extramural research funds expended per faculty member per year and 4) refereed publications per faculty member per year. The development of these indices was based on units of performance per faculty member so that a more effective means of contrasting departments could be developed. Although the technique differed from earlier studies that were made, its results compared quite closely to the findings that were determined by other ranking evaluations [2, 3, 4].

The earlier studies included those published by the American Council on Education (ACE) in 1966 and in 1969 [2, 3]. The 1966 study [2], the now famous Cartter Report, an assessment of quality in graduate education was followed by the later study, a rating of graduate programs by Rouse and Andersen [3]. Basically the ACE studies consisted of polling selected faculty members in universities and then asking them to rank departments on two bases: quality of graduate faculty and effectiveness of doctoral program. It was found in these studies that there was a high degree of correlation between both rank efforts. The results of these studies as well as that of a later study [5] made using a variety of different indices correlated well with the work derived from the graduate productivity index [1].



Richard G. Griskey received his B.S., in Chemical Engineering from Carnegie-Mellon University in 1951. From 1951 to 1953 he was a First Lieutenant in the Combat Engineers of the U. S. Army Corps of Engineers. In 1953 he entered Carnegie-Mellon where he was awarded an M.S. (1955) and Ph.D. (1958).

The National Academy of Science appointed him as Senior Visiting Scientist to Poland in 1971. In the same year he was appointed Dean of the College of Engineering and Applied Science of the University of Wisconsin-Milwaukee as well as Professor of Energetics.

He has had industrial and consulting experience with DuPont, Celanese Fibers, Celanese Research, Phillips Petroleum, Thermo Tech Inc., Hewlett-Packard, Litton Industries and the U. S. Veterans Administration. He is a member of AIChE, Cryogenic Society, Society of Plastics Engineers, ASEE, and the Society of Rheology.

INDICES OF PERFORMANCE

THE STUDY WAS repeated during the present year to see what changes had been made in the relative productivity indices and also in the overall ranking of the departments. Top index values for all categories are shown in Table I. Figures 1 through 4 are of interest in this respect—they present the four indices and compare the 1976 survey to that made in 1977. In looking at these important trends can be detected. For example, if we study the first of these plots that relates to the masters degrees per faculty member per year, we see that the peak is approximately the same for both 1976 and 1977. This of course indicates that the relative productivity has remained the same in both years. However we find that the other indices have changed. For example, Figure 2 which shows the same information for doctorates implies that the highest frequency in terms of productivity has downshifted closer to the zero point being a much smaller figure than was recorded last year. The net result would of course seem to indicate a lessening of productivity and activity at this level. However, this must be tempered in light of recent changes in engineering enrollments. A number of years ago in the early 1970's enrollments declined drastically on the undergraduate level and in addition during the past few years graduate enrollments have gone down somewhat. The net result of these changes may be reflected in the apparent decline in doctorate productivity. In a similar fashion in Figure 3 we can see that the frequency distribution in terms of extramural funds has changed to an upward cycle. It is apparent that more money is being expended per faculty member per year. Now this may seem somewhat anomalous in light of the lessened activity degree for Ph.D.'s.

TABLE I
Top Index Values for Categories.

CATEGORY	TOP INDEX VALUE
M.S. Degrees Awarded/Faculty Member/Year	3.33* (2.08)
Doctorates Awarded/Faculty Member/Year	1.57 (1.14)
Thousands of Dollars in Extramural Funds/Faculty Member/Year	214.7 (122.2)
Refereed Publications/Faculty Member/Year	3.75 (3.62)

*Values in parentheses from (1)

However, inflationary pressures account for more money being spent to do the same or lesser amounts of research. Finally, consider Figure 4 which shows the publications per faculty member per year. The 1977 totals indicate what appears to be a significant decline in the number of publications. This possibly is partially a result of course of the lessened number of Ph.D.'s. It is well known that it is more difficult to publish masters or baccalaureate type research than Ph.D. dissertations. The lessening of this activity is probably interrelated with the doctorate decline. Thus on an overall basis it would appear that the productivity in terms of master's degrees is holding about the same; the amount of extramural funding per faculty member is increased somewhat; and both doctors degrees and publications have declined.

The data that was used to generate this information came from two separate sources. The first was the annual supplement of the engineering education magazine titled *Engineering College Research and Graduate Study* [6]. The volume

It should also be mentioned that a number of suggestions were made relative to other parameters. These included such considerations as graduate student quality, faculty quality etc. These unfortunately are for the most part subjective judgments and cannot be readily quantified.

gave the numbers of master's and doctorate degrees awarded and the amounts of extramural funds expended. The "Directory of Graduate Study" published by the American Chemical Society gave listings of refereed publications. The former source gave annual data while the latter was on a biennial basis. It was found that some data for certain departments were not available in the sources. To remedy this, a number of letters were sent to ChE departments for pieces of informations that were not available. Many responded so the total number of institutions included in this survey is greater than those of the 1976 effort.

OVERALL RANKING

THE OVERALL RANKING of ChE departments by Graduate and Research Productivity Index (GRPI) is given in Table II. In addition

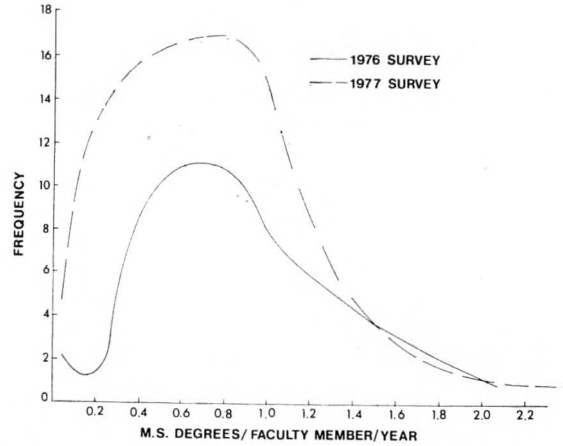


FIGURE 1: Frequency Distribution for M.S. Degrees per Faculty Member per Year.

to the present ranking the 1976 GRPI as well as the ACE 1970 and 1966 survey results are given. Incidentally the 1977 GRPI ranking result had a correlation coefficient of 0.90 with the 1976 GRPI result at a probability level of over 0.001. Table III lists institutions not in the overall survey but which were used to supply certain data. It should be reiterated that all institutions had the opportunity of giving this data as per the mailing mentioned earlier.

As in the previous survey the current GRPI is given as a cumulative function in Figure 5. This makes it possible for any institution not included in the final ranking to determine its relative level. To do this, first calculate the ranking in each of the four categories using the data of Table I. Next, sum these and divide by the top index sum (2.72). This will enable the institution to find its relative percentage rank.

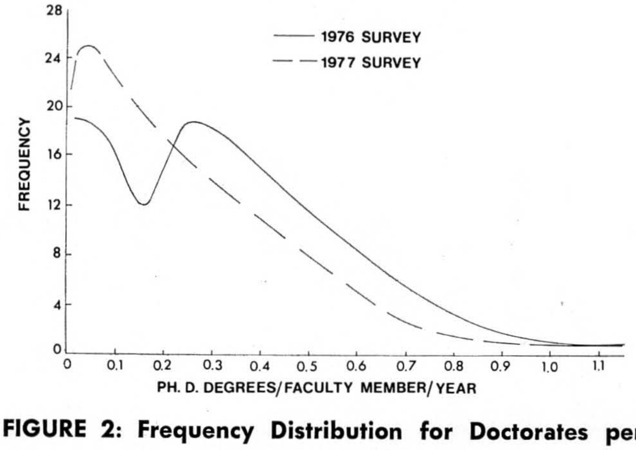


FIGURE 2: Frequency Distribution for Doctorates per Faculty Member per Year.

TABLE II
Ranking of Institutions

SCHOOL	PRESENT SURVEY	1976 SURVEY (1)	1970 A.C.E. ( )	1966 A.C.E. ( )
Stanford	1	1	4	10
Illinois	2	4	6	8
U. Cal. (Berkeley)	3	*	3	4
Cal. Tech.	4	*	9	9
Oklahoma State	5	*	–	–
Lehigh	6	10	–	–
M.I.T.	7	3	4	1
Columbia	8	8	–	–
Princeton	9	*	6	3
SUNY (Buffalo)	10	16	–	–
Florida	11	**	–	–
Pennsylvania	12	6	15	–
PINY	13	16	–	–
I.I.T.	14	7	–	–
Houston	15	*	–	–
Delaware	16	*	10	6
Carnegie-Mellon	17	13	13	12
Purdue	17	20	17	–
CUNY	19	**	–	–
U. Massachusetts	20	**	–	–
Case	21	*	–	–
Kansas State	22	*	–	–
Rutgers	23	*	–	–
Clarkson	24	22	–	–

*Only partial data available in 1976
**Included in 1976 survey but unranked
–Not ranked

DISCUSSION AND CONCLUSIONS

THE 1976 SURVEY [1], to say the least, aroused a considerable amount of interest and discussion. The responses extended from positive attitude and constructive criticism to negative inputs with accompanying denunciations. Some of the more frequent comments concerned the year to year consistency of ranking results, the absence of certain "name" departments, and the possibility of a small department with a "star" or two receiving an inordinately high ranking.

The response to the first point (year to year) consistency is at least partially answered by the correlation of the 1977 and 1976 rankings. While there is some volatility there is also consistency in the ranked departments. The question of continued consistency can of course only be answered by additional future surveys.

The absence of certain departments named in the 1966 and 1970 ACE studies [2, 3] from the present ranking might be at least partially attributed to departmental size since the average number of faculty in these departments was 17.8 (range of 12 to 22) as compared to 13.2 (range of 7 to 23) for the departments ranked as per Table II. Furthermore, the situation seems to be related to the comments made about the possibility of a small department making an exaggerated impact because of a faculty "star." A study was made of the departments ranked in Table II that had fewer than ten faculty to determine if this was possible. The only parameters that could be used were Ph.D. and publications per faculty member since the M.S. and extramural funding data was on a department-wide basis. A check of the nine departments showed only two in which there was what could be considered an excessive influence of one or two faculty members. Both of these instances related to publication per faculty member. Furthermore, since four indices are involved in the overall GRPI it would seem that the overall impact on final rankings of an active faculty member in a smaller department would not be great. Finally, one additional point to be considered is departments even smaller in number (4 to 6 faculty). This factor could be even more sensitive

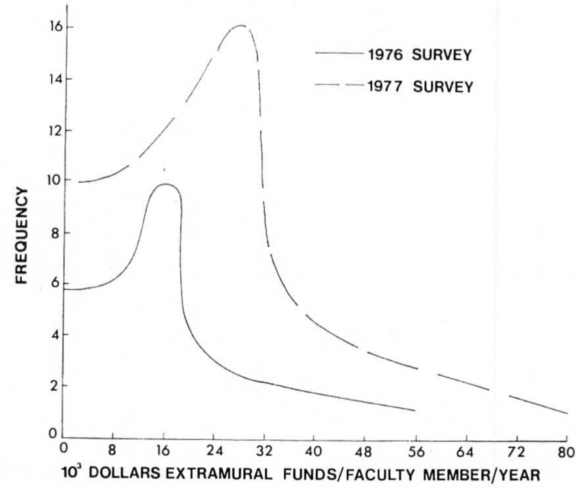


FIGURE 3: Frequency Distribution for Thousands of Dollars of Extramural Funds per Faculty Member per Year.

Some of the more frequent comments concerned the year to year consistency of ranking results, the absence of certain "name" departments, and the possibility of a small department with a "star" or two receiving an inordinately high ranking.

in relation to a faculty member skewing the GRPI. However, this was not the case since such departments were far removed in GRPI from those in Table II.

The foregoing, while indicating the lessened impact of small departments does not indicate why some "name" departments do not appear in the rankings.

Again, a closer examination was made of these departments in terms of publications per faculty member. It was found that about 25% of the faculty in these departments had not published in a two year period. This result would seem to indicate the presence of a surprisingly large group of faculty in those departments whose principal endeavors are apparently dedicated mainly to undergraduate education and public service. In a sense, perhaps there is here an inverse of what is projected for small departments; namely, a sizeable bloc of professors whose involvement in graduate study and research is minimal with the result that the departments GRPI is lowered.

TABLE III
Institutions not Rated but used to Supply Certain Data.

