CEE chemical engineering education

CHEMICAL ENGINEERING DIVISION OF AMERICAN SOCIETY FOR ENGINEERING EDUCATION

SPRING 1969

NEW DIRECTIONS IN CHEMICAL ENGINEERING

Dynamic Educator

STU CHURCHILL OF PENN

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Also RENSSELAER - *the ME or the BS?*

DARTMOUTH'S *doctor of engineering*

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EDITORIAL AND BUSINESS ADDRESS

Department of Chemical Engineering
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Departments

Feature Articles

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from our READERS

Praise from Erb

Sir: The Winter 1969 issue of CEE was exciting and encouraging with the series of articles on "The Engineer and Public Affairs." Not only has the chemical engineering profession been appropriately challenged, but it has been given some specific guidelines in meeting this challenge. You and your staff are to be commended and encouraged in this fine editorial effort. . . .

In the "Editorial" you raise the oft-repeated cry that we or our "professional goals have not been understood . . .". Are we really misunderstood? Or are we sometimes understood only too well? The correspondence from Leigh E. Nelson printed in that issue (p. 44) goes to the heart of the problem.

I wonder to what extent your statement that "Our ultimate aim is to serve our fellow man and to insure him his intrinsic human worth and dignity" is realistic and representative. Is it not too often dust-covered idealism?

You follow this with "Accordingly, if . . ." — with three big "If's". The challenges that follow are commendable and I emphatically agree with them. To me the "If's" are very appropriate, significant and, I suspect, thoughtfully inserted by you.

This leads me to the proposition that before we proceed to try and convince others of our idealistic "ultimate aim," we had better first make sure that we have demonstrably convinced ourselves. I interpret this as your objective, but maybe it needs to be more frankly stated. Or am I being too cynical, or too brusque?

In any case, the corporate structure within which most engineers work makes the realization of these goals so difficult that at times it's hard for him to keep them within his perview.

The concerned engineer will seek to exercise this responsible leadership in his outside activities, and this is being encouraged. But it is as a working engineer in his area of employment that he spends most of his productive time and most fully practices his profession. And it is in how well we as working engineers meet this "ultimate aim" that our professionalism should and will be judged. It is because of our failures in this area that our professional goals have been "misunderstood."

Here is where our professional societies need to exercise more moral leadership. I, at least, feel the need for this kind of support. The societies should not only voice these aims, but work more determindly for their effective translation into practice. The practicing engineer should be lead and encouraged in understanding and applying true professionalism with its sociological implications. The societies should make it dramatically clear to the employers of engineers that these sociological concerns are embodied in this "ultimate aim"; that these concerns are to be expected of the engineers in their employ; and that they go beyond protecting the employer from safety hazards, lawsuits and the wrath of society or the public in general.

The plethora of papers, at AIChE meetings, e.g., concerned with pollution control are a reaction resulting from our having failed society in the past, not an exercise of leadership. I suspect that most are still directed at what must be done, not at what should be done. Above the "hurt" voice of industry crying that they're doing their best, that it's too costly, that some pollution has to be expected and accepted, that it can't be done, should be heard the voice of the engineering profession saying "tommy-rot — it can and will be done."

If — and there's that "If" again — we are true to our "ultimate aim," the engineering profession could bring not only tremendous moral pressure to bear, but also intellectual and economic pressure in the way we carry out our day-by-day working responsibilties as practicing engineers. This means dedication as individuals, but individually the result would probably be to put our own jobs and livelihood in jeopardy to no effective end. Collectively as the engineering profession there is much that can be accomplished.

In the Winter 1969 issue of CEE a beginning has appropriately been made toward putting the house of engineering education in order. But the problems and implications go well beyond the areas of the educational institution per se. As numerically significant and influential voices in the professional societies and as those with a vital stake in the profession of engineering, the engineering educators are in a critical position. By their words and actions they can do much to help all of us toward a more viable and potent professionalism.

Paul W. Erb
Westwood, N. J.

Prof. Shreve retorts

Sir: First, let me compliment you upon CEE. I am referring particularly to Volume 3, Number 1. Your editorial is good and timely.