A. **The following institutions were used to supply all data but publications.**

Akron	Mississippi State
Arizona	New Hampshire
Auburn	Northeastern
Cooper Union	Washington (Seattle)
Michigan Tech.	Wyoming

(1976 total was 40 institutions)

B. **The following institutions were used to supply all data except as noted.**

Catholic U. (M.S., doctorates, extramural funds)
Rochester (extramural funds)

It should also be mentioned that a number of suggestions were made relative to other parameters. These included such considerations as graduate student quality, faculty quality, etc. These unfortunately are for the most part subjective judgments and cannot be readily quantified. Furthermore, is, for example, graduate student quality even a valid consideration? Perhaps the factor should be the intellectual and professional growth of the graduate student in the particular program. In any case the inability to objectively

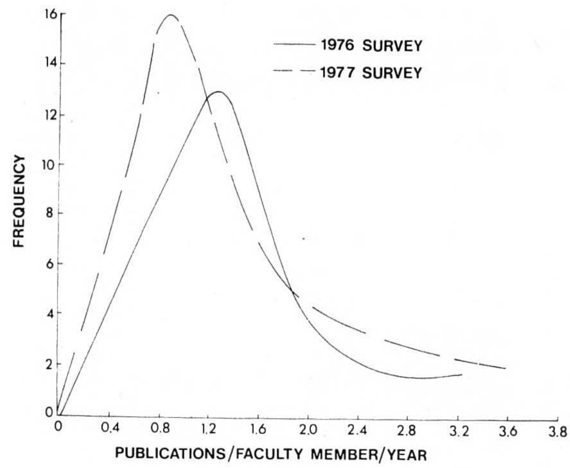


FIGURE 4: Frequency Distribution for Publications per Faculty Member per Year.

evaluate many factors prevents their consideration in a ranking of the type described in this paper.

It is believed that the study described in this paper presents an objective method of evaluating the graduate and research productivity of ChE departments and that the good correlation between the 1976 and 1977 studies indicates an internal consistency in the technique. There are a number of other important points illustrated by the survey apart from rank. For example, even critics will have to admit that productive, less known departments are readily identified by this process. Additionally, the data of Table I and Figures 1-4 provide a means of individual self-examination by faculty. Using these data a pro-

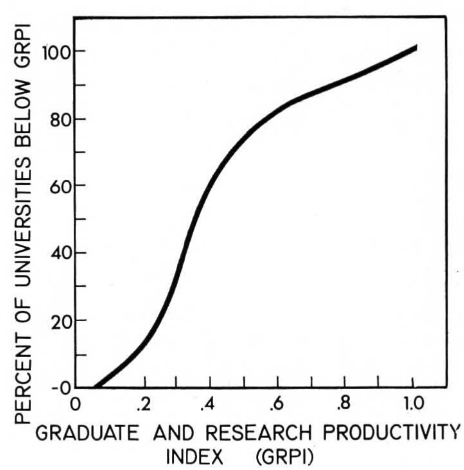


FIGURE 5: Ranking Versus Graduate and Research Productivity Index (GRPI).

fessor's performance can be compared to the top level indices and the frequency curves so that some idea of individual productivity can be obtained. □

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REVIEWER'S COMMENTS

COMMENTS BY PROF. C. JUDSON KING

University of California, Berkeley
Berkeley, California 94720

I am sorry to see continued publication of rankings of this sort, since I feel they provide no positive or useful purpose to the chemical engineering community.

First of all, I feel that rankings of this sort are undesirable in principle. They generate results on bases that must necessarily be subject to much question. They fix numerical rankings in people's minds, without the underpinnings of the number being recognized or remembered. Criteria of excellence must necessarily be subjective, qualitative and variable. All departments should not have similar goals, and variety of emphasis should be encouraged. Variety gets lost in surveys of this sort.

Even without the "in principle" point, the criteria themselves do not seem to me to correspond to excellence, or to factors which would lead me to recommend a school to a would-be graduate student: (1) The size of the research funding does not relate to the quality of education a student will receive. In fact, big money may mean lots of paid professionals, lots of faculty administrative commitment, and a reduction of faculty attention to the students on a project. (2) Simply counting degrees says nothing about the quality of the degree or the worth of the educational experience to the student. It does not differentiate the tutorial experience in a thesis M.S. from a coursework M.S. (3) In some fields of research it is customary to write many short papers, each with small content; in other fields this is not the case. Some professors are overly prolific, publishing much the same thing repeatedly. And again, counting papers does not relate to the quality of a student's educational experience.

Put another way, if I were to push for a substantial increase in any or all of Griskey's categories next year with our present faculty and students, I would necessarily *lower* the quality of graduate education in our department! The faculty would divert more of their time away from students into dealing with government agencies (getting money) and hiring and supervising non-students (using the money); and/or they would have less time to spend on each of their students because of higher enrollments (more degrees); and/or we would eliminate the M.S. thesis or otherwise reduce the content of degree programs (more degrees); and/or some professors would spend time away from students writing papers they shouldn't have (more publications)!

It would be better to put the whole ranking question gently to bed!

GRISKEY'S RESPONSE: The above review has, I feel, missed the point of the paper. It is not to set up a rigid ranking system. Nor is it to *force,* as he seems to think, any one professor or any department to place emphasis on grants, M.S. degrees (etc.). Instead, the paper attempts to focus attention on a subject that will be discussed regardless of our feelings about it. Furthermore, it does this in the most objective fashion possible. For these reasons, I disagree with his recommendation for non-publication.

As a side issue, I am a little concerned about his comment that "Criteria of excellence must necessarily be subjective, qualitative and variable." This type of philosophy leads ultimately to personal feelings with all of their vagaries as a criterion. Such a system is, in my opinion, far worse than even a bad quantitative system (which the paper is not).

COMMENTS BY PROF. RUTHERFORD ARIS

University of Minnesota
Minneapolis, Minnesota 55455

To comment on Dr. Griskey's "objective" rating of chemical engineering departments is to incur the suspicion that one takes it seriously enough to wish to know the "rank" of one's own. However the fortunate omission of Minnesota from the new rankings and your request for comment will perhaps reduce my perusal of part II from the mortal to the venial category of sins. It is unfortunately true that there are people who, as Dr. Griskey says in his opening sentence, regard these rankings as "an important aspect of information for those in industry, government, and academia." It is to be hoped though that they inform (in the true sense of the word) their opinions by something more than quantifiable or so-called objective criteria, for these exercises in numbers are the kind of quantification that renders futile much current research in the social sciences.

In the first place I am sure no one is more aware than Dr. Griskey of the great difficulty of obtaining reliable data on which to base his calculations. Nowadays we are bombarded with so many questionnaires asking for numbers, costs, and other statistical information that it would be a fulltime occupation to answer them with the scrupulous accuracy that they seem to presume. But even if they were accurate the statistics on which the index is based are liable to considerable fluctuations. Perhaps a three or four year moving average would do something to smooth this out, but simply to take the number of PhDs reported in any one year is to invite fluctuations which are quite liable to bounce the candidates around among their rankings in a most haphazard way. Again simply counting the number of refereed publications is bound to give a very variable figure unless averaged over a suitable time period. In any case this ignores the monographs and graduate texts which are just as much an indication of the faculty's concern for graduate education as are the research publications. There have been few more influential texts than the famous Birdfoot nor any more indicative of the high level of graduate (and undergraduate) instruction at Wisconsin, yet such texts would be completely overlooked by the publication index. Moreover since a considerable amount of effort might be diverted from research papers into the writing of such a monograph its neglect is an error of commission as well as of omission. A much more interesting and useful statistic might be compiled from the *Citation Index* for this would give some idea of how the published works of faculty were influencing the research of others. Even this would have to be compiled with great care and indeed would involve an enormous amount of work. But at least it would come closer to weighing publications rather than just counting them. Even the amount of extramural grant money has to be weighed, rather than counted, for in some places it may reflect the activities of a single individual in building up a major laboratory facility rather than any overall health of research activity in the department.

The simple fact is that no quantitative measure can do justice to educational quality. Like the true harvest of Thoreau's daily life it is "somewhat as intangible as the tints of morning and evening." How, for example, is the ethos of the department to be calibrated. A department could have high academic standards and impose them ruthlessly without regard to the nurture of students. Another department could have equally high and productive standards but put much more effort into seeing that those of good, but less than brilliant, abilities were brought along to the highest standard of excellence that they could achieve. No index is going to reflect this. The relationship of the department to the university as a whole is also difficult to quantify. There are some departments which are very good yet set in colleges or universities of fairly dismal proportions. Even an index for the university as a whole will not do, for it ignores the nature of the relationship. We are fortunate at Minnesota in having a mathematics department with quite a few faculty who will discuss problems with engineers. In other universities the faculty of mathematics can be extremely "pure" and there be little intercourse. Clearly this kind of relationship makes for a stronger and more enviable department yet it is hard to see how it could be embodied in any numerical criterion.

In fine, Sir, I would suggest that we are a mature enough profession to put rankings behind us. As I said to a friend at Wisconsin who was on the verge of being apologetic in the face of the

Gill report, "We didn't believe the Carrter or Roos-Anderson, so why should we believe this?"

GRISKEY'S RESPONSE: This review has some good points concerning the paper, some of which already mentioned in the manuscript (see for example the sentence about the intellectual and professional growth of the graduate student). The suggestion of considering influential texts is fine except for the fact that no conclusive agreement could be reached as to what texts fall in this category. To cite my point there are some (not myself) who even question "Birdfoot" as a classic graduate text!

The *Citation Index* (C.I.) approach is one that was also suggested by Gill. This, however, has the defect that some authors conduct a "round-robin" of citing each other's work in somewhat limited areas of endeavor. Furthermore, the C. I. does not allow for situations where industrial practitioners actually use the paper for design or operational purposes. Finally, the use of refereed papers as per "Part II" is, in my opinion, a strong enough safeguard as to quality. If it is not, then we as a profession have failed in our responsibility to provide proper reviews.

I agree that there are other points that could be considered, but again how do we determine these? Generally, they must be extremely subjective which I feel is self- defeating. Incidentally, the question of the remainder of the university is a two-edged sword. A poor department in a strong university also can receive unwarranted acclaim by the reverse of guilt by association.

COMMENTS BY WARREN E. STEWART

University of Wisconsin
Madison, Wisconsin 53706

The strength of a chemical engineering department cannot be measured properly by such rudimentary data as staff size, enrollment, funding and graduation statistics. This claim is borne out by Griskey's calculations (CEE 1976) which show a correlation coefficient of only 0.5 to 0.73 between his productivity index and large-sample peer evaluations. Thus, his method accounts for only 25 to 53 percent of the quality variation indicated by the peer appraisals.

High productivity on the Griskey scale is neither necessary nor sufficient for a strong educational program. Indeed, use of his four productivity measures as guidelines could be harmful, since overemphasis on these goals could compromise the quality of teaching, counseling, research, and publications.

The main problem with so-called "objective" rating systems is the neglect of personal factors. In the present context these include: quality of faculty; rapport between faculty and students; breadth and depth of teaching and research programs. These factors are difficult to quantify, but they are very important to the quality of education.

COMMENTS BY WILLIAM H. CORCORAN

California Institute of Technology
Pasadena, California 91125

Review of this paper is difficult because I have a bias against ranking of chemical engineering departments. The four criteria used are on an annual basis and are M. S. degrees awarded per faculty member per year, doctorates awarded per faculty member per year, thousands of dollars of extramural funds per faculty per year, and refereed publications per year. The author clearly points out that neither quality undergraduate education nor public service are involved. Clearly, then there could be other elements of an index if an author so chose. Professor Griskey chose to stay with his defined criteria. Ranks were developed and presented. There can be no argument about the objectivity based upon the criteria used, but the criteria are really limited.

One of the real functions of a chemical engineering department is to prepare students for graduate work or industry, and so there cannot be any ignoring of undergraduate development. There could be difficulty in evaluating undergraduate development of the student. There clearly is difficulty in evaluating quality in the program. So all we have then, finally, is a ranking based upon some numbers and which may be rather sterile and rather fruitless. Perhaps if we think about this matter further we could stop ranking departments. Ranking clearly is effected in the intelligence network of corporations which hire students and by students themselves as they prepare for graduate school or just ask questions about undergraduate schools.

Professor Griskey's evaluation nevertheless is on sounder ground than some. A recent evaluation published in *Chemical Engineering* by a staff member of a western university uses college catalogs and correspondence with faculty. That process should just about bury ranking of schools, and that might be too bad because there may be some element of truth in what Professor Griskey is trying to do.

COMMENTS BY J. J. MARTIN
University of Michigan
Ann Arbor, Michigan 48109

There are many ways of ranking engineering departments. Dick Griskey has chosen to rank them on the basis of GRPI (Graduate and Research Productivity Index).

Since this is not the only basis, for one could well consider professional activities, consulting, government committees, undergraduate programs, and the like, it is necessary that his particular approach be identified early or it may be misleading. I would support publication of his paper if the title had the particular qualification of the basis of ranking by GRPI. Thus in the Introduction there should be some discussion of the total departments' activities so that the reader can see the narrower basis of Dick's technique of ranking. With these changes I recommend you publish his paper.

COMMENTS BY DAVID HANSEN
Rensselaer Polytechnic Institute
Troy, New York 12181

I believe the manuscript "Ranking Chemical Engineering Departments Part Two" should be published as a natural follow-up to Part One. I expect it will be even more controversial and if there is ever a further sequel you should consider more carefully the value of continuing to publish this type of material. The summary statistics are useful. Personally, I believe the rankings are meaningless.