On page 5, the letter to the editor wanting to drop "chemical" in Chemical Engineering is frightening and awful. We are **Chemical** Engineers first. Our Chemical Engineering has arisen from its root in chemistry and it should be kept that way. To indicate to you what I have done in that regard, I am attaching a copy of the letter I wrote to the President of the AIChE.

One of the things I like about your journal is the articles for the underprivileged on pages 14 and 20.

If you wish, I will write a strong letter about the emphasis upon chemistry in chemical engineering that would answer the letter written by Rex T. Ellington on page 29. The fundamentals he brings up should be taught as a basis of chemistry and for other essential subjects.

R. Norris Shreve
Purdue University

Berg replies to Henley

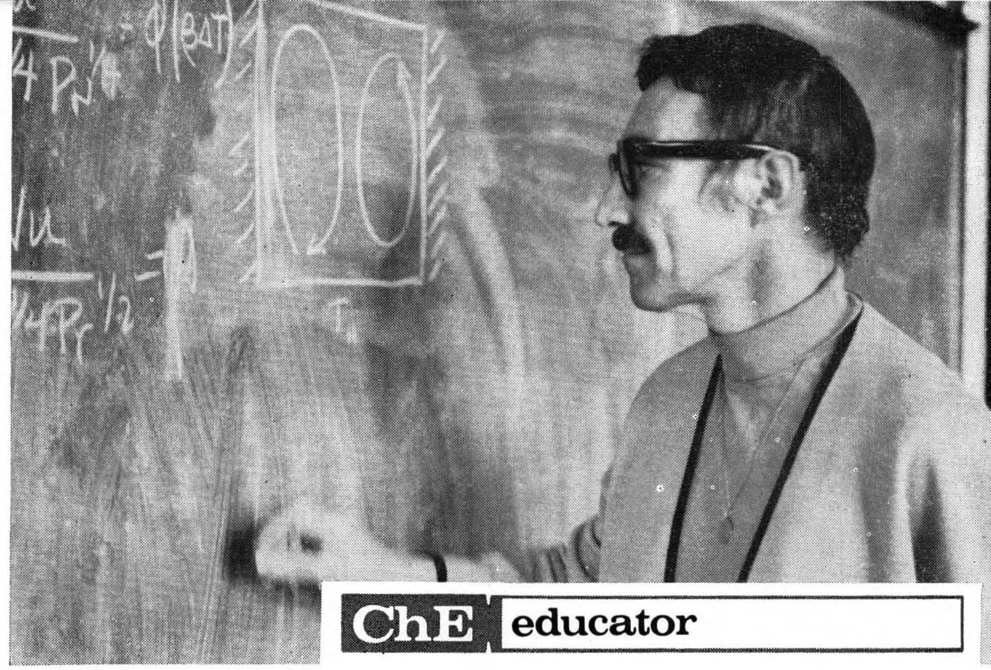
Sir: Professor Henley's thoughtful and well-organized article on "Recruitment" in the Winter 1969 issue of CEE spotlights a very serious problem in the chemical engineering profession. I am sure that this article will spark a variety of response from the profession. It does from me.

Professor Henley deplores "all competitive advertising as self-cancelling." At Montana State, we graduated twelve BS chemical engineers in 1962; we will produce 30 in 1969. In 1962 our total chemical engineering enrollment was 154; today it is 236. The increase was accomplished by advertising.

When I was a little boy, I recall two popular soft drinks, Moxie and Coca-Cola. One of these companies

(Continued on page 68)

STUART W. CHURCHILL OF THE UNIVERSITY OF PENNSYLVANIA



ChE educator

ARTHUR HUMPHREY
University of Pennsylvania
Philadelphia, Pa. 19104

"How can any man do so much?"

豹 HYO is the name Professor Churchill acquired in Japan. The translation of HYO is leopard. This name is symbolic of the vigor with which Stu translates the excitement of Chemical Engineering to students and professionals alike, and also of his deep interest in the international development of chemical engineering education.