COMMENTS BY J. W. WESTWATER
University of Illinois
Urbana, Illinois 61801

This is an interesting study and should be published.

BOOK REVIEW: Biomedical
Continued from page 55.

to a weak and pedantic beginning. However, the book's greatest lack seems to me to be the absence of a precise pedagogical goal. The subject area is clear, but what is being taught about the area is not. For example, large amounts of information are presented in early parts of the book with only suggestions about how the information might be used. The review of blood rheology is not used to teach principles (cf. Bird *et. al.* Transport Phenomena) nor does it lead to clear design-style recommendations about when account must be taken of the various phenomena that are considered. (Incidentally use of the Magnus phenomenon to explain axial accumulation of erythrocytes is incorrect; the particle Reynolds numbers are too small.) The general utility of the information developed on circulatory dynamics is not established; a qualitative, and to me simplistic, discussion about how and where aneurysms develop is given. The fifteen percent of the text dealing with the human thermal system is very detailed in its treatment of previous work in physiological heat transfer but is unclear in its pedagogical intent. The subject has not received and does not seem to deserve as large a role as it has in this book. The chapter on compartmental analysis is clearly written and contains much useful information; but still it does not, in my judgment, spend enough time on principles (e.g. the work of Danckwerts, Zierler, Shinnar, Berman) nor develop general techniques for model building, nor give an adequate appreciation of the wide application of compartmental models in modern bioscience. The step from lumped to distributed models is taken with very little specific recognition of the profound physical and mathematical differences involved. One of the most important practical aspects of compartmental analysis, the requirements that a tracer must meet, is not discussed.

The development of the theory of elementary transmembrane transport for substance passively transported down an electro-chemical gradient is very lucid (although its applicability to situations where active transport is also present should be explained) but the importance of the results is discussed neither from a physiological or engineering viewpoint. The treatment of renal transport mechanisms is also lucid (but incomplete especially with respect to the important countercurrent multiplier mechanism for urine concentra-
Continued on page 91.

COMPARISON OF COURSE TYPES BY DESCRIPTIVE AND PRESCRIPTIVE EDUCATIONAL FACTORS

The following two papers concern subjects presented at the Pentennial Summer School for ChE Faculty in Snowmass, Colorado, July 31 - August 5, 1977. Other Summer School papers will appear in subsequent issues.

J. T. SEARS
West Virginia University
Morgantown, West Virginia 26506

IN PREPARING TO teach a course, there are several major decisions which must be made. What should be the general goals? What content needs are to be included? What type of learning environment should be fostered? How can the selected goals best be achieved? The decisions must rest with the faculty involved.

However, this paper is intended to aid the decision-making process by providing information about course formats and the framework they provide to meet selected objectives. This paper will classify the important possible course structures into five formats and discuss these structures with respect to educational prescriptive and descriptive factors.

John T. Sears is associate professor of chemical engineering. He received his B.S. from Wisconsin and his Ph.D. at Princeton. His research interests include solid-gas reactions, fluidization, and interdisciplinary studies of engineering and economics.

TABLE I
Prescriptive Factors in Educational Design*

These are factors needed to best enhance student learning, irrespective of format.

- **Statement of Intended Outcome (Precise statement of instructional objectives and goals for student to perform)**
- **Pleasant Conditions**
- **Informative Feedback (to students)**
- **Meaningfulness, Relevancy (as perceived by students)**
- **Reinforcement (of student performance, including valid measurement of learning, and rewards)**
- **Hierarchy of Content Organization (Materials)**
- **Active, Appropriate Practice (by students in homework, design, projects)**

*These factors are based on a consensus input from groups at the Engineering Education Conference, New Hampshire 1976; West Virginia University Engineering Education Seminar, 1976; and the A.S.E.E. Summer School, 1977.

Any course needs to include certain features in order to be successful, and these, as listed in Table I, are based on responses of concerned educators from several workshops. Although arguments might be made to include other factors, for brevity, only these composite factors will be discussed.

In addition, a course can be described according to class size, pacing, resource consumption and other factors given in Table II. Most of these factors are self-explanatory, but a few words should be said with respect to group size and problem solving.

For one or two students, a Socrates individualization with the instructor is possible, but this group size is generally unrealistic. For a group size of three to seven, all students have an oprtunity, and can be expected, to participate in class questioning and discussions. For group sizes of seven to twelve, all students have an opportunity to participate without feeling inhibited, but normal interactions will not necessarily result in full participation of everyone. With group sizes of 13 to 35, only those students that are aggressive will normally participate, and many (most) students cannot be expected to participate. With more than about 35 students, hardly any students can be expected to speak up, as the size and environment is very inhibiting.

Problem-solving can be described as either closed-ended or open-ended. If closed-ended, the problem can be simple (one-step solution) or complex (a chained series of steps which need to be known or discovered as the student proceeds). Problem-solving strategies found in the literature usually work towards expanding the students' abilities in solving complex, closed-ended problems or open-ended problems. Simple, closed-ended problems primarily require the thinking abilities [1] described as knowledge, comprehension, and application. Complex, closed-ended problems require, in addition, analysis and evaluation. Open-ended problems also require the use of synthesis (idea generation) thinking skills.

CLASSIFYING COURSE STRUCTURES

THE FIVE COURSE formats discussed are listed in Table III and include lecture, discustion, PSI and group-paced individualization methods. This classification is really a spectrum and should encompass almost all structures normally utilized, except for research and individualized contract. In Table IV are listed major distinguishing features of each of the five structures. It is assumed for the purposes of this paper that each structure is administered to try to meet the prescriptive factors in Table I.

TABLE II
Descriptive Factors of Course Structures

- **Pacing (Student learning in lock-step to complete student freedom)**
- **Specificity of Coverage (Branched, fixed, or flexible in content)**
- **Feedback Rate (Immediate to slow)**
- **Type of Interaction (Student to student, instructor, tutor, or material)**
- **Group Size (One to large lecture)**
- **Instructor Role (Provider, guide, oracle)**
- **Student Role (Active to passive)**
- **Type of Problem-Solving (Closed or open-ended)**
- **Resource Consumption (Paper, audio-TV, computer)**
- **Costs**

TABLE III
Classification of Course Structures

A. **Formal Lecture**
B. **Discussion**
C. **Personalized System of Instruction (PSI)**
D. **Group-Paced Individualization—Class Centered (GPI—Class)**
E. **Group-Paced Individualization—Project Centered (GPI—Project)**

See Grayson, L. and Biedenback, J., Editors, *Individualized Instruction*, A.S.E.E. Press, Washington, D.C. (1975), for further discussion of some of the structures in C, D and E.

Specific examples include the work of Professor Caeenpeel at California-Pomona in operating an engineering discussion course. Professor J. Stice at the University of Texas-Austin has directed a program of 17 PSI courses, and informative reports are available. Professor H. Plants and W. Venable at West Virginia University have operated strict GPI—Class Centered courses in statics and dynamics. The PRIDE program in chemical engineering at West Virginia University has developed GPI—Project Centered courses. Many others throughout the country have operated courses of the various structures.

This comparison is intended to provide a compendium of the merits and possible deficiencies of course structures presently being used in engineering education.

COURSE STRUCTURE COMPARISON

IN TABLE V ARE listed the author's opinions as to how each structure meets the prescriptive factors. These ideas are based on many reported studies of course formats, and include the consensus of opinions expressed by participants at the workshops where the factors were developed.

In Table VI are listed the comparison of the descriptive factors. Cost information statements are admittedly scanty, but are based on the available facts from studies at the University of

TABLE IV
Elements of Five Course Structures

Element/Course	(A) Lecture	(B) Discussion	(C) PSI	(D) GPI—Class Centered	(E) GPI—Project Centered
Special Provisions and Materials	Text	Discussion Groups Students are Required to do Preparative Work Texts, Articles	Required Program Guides with Text	Instruction or Study	Study Guides with Text Project Work in Small Student Groups
Pacing	Instructor	Group—Discussion Sessions Instructor—Discussion Program	Student	Instructor as Modified by Class Needs, with Flexibility on Instructional Units	Project Needs After Instructor Sets Content/Project
Instruction Help	Teaching Assistant for Grading Student Work Helpful	Assistants for Discussion Leaders Helpful	Proctors (Graders) for Instructional Unit Quizzes and Student Tutoring	Proctors for Instructional Unit Quizzes and Student Tutoring	Tutor, Homework Grading
Testing	Tests a Few Times per Semester	Tests on Content for each Major Discussion Topic	Quizzes on Instructional Units (1 hr—1 week length)	Quizzes on Instructional Units (1 hr—1 week length) Tests on Major Topics	Tests on Major Topics (Modules of 2-4 weeks) Design Reports
Grading	Spectrum of Grades Based on Homework and Student Mastery of Instructional Objectives on Tests	Spectrum Based on Student Mastery of Instructional Objectives on Tests Contribution to Discussions and Reports	Work to A, Based on Mastery of all Instructional Units	Spectrum, Based on Student Mastery of Instructional Objectives on Quizzes and Tests, about Equally Weighted	Spectrum, Based on Mastery of Instructional Objectives on Tests, and Design Work and Design Reports

Texas [2], West Virginia University [3, 4], and Oklahoma City Christian College [5].

The range of performance of a course structure in meeting an educational factor in Tables V and VI indicates the results normally to be expected—depending on the quality of instruction, facilities, and program developed to emphasize a particular factor.

This comparison is intended to provide a compendium of the merits and possible deficiencies of course structures presently being used in engineering education. Faculty members can pick a course structure because of its merits, and improve or modify an area where the structure has a tendency to be weak. No one course is seen as preferable for all courses and situations; rather the structor should be chosen to effectively meet the desired goals. □

TABLE V
Comparison of Course Structures for Prescriptive

Factor	Rating: How Does Course Achieve Factors? Poorly 0	1	2	3	Well 4
Statement of Intended Outcome		A	B	E D C	
Pleasant Conditions	A		E	C D B	
Informative Feedback		A		* (*=B, C, D, E)	
Meaningfulness		*		E	
Rewarding Consequences (*=A, B, C, D)			A B	E C D	
Hierarchy of Organization			A B	E C D	
Active, Appropriate			A B	C D E	

A = Lecture
B = Discussion
C = PSI
D = GPI-Class Centered
E = GPI-Project Centered

TABLE VI
Descriptive Comparison of Course Structures

Factor	Comparison										
Pacing	Lock										Student
	Step	A	D	E		B			C		Freedom
Specificity of Coverage:	Branched			B	C						
	Fixed										
	Flexible		A	B	C			D	E		
Feedback Rate	Immediate										Never or Very Long
		C	D E B		A						
Type of Interaction†	Student-Student					B					E
	Student-Tutor							C	D		E
											Possible
	Student-Instructor				A	B			D		E
	Student-Materials					B		C	D		E
Group Size	1			10				20			>>35
		C	(E Project)	D	B				A	E	Content
Instructor Role	Provider				A	B					E
	Guide					B		C	D		E
	Oracle					B					E
Student Role	Passive										Active
				A					B		*
											(*=C, D, E)
Type of Problem-Solving†	Simple, Closed-Ended				A			C	D		E
	Complex, Closed-Ended				A		B	C	D		E
	Open-Ended					B					E
Resource Consumption	Low										High
		A	B			E				D	C
Operating Costs:**	Low					Median					High
Lecture						A					
Discussion, Small Groups						B					
PSI [2], [5], [6]	Large Enrollment←----------				C----------			----------			→Small Enrollment
GPI—Class Centered [3]						D					
GPI—Project Centered [4]						E					
**(Note: Developments of a new course and materials for structures C, D, and E may be quite high.)											

†If these factors can normally be present, they are listed only and not compared.

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WHY PSI?

HOW TO STOP DEMOTIVATING STUDENTS

WILLIAM D. BAASEL
Ohio University
Athens, Ohio 45701

MANY OF YOU reading this article will be teachers who are hoping to improve your effectiveness. You may have even read material on how to motivate students. But a more effective way than trying to motivate them is not to demotivate your students. In order to see how you may be "turning them off" think back to the time you were a student and answer the following questions.

• Have you ever been bored in a class because you understood what the professor was discussing? This could be because he was repeating or elaborating upon an explanation for someone who asked a question or because you had a different background from the average student in the class.

• Have you ever had a struggle to stay awake in a nine o'clock class? Were you worried if you missed that class that you might miss something that might be required later on an exam?

• Have you ever done poorly on an examination even though you knew the material (not just felt you knew it)? Have you ever known everything covered in the course except what was on a test? Have you ever mastered the material by the end of the course but still received less than an "A" because you did poorly on some quizzes and midterms? Have you ever had an extremely difficult time in a course because you had a poor background at the time you entered the course?