No other chemical engineer has so vigorously urged the future importance of Chemical Engineering or so strongly insisted that the ASEE "Goals" Report did not adequately recognize the uniqueness of Chemical Engineering. The Chemical Engineering profession was fortunate to have such a dynamic spokesman as Dr. Churchill in the critical position of AIChE President and AIChE representative on ECPD during the years in which the Goals Report was formulated and discussed.

In recent years, it has been fashionable for humanists and social scientists to attack the engineering profession for contributing to rather than solving society's problems. Stu has been called upon time and again to defend our profession. Like the leopard, he has taken the offense. This position is best illustrated by the closing statement of his AIChE presidential address — "We need to speak confidently to the public as engineers, as Chemical Engineers, as the servants and hope of mankind" — and in his address before the New York Academy of Science on the question of engineering survival and obsolescence —" . . . engineering will not only survive, it will prevail. It will prevail because it holds the only hope for solution of the major problems confronting mankind. It will prevail despite the attacks of its friends and enemies because it has demonstrated the capability of changing and evolving — not through exhortation or formulas, but through response to human needs."

Until recently much of Stu's life has been oriented around the University of Michigan where he received all of his degrees. Note should be made of the fact that Stu played clarinet in the famous Michigan Band. It has been said that at Michigan the Band required more time than football, but he found time for the Band while compiling an outstanding undergraduate record. After receiving a bachelors degree in engineering mathematics as well as chemical engineering he worked four years for the Shell Oil Company at Wood River, Illinois and one year for the Frontier Chemical Company at Denver City, Texas before returning for graduate work. Stu has stated that it was exposure to exceptional professors at Michigan such as A. H. White, C. E. Love, G. G. Brown, D. L. Katz, J. C. Brier, R. R. White, C. M. Sliepcevich, and M. Tribus that really kindled his enthusiasm for Chemical Engineering and teaching. In 1952, following the receipt of his PhD degree, he was appointed to the staff as an Assistant Professor. He achieved the rank of professor only five years later. Between 1962 and 1967 he was Chairman of the

. . . it has been fashionable for humanists . . . to attack the engineering profession. . . .

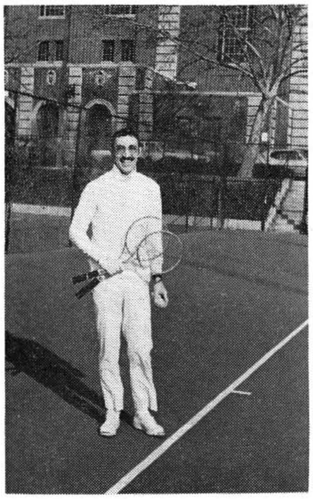
Department of Chemical and Metallurgical Engineering. In his 15 years as a faculty member at Michigan, Stu served on 27 different University committees. These committee duties ranged from Vice Chairman of the Senate Advisory Committee on University Affairs to the President's Commission on Year Around Operations to Vice Chairman of the Board of Control of Intercollegiate Athletics. For most university professors this kind of committee load would have been the kiss of death to their research program. But Stu personally supervised 27 PhD theses, served on the doctoral committees for another 48 PhD students, and wrote 78 technical publications during this time. He also found time for a heavy load of professional society responsibilities culminating in his election as President of the AIChE. During his tenure as president he managed to visit a majority of the AIChE local sections. While an officer of the AIChE, F. J. Van Antwerpen encouraged his interest in international chemical engineering and he became involved in the development of meetings and educational projects in England, France, Germany, Russia, India, Japan and Mexico.

He has been a strong advocate of faculty interchange both internationally and intranationally, and has himself given seminars at over 30 universities.

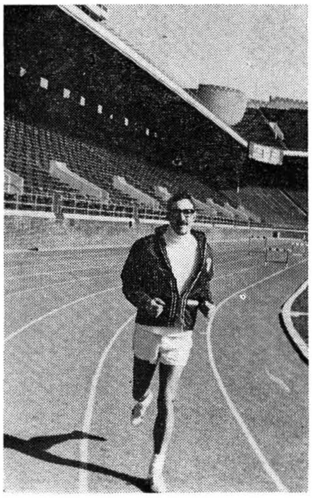
How can any one man do so much? Only those who have seen Stu in action can know. Few people have the ability to understand a situation or grasp a new concept as quickly. He always penetrates to the nub of any problem, quickly discarding the unessentials. He can make decisions with haste without making them seem hasty decisions.

Stu is an outstanding classroom teacher. Students at the University of Pennsylvania rate him one of the best in Engineering. One of the most telling comments is that heard recently from a graduate student taking his course in Advanced Transport Phenomena who said, "Dr. Churchill made the course come alive for me. I am now able to see the meaning and relevance of transport phenomena to Chemical Engineering practice. Transport theory only seemed like an exercise in applied mathematics when I was an undergraduate."

Stu has always argued for a strong interaction between industry and academia. As AIChE President he appointed a Blue Ribbon Committee of industrial executives and faculty leaders to make recommendations for the development of a



Stu has been called upon time and again to defend our profession. . . .



Like the leopard, he has taken the offense.

. . . "engineering courses should be . . . an exciting joint venture by the student and professor into the unknown of chemical engineering .. ."

better liaison. At Michigan he arranged with duPont and Hercules a special program to provide industrial experience for his young faculty members. He tries to live up to this concept in his teaching and research. His lectures and home assignments, however theoretical, always have a flavor of practicality. He says that many of his research ventures have been stimulated by consulting experiences. His research, while centered on heat transfer, combustion and mathematical approximations, has covered a wide range of subjects, perhaps for this reason. He has consulted for over 19 companies, notably for Conch Methane Services, Ltd. in the development of the technology for storing and handling liquefied natural gas and for the 3M Comany. He has also served as a consultant or advisor to many Universities.

Stu has proclaimed on several occasions that "engineering courses should continually evolve. They should be an exciting joint venture by the student and the professor into the unknown of Chemical Engineering." It was, in part, a desire to live this philosophy that brought Stu to the University of Pennsylvania. As the Carl V. S. Patterson Professor of Chemical Engineering at the University of Pennsylvania he has been presented with an opportunity to do a minimum of administrative work and to interact with students at an intensity not previously available to him. The relatively small classes of high quality students at Penn have made it possible for Stu to conduct his classes in seminar style in the true classical sense. One can not help but marvel at the way in which he can get students excited about Chemical Engineering. I suspect that in the future the profession will see more and more of the Churchill enthusiasm for Chemical Engineering being espoused by his former students. He is very proud of his doctoral students, who are listed below. Fifteen have been inspired to follow him into teaching, including our own Warren D. Seider.

There is another side to Stu, a very human side, that few have the opportunity to see or experience. I purposefully say experience because that is exactly what a personal encounter with Stu is. I have not met another person with such a zest for living. He seems to know something about everything. Whether it is a special restaurant, an imported wine, a discotheque, a sitar player, the moves of a basketball player or a new development in rock music, Stu has been there, knows of it, or excells at it.

STUDENTS WHO COMPLETED THEIR DOCTORATE UNDER STUART W. CHURCHILL

Peter H. Abbrecht	William N. Zartman
Morton P. Moyle	James A. Leacock
William R. Martini	John C.-C. Chen
Herbert E. Zellnik	J. David Hellums
Bert K. Larkin	Thomas D. Bath
Martin E. Gluckstein	Lawrence B. Evans
Donald W. Sundstrom	Robert G. Rigg
William N. Luckow	James O. Wilkes
Roy C. Gealer	Carl G. Vinson, Jr.
George C. Clark	Dudley A. Saville
Irving F. Miller	Michael R. Samuels
H. E. Stubbs	Warren D. Seider
Richard A. Ahlbeck	

Unlike our colleagues at Wisconsin who specialize in canoeing, or at Colorado where their thing is ski-racing or the mile run, or at Houston where staff and family all play tennis, Stu does them all — skiing, tennis, running, etc. Whatever the event Stu is the man to challenge amongst the Penn faculty. For over a year now Stu has had five of the Penn Chemical Engineering faculty running 1 to 4 miles each day. He has them aiming for a goal of a 6 minute mile. He has suggested that Penn faculty might challenge other faculties to a post card four-mile relay race. Stu has three of the faculty playing outdoor tennis the year around — even in 20°F weather. On one or two occasions a few patches of snow have had to be removed so as not to encumber play. He says he almost has his colleagues in shape to take on other schools. This spring when Bob Bird visits Penn, Stu, Bob and some Penn faculty and students are going to canoe the Delaware River.