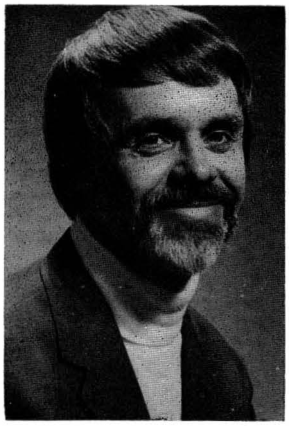
• Have you ever been distracted and lost the thread of a lecture? This could be because there was some commotion, or a particularly intriguing idea which you pursued in your mind while you ignored the lecturer, or you couldn't take notes fast enough.

The instructor must present himself as a facilitator of knowledge. He must appear to be trying to help the student learn, as somebody who is interested in each student and truly wants them to succeed. Arrogance and ego trips have no place in a self-paced course.

You can avoid subjecting your students to all these demotivating situations if you are willing to adopt the Personalized System of Instruction (PSI). This is a method of instruction developed in the early 1960's by Fred Keller (hence it is also called the Keller plan) and some of his associates [1]. It is based on positive reinforcement and has been successfully adopted by hundreds of college teachers in numerous different disciplines.

Kulik and Kulik [2] evaluated most of the studies which compared PSI and lecture method. They found 39 studies based on final exam comparisons which seemed to be designed properly and had used control methods to prevent biases. In 34 of these, PSI was shown to be statistically superior. The others gave no statistically significant results but four indicated PSI was better and only one gave lecturing the edge.

These results are especially amazing in the light of a study made by Dubin and Taveggia [3]. They made a comparison of all studies prior to 1968 which attempted to determine if one teaching method was superior to another. They found that whenever there were a number of studies showing one method was best there were almost an equal number of studies which showed that it wasn't. For instance, when the lecture and discussion methods were compared, 51 percent of the time lecturing was superior while the discussion method was shown to be best 49 percent of the time. These are hardly conclusive results.



William D. Baasel is a Professor of Chemical Engineering at Ohio University. His Bachelors and Master's degrees were obtained from Northwestern University and his Doctorate from Cornell University. He is the author of **Preliminary Chemical Engineering Plant Design**, Elsevier, 1976. He is currently Secretary-Treasurer of the Chemical Engineering Division of ASEE and was previously Program Chairman of the Division. Next year, he will be on leave at the U.S. Environmental Protection Agency in North Carolina.

The Kuliks also reported that in nine different studies where tests were given some period of time after the students had completed the course, the PSI students' performances were statistically better than those who had had a traditional lecture course. They also found four studies where PSI students performed significantly better in subsequent courses. One additional study of this latter type was statistically inconclusive.

The PSI method replaces the oral communication of a lecture with written instructions. It directs the student to concentrate on the important aspects of the course by providing behavioral objectives. These instructions tell the student precisely what he must know to pass the next test. PSI ends the vaguaries of grading by demanding mastery. It provides immediate, and hopefully, positive feedback by grading a completed exam in the student's presence as soon as he has completed it, and reduces anxiety by exacting no penalty if a student fails an exam. He merely retakes another over the same material. If the student is ill, emotionally upset, tired or overburdened, he does not need to take a test that day or even that week. He is allowed to proceed at his own pace.

ADOPTING THE METHOD

WHAT MUST YOU DO to adopt this highly successful method? First, a professor must determine the educational objectives of his course. These state what he expects the students should have achieved when they have completed the course. Then he divides the course into coherent units. The ideal number should be somewhat greater than one unit per week. For each of these units he prepares a written communication which includes an introduction, behavioral objectives, and a procedure for meeting the behavioral objectives. The introduction is a pep talk which should arouse the student's interest and tell why the material is important. The behavioral objectives tell in a specific manner what the student must be able to do to master the unit. For details on how to write these, one can consult Mager's book, *Preparing Instructional Objectives.* All the behavioral objectives given should in some way help the student to reach the educational objectives which the professor originally set.

This procedure gives a method whereby the student may learn the material. It may include doing problems and/or laboratory experiments, reading, reviewing film strips, and completing programmed material. This is merely a method and the student is not required to follow it. He may devise his own way for mastering the material. I have added to my written communications a fourth item, a concept list. This is a list of words or ideas with which I expect the student to be familiar and which I shall be using on tests.

Next, the professor must make up four tests for each unit. These tests should only ask the student to do what has been stated in the behavioral objectives. In five years of teaching this course, only two students on one examination each have ever required more than four tests on a unit. To both of these I administered an oral examination over the unit.

Any text has its failings and these will become very apparent in a PSI course. To correct these, the instructor must often burn the midnight oil writing supplementary material.

The grading policies in PSI courses vary greatly. My students are told that everyone who masters all the units within the quarter will receive an "A" and all others an "F". Other professors base the grade on the number of units completed. Some use a final exam to determine who should receive "A's" and who should receive "B's" among those who have completed the material. The reason I decided on an "A" or "F" policy was twofold. First, my course is required, and I feel that all the units are important. If they weren't all important I would eliminate those that weren't and appropriately reduce the number of credit hours. Second, if a student has shown at some time during the quarter that he has mastered everything I asked him to do, he deserves an "A".

CONDUCTING THE COURSE

SINCE LECTURES ARE RARE and the student can proceed at his own pace, the class meeting time has a different purpose than the usual lecture course. At the introductory section of the class the way in which the course is conducted is explained. From then on the scheduled hours are used to answer student questions and for examination taking and grading. There are no attendance requirements. When a student feels he can meet the performance objectives for a unit, he takes an examination. Immediately after he has finished the examination, it is graded in his presence. During the grading he is asked questions by the grader. If he cannot answer these questions, even though he has completed the exam correctly, he is failed. This makes certain the student truly understands the material and prevents cheating. If he fails, he is told how he can remedy his deficiency. After an appropriate time, he may then request another exam. To prevent students from taking examinations without proper advance preparation, I inform them that if they fail more than two tests on a given unit, all study problems given in the procedure section of each future unit must be completed and graded before taking an examination covering that unit.

TABLE 1
Subjects of Units

1. The Reasons for Process Control (1)*
2. Introduction to Laplace Transforms (2, 3)
3. Systems and First Order Responses (5, 6)
4. Combined Systems and Second Order Responses (7, 8)
5. Linearization
6. Modeling
7. Pressure Tank Response and Modeling (Lab)
8. Response of Temperature Measuring Devices (Lab)
9. Controllers, Control Valves, and the Control System (9, 10)
10. Block Diagrams (11, 12)
11. Transient Response of Simple Control Systems (13)
12. Modeling and Response of a Liquid Level System (Lab)
13. Valves and Controllers (Lab)
14. Stability (14)
15. Root Locus Diagrams (15)
16. Introduction to Frequency Response (18)
17. Control System Design by Frequency Response Methods (19)
18. Scale-Up of a Jacketed Heat Exchanger (Lab)
19. Optimum-Control Settings by the Methods of Zeigler-Nichols and Cohen-Coon (Lab)
20. Response of Closed-Loop System (Lab)
21. Simulation of a Closed-Loop System (Lab)
22. Integration of all Material Learned in This Course

*In parenthesis are given the appropriate chapters of the text: Coughanowr, D. R., Koppel, L. B., *Process Systems Analysis and Control,* McGraw-Hill, 1965.

TABLE 2
Student Evaluation of a PSI Course In Process Dynamics and Control

(59 student responses in five years. 29 students did not complete questionnaire.)

1. Would you rather have had process control taught by the Keller Plan than by the traditional lecture manner? (check one)

   YES 80% NO 10% UNSURE 10%

2. Do you feel that you have a good mastery of process control? (check one)

   YES 72% NO 12% UNSURE 16%

3. Would you like to have other courses taught using the Keller Plan? (check one)

   YES 84% NO 2% UNSURE 14%

The instructor will need help in grading examinations and answering questions if he has more than 15 students in a lower level introductory course or 10 students for very advanced classes. These can be graduate students, undergraduates who have passed the course, or students who are taking the course. The latter may evaluate examinations over units they have passed.

Choosing these graders is very important. They need to be understanding and encouraging. One year, when it was time to complete our annual faculty evaluation form on the PSI course, the students asked whether I or my proctor was to be rated. I decided both of us should be given separate ratings. I received one of the best ratings for the college; he, one of the worst.

The personality of the instructor and proctor are major factors in the success or failure of a self-paced course. If the person in charge feels the PSI system is a way of reducing his academic load by eliminating lectures and getting others to grade exams, it will fail. If he feels that he will be a stickler for trivial detail—that this is a way to separate those that have it from the dummies, or that he will show the students who knows most—he will also fail. The instructor must present himself as a facilitator of knowledge. He must appear to be trying to help the student learn, as somebody who is interested in each student and truly wants them to succeed. Arrogance and ego trips have no place in a self-paced course.

PROBLEMS IN PROCRASTINATION

PROBLEMS IN PROCRASTINATION THAT often arise when the PSI method is used are insufficient clarity of examples and explanations in the written material, and the tendency of some students to procrastinate. Any text has its failings and these will become very apparent in a PSI course. To correct these, the instructor must often burn the midnight oil writing supplementary material. His alternative is to spend hours explaining it to every student. Since the background of the students varies from year to year, this is a continuing process.

A number of different things can be done to minimize procrastination. One is to set a time limit for completing the material. I use the last day of final exam week. Another is to conspicuously post a wall chart giving each student's progress. No one likes to be last. A third way to minimize procrastination is to have each student make an appearance at least once a week. It's hard to tell a professor, "I couldn't find time for your course." A fourth is to give occasional stimulating lectures which require that a student complete a certain number of units before he can attend. Other gimmicks like giving buttons saying, "I passed Unit 4," where this is a particularly hard unit, can also be used.

TABLE 3

Student Response to the Question

1. **Did you put more time into this course than most other 6-hour credit (both quarters) courses? (check one)**

YES 61% **NO 29%** **UNSURE 10%**

The course I teach using PSI is a senior course in Process-Dynamics and Control. It uses *Process Systems Analysis and Control,* by D. Coughanour and L. Koppel as a text and covers essentially the first 19 chapters. The course is divided into 22 units (including eight laboratory units), and has a total of six quarter hours credit spread over two quarters. The titles of the units and the corresponding chapters in the text are given in Table 1.

TABLE 4

PSI Courses in Chemical Engineering Subjects

Professor	Affiliation	Text Used or Subject
William D. Baasel	Ohio University	*Process Systems Analysis and Control* Coughanour & Koppel
Karen Cohen	Massachusetts Institute of Technology	Energy Conservation
Ray W. Fahien	University of Florida	Transport Phenomena
David Himmelblau	University of Texas	Optimization
R. Heal Houze	Purdue University	*Transfer Operations* Greenkorn & Kessler
John Molinder	Harvey Mudd College	*Process Systems Analysis and Control* Coughanour & Koppel
Noel E. Moore	Rose Hulman Institute of Technology	*Process Systems Analysis and Control* Coughanour & Koppel
Phillip C. Wankat	Purdue University	*Separation Processes* C. J. King

This course is an ideal PSI course for two reasons. First, each unit is dependent on a thorough understanding of what has been presented in previous units. If a student does not understand some aspect of the course as it progresses, he will not be able to understand much of what is presented in future units. Second, what is presented initially is not especially exciting to the student because he has difficulty seeing how what he is learning will be useful to him. Because of these two interacting problems, the overall result for a lecture course may be that although the student can manipulate the mathematics adequately enough to pass the course, he often obtains little satisfaction and almost no knowledge. The little he has learned is not integrated into his overall knowledge. It therefore rapidly disinte-

TABLE 5

PSI Seems to Work Well Because It Involves

1. **Small Units of Work.**
2. **Immediate and Specific Feedback About Performance.**
3. **Requirements of Mastery at Every Step.**

grates and is forgotten. The best ways of learning something is to tie it to one's past experience. This is why any instructor should attempt to relate what he is presenting to things in the student's life, or at least to what the student has learned in previous courses. The more relationships of this type the instructor can establish, the better the student will learn the material and the greater will be his retention of the concepts which were presented. This is one of the major purposes of the introduction to each unit. If the introduction is well written, it can help overcome the first problem. The requirement of mastery before the student can progress to the next unit resolves the second. At least he was at one time able to do each important task in each unit. When he needs to use these concepts in later units, he will be able to refresh his memory and not be in the position of having to learn them.

My students' evaluation of the course is given in Table 2. This is a compilation of the responses for five different classes taught in five separate years. In general, they prefer the course, would like more courses taught this way, and felt secure with the subject matter. Various student comments follow:

> **"Previously I only spent so much time on a course and if I didn't understand something I hoped it wasn't on an exam. I couldn't do that with this course."**
> **"I felt I couldn't do 'A' work, but now I realize I can."**
> **"It built up my confidence. I felt I could do as well as others."**

One criticism I have received from other instructors is that the course requires more time on the part of a student than a traditional lecture course. The students also feel this is true as shown by Table 3. One student, however, placed this in a different context by saying, "This course took no more time than any other course for which I desired and worked for an 'A'." This of course means the average and below average student must put in more time than usual.