We at Penn feel most fortunate to have Stu within our midst. However, I believe all Chemical Engineering shares this good fortune. We have Howard and Faye Churchill to thank for conspiring to create on June 13, 1920 at Inlay City, Michigan, one Stuart Winston Churchill. Not only past and present Chemical Engineers but a generation yet to be educated will owe some of their excitement for the practice of Chemical Engineering to this man.

NEW DIRECTIONS FOR ENGINEERING*

STUART W. CHURCHILL

Carl V. S. Patterson Professor of Chemical Engineering
University of Pennsylvania
Philadelphia, Pa. 19104

The engineering profession remains vital because of the continual re-examination and criticism of its own goals and practices. Engineering education is traditionally in a state of flux. The current stimulants to re-examination and change are (1) public problems and scandals such as air pollution, population growth and mass transportation in which the engineer is involved as both culprit and savior; (2) high speed computation which is revolutionizing every aspect of engineering practice; (3) the rapid production of technical information which is forcing the practicing engineer to spend a considerable effort on re-education; (4) the diversion of much of engineering education and research away from application and toward science and (5) the development of new opportunities such as bioengineering and medical-engineering.

The recent ASEE study has not provided a sufficient set of goals or an acceptable set of recommendations for the future development of engineering education. Hence further efforts on the part of the engineering community are necessary to establish new goals and directions.

These goals should include better communication with the public, recognition of the social consequences of engineering projects, enhancement of engineering as a professional career, development of stronger support of the engineering profession by industry and the government, increased flexibility in the curriculum without the loss of depth or motivation which is characteristic of specialization, encouragement of diversity in engineering education, more effective programs for continuing education, and a response to new developments in technology that goes beyond the assignment of new labels.

INTRODUCTION

The engineering profession is currently in the throes of a very thorough re-examination of its practices, status and goals. Continual re-examination and revision is a characteristic of engineering education but the engineering profession as a whole re-examines itself in a more periodic and dramatic fashion. This process involves much self-recrimination and is carried out in full view of the public. The primary result is a new set of directions and goals, or rather many sets of directions and goals. A secondary result is a very confused public, including our immediate colleagues in the universities and other professions.

SOME SHORTCOMINGS

I will first note some of the problem areas which have been identified by the current self-study.

(1) **Engineering is very much in the public eye, but our image is not very good.** Engineering is much harder to explain to the public than science and we make far less effort.

My companions today in the airport limousine fouled the air with cigarette smoke while they cursed the engineers (and perhaps legitimately) for allowing pollutants to pour out of the refineries we were passing.

* *This article was presented to the Engineering Division of the New York Academy of Sciences at a Forum on "Is Engineering Becoming Obsolete?" It is reprinted with permission of the Academy.*

One of the strengths of engineering education has been its diversity. . . . A significant factor in the continual improvement of engineering education has been the accreditation process conducted by an organization of the professional societies, — ECPD.

The public sees us as the generator of air pollution, weapons for mass destruction, traffic snarls, planned obsolescence of automobiles and appliances, sonic booms, etc. They do not realize that we hold the only hope for alleviation of these problems. Nor do they know how to seek or utilize our services in their behalf.

(2) **The humanists and social scientists are openly pleased at our disgrace and have little appetite for cooperating with us.** They are afraid of us and grandly contemptuous of a subject they do not understand. Aristotle in his Politics-VIII said, "Occupations are divided into those which are fit for free man and those which are unfit for them; and it follows from this the total amount of useful knowledge imparted to children should never be large enough to make them mechanically minded.