Most people teaching PSI courses like them. We encourage those who haven't used the method to try it. In trying the PSI method, one should be careful not to diverge too greatly from the procedure presented in this paper or the first reference. One should be especially sure to include the aspects given in Table 5, for these have been found by studies to be essential to the success of the PSI method.

There are many ChE's teaching modified PSI Courses. At the 1977 Summer School which was sponsored by the ChE Division of ASEE at Snowmass, Colorado, those listed in Table 4 indicated they were using the method. □

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PERIODICALS IN WHICH ARTICLES ON THE USE OF PSI IN ENGINEERING COURSES MAY BE FOUND

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2. PSI Newsletter—Same address as No. 1.
3. *Chemical Engineering Education*, Chemical Engineering Department, University of Florida, Gainesville, Fla. 32611.
4. *Engineering Education*, Publication of ASEE, One DuPont Circle, Washington, D. C. 20036.
5. *IEEE Transactions on Education.*
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SUPERHEATED LIQUIDS: Reid

Continued from page 63.

If one begins with the system in a stable state, then the limit of stability results when

$$y^{(n)}_{(n+1)(n+1)} = 0 \tag{2}$$

For example, with a pure component (n = 1), and with the ordering of variables such that*

$$\underline{U} = U(\underline{S},\underline{V},N) \tag{3}$$

then $y^{(1)}$ is identically equivalent to the Helmholtz energy, $\underline{A}$, and the variable (n + 1) is $\underline{V}$. Thus

$$y^{(1)}_{(n+1)(n+1)} = A_{VV} = (\partial^2\underline{A}/\partial\underline{V}^2)_{T,N} = -(\partial P/\partial\underline{V})_{T,N} = 0 \tag{4}$$

for the limit of stability or

$$-(\partial P/\partial\underline{V})_{T,N} > 0 \tag{5}$$

for a stable system.

With Eq. (4), one may estimate the superheat-limit temperature provided that an equation of state relating P, V, and T is available for the liquid phase. To illustrate the technique, assume the recent Peng-Robinson equation (1976) is applicable to relate P, $\underline{V}$, T. Written on a molar basis,

$$P = \frac{RT}{V-b} - \frac{a}{V(V+b)+b(V-b)} \tag{6}$$

where a and b are functions of the critical properties; a also depends on the Pitzer acentric factor and upon T. With Eqs. (4) and (6), the limit of stability is predicted when

$$\frac{RT}{(V-b)^2} - \frac{2a(V+b)}{[V(V+b)+b(V-b)]^2} = 0 \tag{7}$$

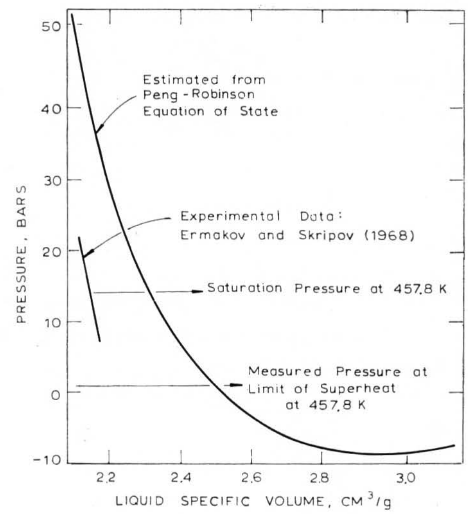
TABLE 1

Measured Superheat-Limit Temperatures.

- 1 Bar -

Substance	T_b (K)	T_c (K)	T_{SL} (K)	T_{SL}/T_c
Ethane	184.6	305.4	269.2	0.881
Propane	231.1	369.8	326.2	0.882
n-Butane	272.7	425.2	378.2	0.889
n-Heptane	371.6	540.2	487.2	0.902
2,2,4-Trimethylpentane	372.4	543.9	488.5	0.898
Cyclohexane	353.9	553.4	492.8	0.890
Benzene	353.3	562.1	498.5	0.887
1-Butene	266.9	419.6	371.0	0.884
Hexafluorobenzene	353.4	516.7	467.9	0.906
Methanol	337.8	512.6	459.2	0.896
Ethyl ether	307.7	466.7	420.2	0.900
Acrylonitrile	350.5	536.0	474.0	0.884

FIGURE 7
P-V DIAGRAM FOR N-HEXANE AT 457.8 K



In Figure 7, we show a graph of Eq. (6) for liquid *n*-hexane at 457.8 K. The branch above the saturation (vapor) pressure of 14 bar represents subcooled liquid. Below this pressure the liquid hexane is superheated. The P-V isotherm shows a minimum at about —8 bar and 3 cm^3/g; these values are, of course, those that would be found if Eqs. (6) and (7) were solved simultaneously. Also shown in Figure 7 are some measured specific volumes from Ermakov and Skripov (1968) that cover both the subcooled and superheated range. The Peng-Robinson equation predicts specific volume to within a few percent when the pressure and temperature are given; much larger errors result if volume and temperature are the independent variables.

Finally, in Figure 7 the temperature, 457.8 K, was selected since this is the reported SLT for *n*-hexane at one bar. If the Peng-Robinson equa-

---

*U, S, and V are, respectively, the system internal energy, entropy, and volume. The underbar represents total, not specific, quantities. N is the system mass (or moles).

Those who take time to follow this procedure soon note that bubble formation rate is essentially zero until a certain temperature is reached where, over a small temperature range, the rate becomes very large.

tion accurately predicts stability limits, then it indicates that one could decrease the pressure to —8 bar before reaching the limit.

The discrepancy between measured values of the SLT and those predicted from thermodynamics is shown in a different way in Figure 8. Here, the reduced SLT is plotted vs. reduced pressure for R-12 (dichlorodifluoromethane). The curve marked Peng-Robinson was calculated from Eqs. (6) and (7), eliminating the volume, and varying the temperature. Curves calculated from three other simple equations of state are also shown, i.e., from the Redlich-Kwong (1949), the Soave (1972), and the Fuller (1976) relations. All give curves similar in shape and all fall below the experimental values. At one bar, the experimental data (Moore, 1956, 1959) indicate a superheat limit temperature of 342 K (T_r = 0.887) whereas the Peng-Robinson equation would predict a value of 352 K (T_r = 0.913).* Comparison then shows that thermodynamics yields values of the superheat-limit temperature close to, but consistently higher, than those found experimentally. The equations of state are certainly not exact, but the results are reasonable when one remembers that thermodynamics provides the upper limit to the superheat-limit temperature. Experimental values must always be less.

For mixtures, the basic approach is similar but Eq. (7) is replaced by a considerably more complex relation. (See Beegle et al., 1974). For example, with a binary system composed of A and B, the superheat-limit temperature may be calculated from the relation

$$\begin{vmatrix} A_{VV} & A_{VA} \\ A_{VA} & A_{AA} \end{vmatrix} = 0 \tag{8}$$

where $A_{VV} = (\partial^2 \underline{A}/\partial \underline{V}^2)_{T,N} = -(\partial P/\partial \underline{V})_{T,N}$

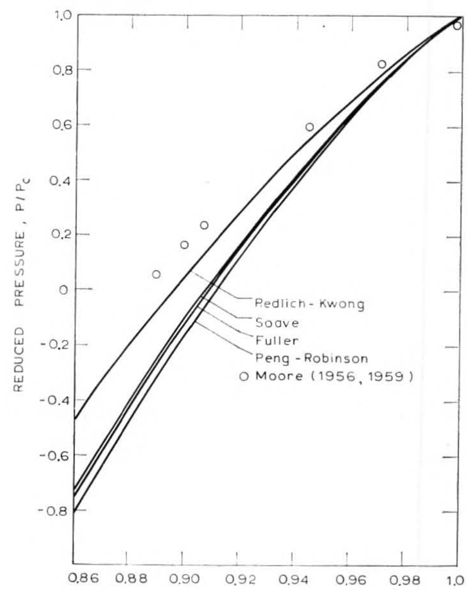
$$A_{VA} = \partial^2 \underline{A}/\partial \underline{V} \partial N_A = -(\partial P/\partial N_A)_{T,\underline{V},N_B}$$

$$A_{AA} = (\partial^2 \underline{A}/\partial N_A^2)_{T,\underline{V},N_B}$$

In a pure component case, the comparable equation would be Eq. (5) which can be written as

$$A_{VV} = 0 \tag{9}$$

When heating a binary mixture at constant pressure (or depressurizing isothermally), the limit of superheat is first reached when Eq. (8) is



Estimated Limit of Superheat Temperatures from Equations of State for Dichlorodifluoromethane (R-12)

FIGURE 8

satisfied. At this point, $A_{VV} > 0$. Therefore, the mixture has attained the limit of stability at less severe conditions than would have been expected if the mixture had been treated as a pseudo-pure component and the test limited to Eq. (9) or Eq. (5). A ternary mixture would have even wider limits, etc.

We show in Figure 9 the pressure-volume graph for a 50 mole percent mixture of ethane and *n*-butane as calculated from the Peng-Robinson equation of state. The stability-limit curves from both Eqs. (8) and (9) are shown. Note that the slope $(\partial P/\partial V)_T$ is still negative when Eq. (8) is satisfied. The use of Eq. (9) would be incorrect to define stability limits in this binary system.

At P = 1 bar, Eq. (8) is satisfied when T = 335.5 K. Constructing graphs similar to Figure

*In a plot of P_r vs. T_{SL}/T_c, for similar compounds, all experimental data fall on one curve (actually very close to a straight line). This has been shown for the aliphatic hydrocarbons, *n*-pentane, *n*-hexane, and *n*-heptane (Skripov and Ermakov, 1964).

9 for other compositions indicates that, at 1 bar, the superheat-limit temperature is essentially a mole-fraction average of the superheat limit temperatures of the pure components. This result is in agreement with the data of Porteous and Blander (1975).

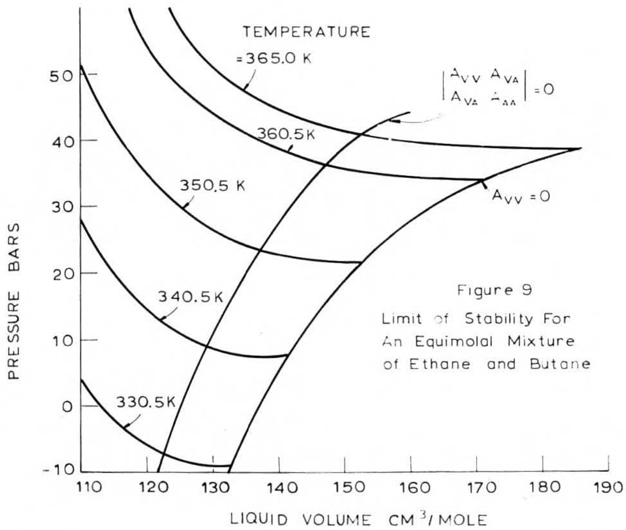


Figure 9 Limit of Stability For An Equimolal Mixture of Ethane and Butane

KINETIC THEORY

SUPERHEATED LIQUIDS HAVE also been modelled by using kinetic theory.* In this case, the end result shows the probability of forming a macroscopic vapor bubble from a given quantity of liquid in a given time interval.

The superheated liquid is visualized as a mixture of continuum liquid molecules with many vapor embryos of different sizes. These embryos probably form from small density fluctuations and grow (or decay) by the vaporization (or condensation) of liquid molecules. Thermodynamic reasoning indicates that for each system (at a given temperature, pressure and composition), there exists a critical-size vapor embryo which is in unstable equilibrium with the bulk liquid. Embryos below this critical size tend to become even smaller while those larger than the critical size grow even larger—and soon become macroscopic in size.

We are interested in developing means to estimate the rate at which embryos attain the critical size for given experimental conditions. This rate J is then the bubble nucleation rate, and, from theory,

$$J \simeq N_L f \exp[-16\pi\sigma^3/3kT(P - P_o)^2] \tag{10}$$

where N_L is the number density of liquid molecules, f is a frequency factor of the order of $10^{11}s^{-1}$ to account for the rate phenomena of vaporizing—and condensing—molecules in the vapor embryo. σ is the surface tension, P is the pressure inside the embryo and P_o is the bulk liquid pressure. P is normally very close to the equilibrium vapor pressure at the bulk liquid temperature.

As temperature is increased, the surface tension decreases and the embryo pressure increases. Thus J is a strong function of temperature. In some range of elevated temperatures, the probability of forming critical-size nuclei is not vanishingly small. It is this temperature range that interests us.