"The term mechanical should properly be applied to any occupation, art, or instruction which is calculated to make the body, soul, or mind of a free man unfit for the pursuit and practice of goodness. We may accordingly apply the word mechanical to any art or craft which adversely affects man's physical fitness, and to any product which is pursued for the sake of gain, and keeps man's minds too much and too meaningfully occupied."

Robert Hutchins is quoted[1] as saying recently that engineering schools should be stamped out. It is unlikely that we will convince the classicists of the merits of engineering even in another 2000 years.

(3) **Industry frequently acts as if it has no stake in the health and future of engineering.** It complains about the direction of engineering education and research and about the influence of the federal government, but defaults in the support of engineering education. It contributes preferentially and publicly to the colleges of liberal arts. It complains at the shortage of engineers but does not work hard to encourage students to take engineering. It emphasizes that advancement only comes through management and encourages engineers to divert to business administration. It offers a strong financial incentive to students to continue to the doctorate and discourages the practice of engineering with a bachelors degree by treating them as sub-professionals. I am quite aware of the many positive contributions of industry, but that is not our concern tonight.

(4) **Engineering education has itself taken some false directions.** Much engineering research in universities is merely imitative science. The recent change in name from Metallurgical Engineering to Metallurgy in my University acknowledges this development. The employment of new Ph.D.'s without industrial experience creates a closed loop that accelerates this trend. The core curriculum and the reduction in specialized courses have reduced the professional motivation of our students. "Mission-oriented" departments and curricula have been created which have no real justification other than temporary compatibility with Federal agencies that have funds to dispense. The addition of more abstract material to the curriculum has resulted in decreased comprehension by the students. Faculty attention has been increasingly diverted to graduate work and to those undergraduates who are potential graduate students. As a result of these several changes, the bottom half of the class is completely demoralized by the time they graduate. Again I have confined my remarks to the unfavorable changes.

(5) **We have discovered that technical achievements may create or aggravate social problems.** We advocate the addition of courses in the humanities and social sciences to ease our guilt. We even assert that engineers should themselves solve or prevent these social problems.

(6) **We are not yet prepared to intervene as a profession in behalf of the public interest.** For example, we silently design and operate plants that unnecessarily pollute the air and water instead of offering leadership to the public in this field.

(7) **We have discovered that our technical education rapidly becomes obsolete** primarily because of the outpouring of new technology and the revolution engendered by computing machinery. We have proudly announced to the public that we are obsolete. I do not recall scientists making this statement although they are in the same dilemma. We favor continuing education for our colleagues but are unwilling to undertake it on a meaningful level ourselves.

(8) **The engineering students must withstand the contempt of their fellow students in the liberal arts.** They are often neglected by the faculty. They are advised that they are second-class citizens unless they go to graduate school. They are told by industry that managerial skills are far more important than technical skills. Now they hear the self-recriminations of the profession. They are reacting as might be expected. They are "chickening out" of engineering in large numbers into science, business, medicine, law, etc., or are phasing out of engineering practice by continuing to the Ph.D. and seeking a career in teaching and/or basic research.

These are some of the problems we have identified. What are we doing about them?

THE GOALS STUDY

Engineers Council for Professional Development requested and the National Science Foundation funded a study of the goals of engineering education. Unfortunately despite the vast expenditure of funds and effort by the American Society for Engineering Education, the report[2,3] which has resulted from the study does not state goals with which the profession can identify.[4,5,6,7] It concerns itself instead with the labels and mechanics of education. Acceptance of the specific recommendations of this report would aggravate rather than alleviate the above-mentioned problems of the engineering profession and engineering education.

Industry must recognize its stake in engineering education and provide support by word and deed. . . . It must permit and encourage engineers to retain their identity as professionals.

The preliminary version deprecates the baccalaureate degree outright, the interim version by implication. The authors would withhold professional acceptance from a would-be engineer until he had been awarded a masters degree. However they would award the masters degree in engineering for essentially the same effort as now required for a baccalaureate degree in engineering—but spread over five years instead of four. A specious degree will hardly raise the quality or prestige of engineering education.