The probability calculations then proceed as follows: For any given temperature, the molecular density of molecules is multiplied by the product of the frequency factor times the exponential term. The answer is the "expected" number of macroscopic bubbles one might expect to appear from a given volume of liquid in a given time. Those who take time to follow this procedure soon note that the bubble formation rate is essentially zero until a certain temperature is reached where, over a small temperature range, the rate becomes very large. In the laboratory, this corresponds to heating a liquid well beyond the expected boiling point when, in a small temperature range, vapor bubbles appear so rapidly the event could be labeled as an explosion!

In calculations to estimate the temperature where rapid, homogeneous nucleation occurs, we define some physically reasonable value of the rate and iterate to determine the temperature. To emphasize the rapidity of the events, to define a

*See, for example, Blander and Katz (1975), Kagan (1960), Moore (1956, 1959), Volmer (1939).

... in some cases the agreement is poor, i.e., estimated superheat limit temperatures are larger than those measured experimentally. In these instances, it appears that nucleation occurs at the superheated liquid boundaries from either a vapor pocket or by surface nucleation or nucleation was initiated by the evolution of dissolved gas.

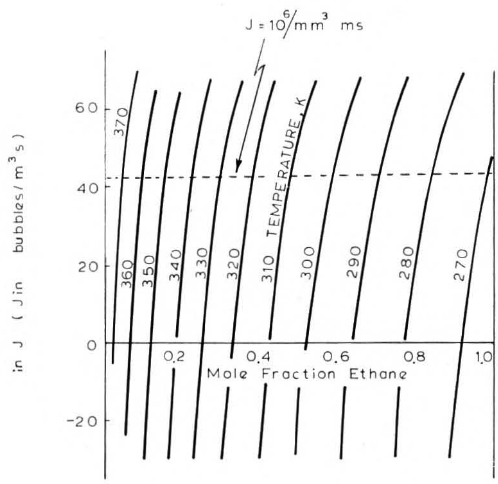


Figure 10 Estimated Rates of Bubble Nucleation For the Ethane - n - Butane System at One Bar

vapor explosion, we have chosen a temperature which would produce one million bubbles every millisecond in each and every cubic millimeter. With this, or similar choices, calculated superheat-limit temperatures usually agree within a few degrees when compared with those measured experimentally. Such agreement is rather remarkable in view of the approximations used in the theory and the difficulties of estimating physical properties (e.g., surface tension) for liquids heated well beyond their boiling points.

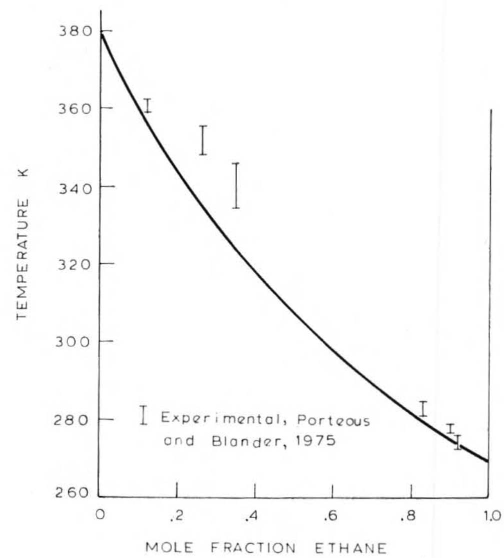
And, in some cases, the agreement is poor, i.e., estimated superheat limit temperatures are larger than those measured experimentally. In these instances, it appears that nucleation occurs at the superheated liquid boundaries from either a vapor pocket or by surface nucleation (Jarvis et al., 1975), or nucleation was initiated by the evolution of dissolved gas (Mori et al., 1976; Forest and Ward, 1977). In spite of these cases, the use of kinetic theory to provide good estimates of superheat-limit temperatures for many pure materials and simple (ideal) liquid mixtures is well documented (Blander and Katz, 1974).

In Figure 10 we show some estimates of the expected rate of bubble formation for the system ethane-butane as a function of temperature and ethane concentration. The external pressure is one bar. The explosion criterion noted above was used. Clearly, both the bulk liquid composition and the temperature significantly affect the "expected" number of bubbles appearing in the superheated liquid. The experimental superheat-limit temperature for pure ethane is about 270 K and, for *n*-butane, 378 K (Porteous and Blander, 1975).

Crossplotting the temperature and ethane composition when J = 10^6 bubbles/mm^3 ms yields Figure 11. The smooth curve represents the predicted superheat-limit temperatures for an ethane-*n*-butane binary at one bar. The curve is not linear. The vertical bars show the few existing experimental data (Porteous and Blander, 1975).

We are currently studying the superheat-limit temperatures of highly nonideal liquid mixtures and we expect to find significant deviations from simple mole fraction averages. There is also no well developed kinetic theory applicable to nonideal liquid mixtures and we are in the process of building upon the earlier work of Reiss (1950), Hirschfelder (1974), and Katz (1977).

Figure 11 Predicted and Experimental Superheat - Limit Temperatures of the Ethane - n - Butane System at One Bar



Besides the modifications in the mixture kinetic model caused by treating embryos differing in number as well as composition, one may also question whether diffusional limitations enter. For example, in the ethane - *n*-butane case, the vapor embryo is significantly enriched in the more volatile ethane. A "skin" or boundary layer would, therefore, be expected to be enriched in *n*-butane. Blander (1972) argues that such enrichment may not be important since, near the critical size, the subcritical-size embryo has a relatively long life and he solves, approximately, the diffusion equation to predict the effect quantitatively. The principal effect found was a slight change in the pre-exponential frequency factor described earlier.

Another point of view may be presented that possesses some physical meaning. Suppose we select an ethane - *n*-butane mixture containing 96 mole percent ethane.* Figure 10 indicates that the superheat-limit temperature is about 272 K. The pressure difference between that within the embryo and the bulk superheated liquid (at one bar) is estimated to be 21.8 bars. Also the surface tension for this mixture, at 272 K, is estimated to be about 3.7 dynes/cm. Assuming the Laplace equation to apply, the radius of the critical embryo, $r_c = 2\sigma/\Delta P = (2)(3.7 \times 10^{-3})/(21.8 \times 10^5) = 3.4$ nm. The number of molecules in the embryo is about 100. To supply this number of molecules to the vapor embryo would require less than a single molecular layer on the surface. Clearly with such a picture, it is difficult to conceive that diffusion could play an important role.

Editor's Note: This paper will be continued in the next issue of **CEE**.

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REQUEST FOR FALL ISSUE PAPERS

Each year CHEMICAL ENGINEERING EDUCATION publishes a special Fall issue devoted to graduate education. This issue consists mainly of articles on graduate courses written by professors at various universities, and of advertisements placed by ChE departments describing their graduate programs. Since we are not planning a similar issue for Fall 1978, we would like to know whether you are interested in contributing to the editorial content of this special issue. If so, please write to the Editor indicating the subject of the paper and tentative date the paper can be submitted. This information should be sent to Ray Fahien, Editor, CHEMICAL ENGINEERING EDUCATION, c/o Chemical Engineering Dept., University of Florida, Gainesville, Florida 32611.

BIOCHEMICAL ENGINEERING PROGRAMS: A Survey Of U.S. And Canadian ChE Departments

MURRAY MOO-YOUNG
University of Waterloo
Waterloo, Ontario, Canada

RECENT SOCIO-ECONOMIC problems which have resulted from certain inadequacies in such activities as food production, pollution abatement, energy recycling, and health-care, have indicated an increasing need for biochemical engineering on a global scale. Many chemical engineering departments in North America offer programs of study in this field. The nature and extent of these programs were surveyed in the summer of 1977 and the results were presented at the A.S.E.E. Meeting in Snowmass, Colorado, August 1977. The accompanying series of 7 tables summarize some of the findings of this survey.

The results are based on the replies to questionnaires which were sent out to the 138 U.S. and 18 Canadian ChE departments, which are listed in the AIChE faculties brochure, with the following "working definition of biochemical engineering: the application of ChE principles to the analysis, operation and design of process systems in which biological or biochemical variables are involved." With a little prodding, 88% of the departments responded to the questionnaire: 87% U.S. and 94% Canadian.

TABLE 1. Sizes of ChE Departments which Offer Biochem. Eng. Programs.

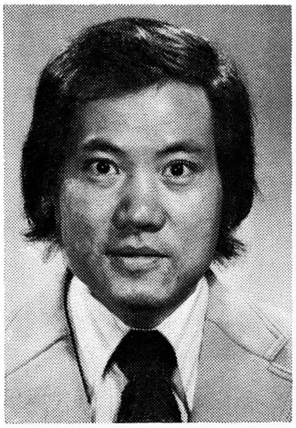
Number of faculty	Number of dept's.	With undergrad. Program	With postgrad. Program
1-5	2	1	1
6-10	17	16	17
11-15	22	22	20
16-20	8	4	8
21-25	3	2	3
26-30	1	1	1
31-35	1	1	1
Totals	54	47	51

TABLE 2. Three-year Growth of Biochem. Eng. Programs (No. = 37).

	1974-75	1975-76	1976-77
UG: Students	306	383	371
Faculty	79	86	87
Total ChE Students	1065	1142	1394
PG: Students	159	206	235
Postdocs	20	29	43
Faculty	94	106	114
Publications (Bioch. E.)	156	169	226
Total ChE Faculty	468	485	513

To elaborate on the tables, the following points are noted:

- Not all the respondents answered all the questions on the questionnaire; thus, some of the tables have different response-bases, as indicated.
- Only ChE departments were surveyed. At least one university is known to offer a major biochemical engineering program in its department of nutrition and food science (M.I.T.). In addition some universities, notably Pennsylvania, are known to offer biomedical engineering programs in non-ChE departments.
- The number of biochemical engineering programs have increased from only a hand-full a decade ago (notably, Columbia, Pennsylvania, Waterloo) to 54 today, representing 35% of all the 156 ChE departments which responded to the survey (Table 1, 6 and 13% of those 1,174 department faculty members. Of these 54 departments, 94% offer postgraduate programs and 89% also offer undergraduate programs; of the latter, 36% have structed curricula.
- The majority of ChE departments (72%) offering biochemical engineering programs have 6-15 faculty



Murray Moo-Young received his university degrees from London (B.Sc., Ph.D.) and Toronto (M.Sc.). He is now a professor of Chemical Engineering at Waterloo and a licensed professional engineer in Ontario. His main technical interest is Biochemical Engineering, an area in which he presently has 46 publications and 3 patented inventions. In 1973, he received the C.S.Ch.E. Erco award for "distinguished contribution to the field of Chemical Engineering."

members, the average size of ChE departments in North America; there is no trend to suggest that the larger the department, the more likely it is to offer these programs (Table 1).

- Over the past three years, there have been various degrees of growth in biochemical engineering programs with respect to the involvement of undergraduate students (21%), postgraduate students (48%), postdoctorals (115%) and faculty (10% for undergraduate vs 21% for postgraduate programs); relevant publications also increased (45%). Over the same period of time, total ChE undergraduate enrollment increased (31%) while the total ChE faculty increased to a lesser extent (10%). (Table 2).
- Despite the proliferation of biochemical engineering programs, there appears to be little or no difficulty in finding jobs by graduates of these programs (Table 3); whether or not these jobs are in the biochemical engineering areas is not known.
- The six areas of research activities designated in the survey, show the following priority patterns: fermentations, followed by pollution, biomedical, enzyme engineering, foods, (applied) microbiology, (applied) biochemistry. These patterns are similar for both postgraduate and faculty involvements (Table 4). The high priority given to fermentation is expected; however, the relatively low priority given to foods is unexpected in view of the recent pleas from the food industries for more (bio)chemical engineers.
- The topics treated in the courses, for both lectures and laboratories, follow similar weighting patterns to the research activities except for the basic subjects of Microbiology and Biochemistry, which are dominant, as expected (Tables 4, 5).
- During the academic year 1976-77, course-work contact times showed a wide spread between the various programs for both undergraduate and postgraduate courses, but much less so for the latter (Table 5); the latter result is expected, the former not. As expected, much more time is devoted to lectures than to labs (80% vs 20% for undergraduate and 92% vs 8% for postgraduate courses).
- Of the 54 ChE departments which claim to offer biochemical engineering programs, very wide variations in the departmental involvements for the 1976-77 academic year were found for the following: undergraduates (0-25), publications (0-25), faculty (1-11), research postgraduates (0-38); the research areas were also quite varied (Tables 4, 6). Some of the 54 departments (22%) indicated that they also offered non-research (course-work oriented) postgraduate programs in biochemical engineering.
- The above overall observations are similar for both the U.S. and Canadian statistics when considered separately.

TABLE 3. Job Placement Pattern for Graduates from Biochem. Eng. Programs (No. = 43).

Graduate Type	No difficulty	Little difficulty	Much difficulty
B.Sc.	36	7	0
M.Sc., Ph.D.	36	7	0

TABLE 4. Research Activities (No. = 28).

Area	Postgraduate (%)	Faculty (%)
Microbiology	6.6	9.4
Biochemistry	4.1	5.7
Foods	8.2	7.5
Fermentation	36.5	27.4
Pollution	23.4	17.0
Enzyme Eng.	9.4	14.2
Biomedical	11.8	18.8

TABLE 5. Topics Covered in Courses as % Times Checked.

	Undergraduate (No. = 39)		Postgraduate (No. = 27)	
Topic	Lecture (%)	Lab. (%)	Lecture (%)	Lab. (%)
Microbiology	19.5	29.4	15.8	18.5
Biochemistry	18.8	15.7	19.	14.8
Foods	9.4	3.9	9.5	7.4
Fermentation	16.1	21.6	19	25.9
Pollution	12.8	11.8	14.7	18.5
Enzyme Eng.	13.4	11.8	14.7	14.9
Biomedical	10.1	5.8	7.3	0

TABLE 6. List of 54 U.S. and Canadian ChE Depts. offering Biochem. Eng. Programs. 1976-77 data for total ChE faculty (CHE) and extent of Biochem. Eng. involvement of the professors (PROF), undergrad. students (UGS) with structured curricula identified by S, research postgrads. including postdocts. (RPG) with additional availability of non-research graduate program indicated by C, publications (PUB) and areas of research. (—) indicates if a program type is not available.

CHE	PROF	UGS	UNIVERSITY	RPG	PUB	FERM	POLLN	ENZ	FOOD	BIOMED
11	3	10 S	B.Y.U.	(—)	1					
16	4	(—)	Calgary, Can.	3	5		X			
20	3	6	U.C., Berkeley	18	6	X	X		X	X
7	3	1	U.C., Davis	1	4					
10	4	(—)	U.C.L.A.	3	3		X			
8	1	0	U.C., S. Barbara	2	5	X				
20	1	3 S	Carnegie-Mellon	1	8					X
6	2	24 S	Cleveland St.	(—)	0					
11	3	25 S	Colorado	3	0					X
12	3	0	Connecticut	2	4					
4	1	4	Cooper Union	0	0					
15	2	6	Cornell	10 C	8	X	X			X
20	3	20 S	Delaware	10	10	X				X
6	1	0	Drexel	2	1	X				
14	3	5	Florida	0	3					
18	2	2	Houston	10	15	X	X	X		
17	2	0	Iowa St.	4 C	5			X		
10	2	3	Kansas	6	7	X		X	X	
11	3	8	Laval, Can.	7	4					
12	2	16	Lehigh	12	12	X	X	X		
15		0 S	Louisiana St.							
11	3	(—)	Maryland	4	3	X		X		
14	3	15 S	Mass.	3	6			X		X
12	1.5	17 S	McGill, Can.	5 C	8	X	X			
18	3	20 S	Michigan	6	4	X	X	X		X
7	2	17	Mich. Tech.	2	2	X				
15	4	25 S	Minnesota	8 C	9				X	X
8	2	4	Missouri-Coll.	3 C	4	X				
13	3	0	Missouri-Rolla	5	9	X				
14	2	0 S	N.J.I. Tech.	2	4	X				
9	1	(—)	S.U.N.Y., Buff.	1	4	X				
12	4	5 S	Pennsylvania	13 C	18	X	X	X		
15	5	20	Pittsburgh	3	12		X	X		
6	1	1 S	Poly. Inst. N.Y.	2	0	X	X	X		
15	3	20	Princeton	3	5			X		X
21	8	26	Purdue	38	25					
12	1	8 S	Queen's, Can.	5	2	X	X			
11	2	1	Rhode Island	5	4	X			X	
11	3	10	Rochester	2 C	2			X		X
18	4	(—)	R.P.I.	14	8	X	X			
7	4	17 S	Rutgers	31 C	10	X	X	X		X
15	2	0	Texas, Austin	6	20					X
13	2	1	Tennessee	1	5					X
32	3	20 S	Toronto, Can.	2	8	X				X
11	3	10	Utah	0	1					
6	3	0	Virginia	11	62 ?	X	X			X
10	2	10	V.P.I.	8	8	X	X	X	X	
7	3	(—)	Washington							
9	6	6	Wash., Seattle	3 C	6					X
21			Wisconsin							
28	11	22 S	Waterloo, Can.	21 C	18	X	X	X	X	X
10	7	(—)	U.W.O., Can.	20 C	15	X	X	X	X	
9	2	5	W.P.I.	0 C	0					
7	1	2	Wyoming	(—)	0					

TABLE 7. Duration of Courses for Academic Year 1976-77 (No. = 42).

Contact Hours	Undergraduate Courses Total (%)	Undergraduate Lecture (%)	Undergraduate Lab (%)	Postgraduate Courses Total (%)	Postgraduate Lecture (%)	Postgraduate Lab (%)
11-20	6.8	6.3	0.5	5.5	5.5	—
21-30	11.4	10.7	0.7	27.8	27.5	0.3
31-40	13.8	9.3	4.5	14.5	10.7	3.8
41-50	10.4	6.2	4.2	4.3	2.6	1.7
51-60	9.5	8.4	1.1	20.7	19.9	0.8
61-70	3.7	2.8	0.9	17.8	16.1	1.7
71-80	4.3	4.3	—	6.2	6.2	—
81-90	4.9	4.9	—	—	—	—
101-110	5.6	5.6	—	—	—	—
121-130	6.5	6.5	—	—	—	—
131-140	7.1	4.5	2.6	—	—	—
141-150	7.8	3.9	3.9	3.2	3.2	—
151-160	8.2	6.9	1.3	—	—	—
% Total	100	80.3	19.7	100	91.7	8.3

BOOK REVIEW: Biomedical

Continued from page 73.

tion). Far too little is said of the difficulty of experimentation in this field or of the problems of developing models that can be confirmed by experiment.

The immediately following chapter defines the mass transfer problem involved in treating kidney failure. It defines the problem, describes the solutions proposed, and summarizes the mass transfer analyses usually applied to the artificial kidney. It is not written from the viewpoint of design or synthesis and does not touch on contemporary problems of analysis ("controlling" solutes; solute redistribution from cells to plasma during dialyzer transit; maldistribution of flow). The final two chapters deal with transport of respiratory gases first in the natural lung and then in heart-lung devices. The treatment of oxygen transport is thorough and reasonably clear; the treatment of carbon dioxide transport ignores all of the complexities of distribution among chemical species and between plasma and cells, and represents a lost opportunity to give a meaningful and sophisticated example of transport across cell walls. The treatment of artificial lung devices describes, very succinctly, the principal simplifications used to analyze these systems but again stops short of a design approach.

My uneasiness about this presently best text is, in short, that it is not what I think of as an engineering text. It consistently deals with material without a clear sense of purpose. It does not show well enough how judgment enters into defining a problem, choosing a method to solve it, and analyzing the import of the solution. The book is a microcosm of a serious problem facing chemical engineering education: how and for what kind of career we are educating the growing fraction of students in our departments for whom the area represented by this book is their first career preference. There are possible answers: Chemical engineering has served over many years as a premedical program for some. There is a small but growing artificial organs industry. The diverse medical devices industry needs larger numbers of engineers, some of them chemical. Paramedical careers involving work with physicians to perform complex diagnoses and deliver sophisticated therapy, are being defined. Unfortunately none of these areas is well addressed in the present book. I think we lose our fundamental reason for being when we do not teach the practice of engineering and the engineering approach in our courses.

A necessary, unhappy word about the production and pricing of this text: Each page is a photograph of an 8½" x 11" page, typewritten, double spaced. Its 458 numbered pages each contain some 300 words per page, about 2/3 that of a conventionally typeset page. A hardcover binding finished in plastic-coated paper has been used; my copy showed signs of serious wear after a few days of use. At $36.50 this indifferently bound book costs 12 cents per equivalent page, surely an unenviable record for a textbook. □

ChE laboratory

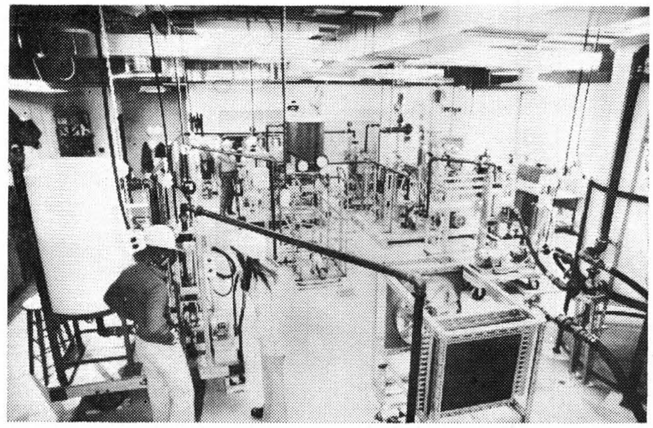
LESSONS IN A LAB

Incorporating Laboratory Exercises Into Industrial Practices

JOHN R. HALLMAN and PAUL D. NEUMANN
Nashville State Technical Institute
Nashville, Tennessee 37209

A QUESTION FREQUENTLY asked by the academic community is how extensively or to what depth should laboratory exercises duplicate the industrial scene? In typical professional BS engineering programs, a certain amount of laboratory practice is included in each curriculum; however, that amount varies usually with the attitude and philosophy of the faculty. It is apparent that reduction of the laboratory program to a minimum in many professional BS engineering curricula and the substitution of math, computer and system/process simulation in its place has stimulated the formation of programs in engineering technology. These latter programs in technology are justified to legislatures, school administration and the industrial employers because they include the laboratory exercises in hands-on-training with industrial-type equipment. The use of both bench scale and larger items of equipment to demonstrate and train the four-year Bachelor of Technology students appears to satisfy the employers of the BT engineering graduates.

In the area of a two-year engineering technology curriculum, a strong laboratory program is an absolute necessity. If the graduate technician is to be capable of performing the tasks for which he/she was hired, then the academic training should have contained a strong industrial oriented laboratory experience on real industrial equipment or equipment that is a very close approximation. Another important feature of an academic-type industrial laboratory experience is that the instructor should have had industrial experience himself: the longer his length of service, the more vital the applied training to the student.



View of laboratory looking northwest.

At Nashville State Tech, we have attempted to develop laboratories that would incorporate as many of the previously discussed training philosophies that could be attempted in our academic environment. Particularly, the Chemical Engineering Technology laboratory has been designed, installed, tested, checked and finally operated in the concept of an industrial pilot plant. The present lab equipment was assembled essentially by six classes of students who had a variety of experiences in that assembly and checkout. While previous papers and publications have described the general philosophy of the ChE Technology lab and its intended program [1, 2, 3], this paper will discuss those experiences with reference to the orientation of the training involved in the actual assembly and testing.

In any pilot plant facility, the system is redesigned and assembled into a specific configuration based upon the actual chemical plant or process. It is intended, after the pilot plant is checked and tested, that the operation should proceed in a manner as the original plant. The efforts of the ChE Technology laboratory program was directed towards the assembly of a simulated pilot plant in order to test, check out, maintain and operate a system in a similar to, or equivalent to, an ordinary chemical process in the manufacture of a product. Since Nashville Tech is not a competitive company, our product from the loop system, here described, is also our raw material. The operations in the laboratory should be the same in the transport of fluids, the heating and cooling processes and the separation and blending operations normally found in any chemical plant system. Our first activities in performing these tests are described in this article.

PROGRAM DEVELOPMENT

NASHVILLE STATE TECH began its function in the fall term of 1970. All Engineering Technology curricular areas were engaged in planning, in the program development, and in the acquisition of hardware for the various laboratories.

The ChE laboratory was to be unique in that it would provide hands-on-training by the assembly of the facility by the students themselves. In addition, the laboratory was to be different from others by being a total process system. In the laboratory and "pilot plant assembly," the stream-stream blender unit was temporarily removed from the system to avoid damage during piping flow checks. All of the equipment and piping shown was assembled by the various classes of second-year students. Figure 1 is a view of the laboratory looking northwest. Our first major assembly was the evaporator system. It was a standard philosophy in purchasing equipment that it should be sent unassembled (at reduced cost) so that the students could receive on-the-job training in following commercial assembly blueprints. In all classes, the use of a level and square was stressed in the equipment assembly. None of the different student classes had any trouble continuing the assemblies that were started by a previous class since all components and parts of these various assemblies were fitted properly into the desired configuration.

. . . the laboratory has been designed, installed, tested, checked and finally operated in the concept of an industrial pilot plant. The present lab equipment was assembled essentially by six classes of students who had a variety of experiences in that assembly and checkout.

John R. Hallman received his BS degree in Chemical Engineering from the Pennsylvania State College, his MSE degree in chemical and metallurgical engineering from the University of Michigan and his Ph.D. degree in Chemical Engineering from the University of Oklahoma. Professor Hallman is head of the Chemical Engineering Technology Department at Nashville State Technical Institute. Prior to joining Nashville State Technical Institute, he was research associate and special consultant to University Engineers, Norman, Oklahoma, and prior to that, senior design engineer at General Dynamics Convair, San Diego, California. He is a registered Professional Engineer and has authored several papers on technical education and co-authored papers on plastics ignition and surface absorption. **(L)**

Paul D. Neumann received the Bachelor of Arts degree, cum laude, in chemistry, physics, and mathematics from the University of Minnesota. He has done graduate work in chemistry at Cornell University and in Environmental Engineering at Vanderbilt University. Currently, he holds an appointment as Associate Professor in the Chemical Engineering Technology Department at Nashville State Technical Institute. Before joining the faculty at NSTI he was employed at the Oak Ridge National Laboratory in the development of coolant systems for nuclear power and research reactors. He was also employed as an industrial chemist by the Corning Glass Works in their main plant in Corning, New York. Mr. Neumann is a registered professional engineer, a member of numerous professional organizations and has authored papers in several areas of nuclear power plant coolant systems design and on technical education. **(R)**

The first major commercial installation was the 40 HP boiler unit in fall of 1972. Unfortunately, the steam piping was not a part of the facility. It was not until March 1976 that steam was available in the laboratory. There is still one problem area in the operation of the "pilot plant." Insufficient cooling water for the condenser on the evaporator is available; the only sources are the two water taps in the sinks. As one can visualize, there have been several exciting moments when the condenser temperature has risen too high for proper evaporator operation.

ON-THE-JOB TRAINING

IT IS AN ACCEPTED practice in the chemical industry that a small but essential production unit is constructed and operated before a full-scale plant is built. Although there are some exceptions in other industrial systems, these "pilot plants" are an accepted part of the chemical complex. At the Nashville Tech "pilot plant system," our first experience dealt with process piping and sub-systems cleanout. We prepared a 10 percent trisodium phosphate solution in our large tank, approximately 400 gallons, and proceeded to operate our pumps individually for a degreasing operation. It was immediately apparent that not all of the piping was leak tight; in fact, there were few fittings that did not leak. As the students quickly learned, we not only cleaned the system, but we had to tighten the process piping. At system shutdown, we all learned a bitter lesson; there were no drain valves on the low points in the piping. It required a week of disassembling and reassembling to correct this small detail.

Process instrumentation and control are offered jointly with the pilot plant laboratory. Students have assembled manometers and recorders in the necessary mobile frames for the past four years. Other groups electrically wired these units for power and added the wiring for the instrument to measure the desired variable. All of these instrumentation units have been placed in the pilot plant system when required. As a part of this instrumentation course, techniques in calibration and rate of response were (and continue to be) demonstrated and practiced. The experiences of the students were most useful in designing a liquid level assembly for one of the process tanks after a near overflow during a checkout exercise.

One of the features of the "pilot plant" was to enable the instructors to acquaint students with the complexity of a process system during installation, checkout, testing, maintenance and operation.

One of the features of the "pilot plant" was to enable the instructors to acquaint students with the complexity of a process system during installation, checkout, testing, maintenance and operation. On the morning of the first actual attempt to go "operational," a first-year student was teamed with a second-year student to give training to both; the first year to learn and the second year to teach and supervise. The operation worked well as long as the laboratory facility was able to perform.

On schedule, the Loop System pump No. 1 was started and we found the entire evaporator unit leaked. This was remedied rapidly by some of the fastest pipe wrench action ever seen in the lab. Next, one of the students noticed that the steam condensate tank was not emptying; in fact, the pump would not start. We then discovered that there was an improper electrical connection for the condensate tank pump, no fuses for the auxiliary pump control switches, and no designations or names on the switches for turning on or off. After a lapse of two hours, we resumed only to discover that no pumps were pumping and our condensate pump controls had burned out. Somehow, a 208-volt line had been wired to a 110-volt solenoid. The lab exercise was terminated at this time. Several days later, after installing the correct solenoid, our exercise was started again.

MAKING THE SYSTEM WORK

SINCE OUR EVAPORATOR had filled up rather than operating properly during this brief operation, the pump motors had to be operated singly to determine the pump rotation. All operated, but backwards. The direction of the centrifugal pumps was easy to detect, but the gear pump required dismantling to determine the rotation of the pump in relation to that of the motor. It too was operating backwards. Simple remedies were made by reversing two leads of the 208-volt AC power system. Now the evaporator was a part of the operating system. One of the flow measuring instrumentation units was installed in the main liquid line to determine the amount of fluid bypassing the evaporator; it did not operate, nor did the included recorder. Electrical checks were performed, wire checks were made, a circuit ring-out was made, but still no operation. After two hours of frustration, one of the students grabbed the wires and discovered that one terminal was not crimped to a lead wire; in fact, none of the wires in one set were crimped.

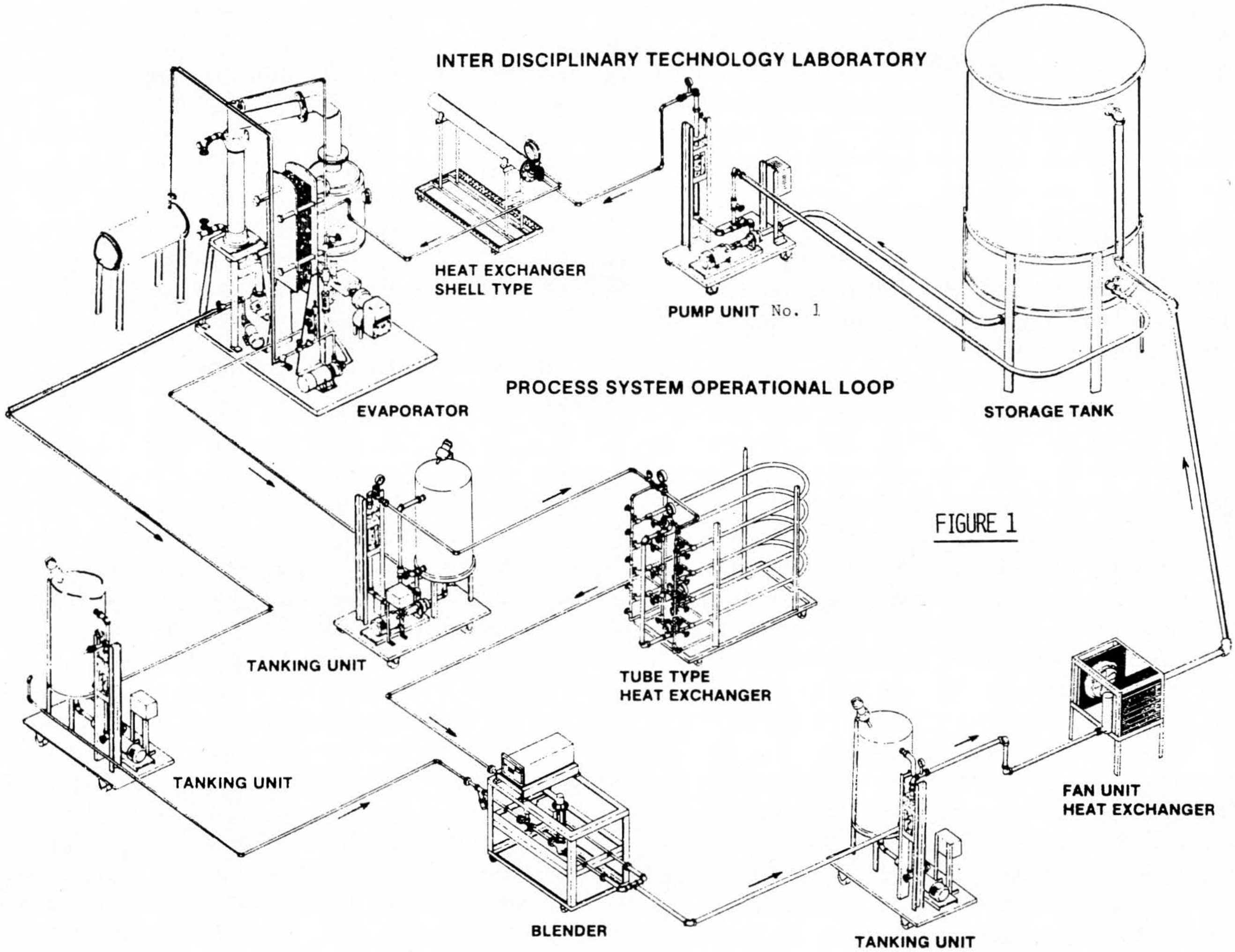


FIGURE 1

After immediate repairs, we had a magnetic flow meter that worked. Unfortunately, the recorder was not calibrated so that our readings at first were not too accurate. During all of these attempts to operate the pilot plant, the students all agreed on one question—"What actions are taken when this happens in an industrial plant?" Both of the instructors just smiled and said, "The same thing that you are doing here, trouble shooting the cause and making the necessary repairs or alterations to make the system work."

After an hour of relatively calm performance, by both the system and the operating personnel, it was discovered that the flow rate of pump No. 1 was gradually decreasing. In the supply line between the pump and supply tank, a strainer was originally installed. Its purpose was to prevent any collected sediment and/or debris from entering the pump. This strainer was cleaned at least twenty times with some recovery of flow, but the overall condition did not improve satisfactorily. Again, the process system operation was terminated because of completion of the daily scheduled lab exercise.

During the next lab period, an observer was stationed to observe the interior of the tank. The normal tank level for these initial test exercises was five feet from the bottom with an NPSH* of six feet. After an hour of operation (tank level stabilized, from the input/output flows), the observer reported that a vortex had formed and gradually increased in size as the pump speed and flow rate also increased. After observing this vortex and having the flow rate decrease to 25 percent capacity, the regular shut down procedures were started and the system gradually returned to zero flow conditions.

A new problem arose when the students reported that there was little or no information on anti-vortex baffle plate. Since the tank is manu-

*Net Positive Suction Head (Pump Inlet Pressure) factured of polyethylene, by necessity the plate had to be hot-welded to the tank bottom. Author Hallman had that privilege, but not by choice. The plate worked; no further problems in vortexing were encountered, and the flow rate remained steady at the maximum value of 80 gpm.

PIPING PROBLEMS

IT SHOULD BE NOTED that piping leaks were encountered frequently during all check outs and systems operations. All piping in the process laboratory and an air supply line were installed by the second-year ChE Technology students as a part of the unit operations laboratory; the air line was installed by the 1976 graduating class. It has been a learning experience for both instructors and students in teaching and learning to properly measure and thread pipe of various sizes. Although a pipe threading machine was available for the larger sizes of pipe (1½″ and 2″ diameter), the small pipe sizes (1″ diameter and less) were always threaded by hand; the larger pipe was threaded by machine, after the students had the opportunity to hand thread those larger diameters. In the manipulations of assembling the piping system, the assortment of pipe fittings, valves, and associated items gave the students the experience and actual training in choice, selection, and determination of pipe and piping equipment. It is interesting to note that not all of the mistakes and errors were made by the students; one commercially purchased assembly had a check valve installed backwards; this improper assembly caused several hours of lost time and many heated tempers, because the system did not contain any piping unions which could be used for the disassembly of the system. The students learned that pipe unions were made to be installed in the event a system must be cleaned, revised, or removed.

The Spring Quarter, 1976, ended with the graduation of the students and their employment in various companies. The lab was approximately 85% complete in its assembly. The 1977 class has finished all of the assembly required, both subunit and the instrumentation/control systems, and have installed all in the loop. We have operated the total loop system for several hours at a steady state flow (about 30 gallons/minute) without serious malfunction. Our only problems have arisen due to excessive pressure drop and dirty filters. As the quarter ends on the 1977 class of graduates, all have expressed the same opinion: that the laboratory was an exercise in patience, fortitude and real training, coupled with entertainment.

In several visitations by ChE professors of other colleges and universities as well as the chemical engineers employed in our local industry, the general comment has been the same; they wished their employees could have had some training on the Nashville Tech ChE loop.

CONCLUSIONS: BY APPLICATION

THE USEFULNESS of these past seven years in the operations of the ChE Technology laboratory has been demonstrated by the applications being used by the graduates. One of the 1976 graduates has been assigned the task of designing the process piping system for an actual pilot plant; he has attributed his assignment particularly to his experiences in the assembly and checkout of the Nashville Tech system. Other graduates are employed in system design, pollution/environmental controls, pilot plant operations and production. Each graduate, in visits to the school, has expressed his gratitude for the laboratory training experiences. Many present and potential employers have commented favorably on the philosophy of the laboratory training. It is apparent that we have developed one method of providing a student with the opportunity to practice in school some of the industrial practices he will use in his own career. Future planning contains our same philosophy: change, modify, test and operate the laboratory as before; give to the student what he/she will require to perform the job for which he/she will be hired. □

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