Specialization is condemned by the reports. Somehow knowing less and less about more and more is supposed to produce a better engineer. All experience is against this recommendation. A few engineering administrators have given loud vocal support to unspecialized engineering education for years but it has not gained general acceptance. Chemical engineers have protested this trend because they have learned through bitter experience that the core curriculum and general engineering result in the minimization of chemistry and hence in the elimination of chemical engineering at both the undergraduate and graduate level.

Mission-oriented programs are favored over the technically-oriented programs. This approach gains much public attention and attracts the opportunists. However interdisciplinary problems are usually solved most effectively by teams of specialists who have some knowledge in depth in the fundamentals which are common to all problems—new or old, of large or small scale.

One of the strengths of engineering education has been its diversity. Students are offered a different education by different schools and new approaches are tested in practice. The Goals Report would make every school conform to a single pattern—and to one that has already been tried and found wanting.

A significant factor in the continual improvement of engineering education has been the accreditation process conducted by an organization of the professional societies—Engineers Council for Professional Development. The recommendation that accreditation be shifted from a professional to an institutional basis on the whim of the institution would certainly undermine the strength and value of this activity. It would also eliminate the role of the professional societies in accreditation.

The report recommends increased course work in the humanities and social sciences. We all agree that the engineer should be cultured and should be aware of the social consequences of his work. It is questionable whether these objectives would be accomplished merely by forcing more ill-taught courses down the unwilling throat of the student.

The report identifies the weakness of engineers in written exposition and then provides an excellent example of poor logic, poor writing and poor organization.

Clearly, the Goals Report fails to provide valid guidance for the improvement of engineering education. Unfortunately the prestige of the sponsors of the report will result in more attention and acceptance than the report itself merits.

The effort expended on the Goals study has wearied and discouraged us. Nevertheless, we must recognize that its failure forces us to assume the burden of formulating new and more acceptable goals.

NEW DIRECTIONS

In what direction should we go? What goals should we set? Once we have stated the problems, as above, the solutions are evident, even though difficult.

We must explain our capabilities, methods and goals to the public. We must act as professionals, not merely as employees of the public, the universities and industry. We must learn to build the public and the social sciences into the loop of our activities rather than operating independently. We should neither ignore the social aspects of our work nor naively try to solve the social problems ourselves.

We should spend less time reciting our belief in continuing education and more time developing sound programs, not just as a fad, but as an accepted part of our professional life. Industry must give greater encouragement and support to such activities. The universities and professional societies must cooperate, not compete.

We must make engineering a more attractive profession to the youth of today. We must encourage him to choose engineering education. We must nuture him as a student. We must treat him as a professional when he practices engineering. We must recognize that he listens particularly to our public statements and watches our public behavior and that he has virtually no other source of information on engineering. Industry has a great opportunity here.

We must motivate and prepare students for careers in engineering as well as in graduate school.

We must motivate students to develop an interest in and an understanding of the humanities and social sciences, particularly as they relate to engineering.

We must increase the flexibility of our curricula without losing the depth which is characteristic of specialization.

We must encourage diversity of objectives and programs in our universities and we must study the results of experiments in engineering education.

We must prepare our students for careers in the new fields of activity and need such as bio-engineering, medical-engineering and urban transportation. We should do this by inclusion of the appropriate fundamentals in the curriculum rather than by the creation of new curricula and new labels.

Industry must recognize its stake in engineering education and provide support by word and deed. It must treat engineers more consistently as professionals and even afford them some freedom for dissent. It must permit and encourage them to retain their identity as professionals.

CONCLUSIONS

Engineering has an uphill battle for survival in the face of

- Public misunderstanding
- Congenital suspicion, fear, and dislike by the humanists
- Half-hearted support by industry
- Second-hand support by the government
- Unconstructive diversions from within as per the Goals Report
- The continual burden of response to new problems and technology

Nevertheless, to paraphrase the words of William Faulkner in acceptance of the Nobel Prize for Literature, engineering will not only survive, it will prevail. It will prevail because it holds the only hope for the solution of the major problems confronting mankind. It will prevail despite the attacks of its friends and enemies because it has demonstrated the capability of changing and evolving—not through exhortation or formulas, but through response to needs.

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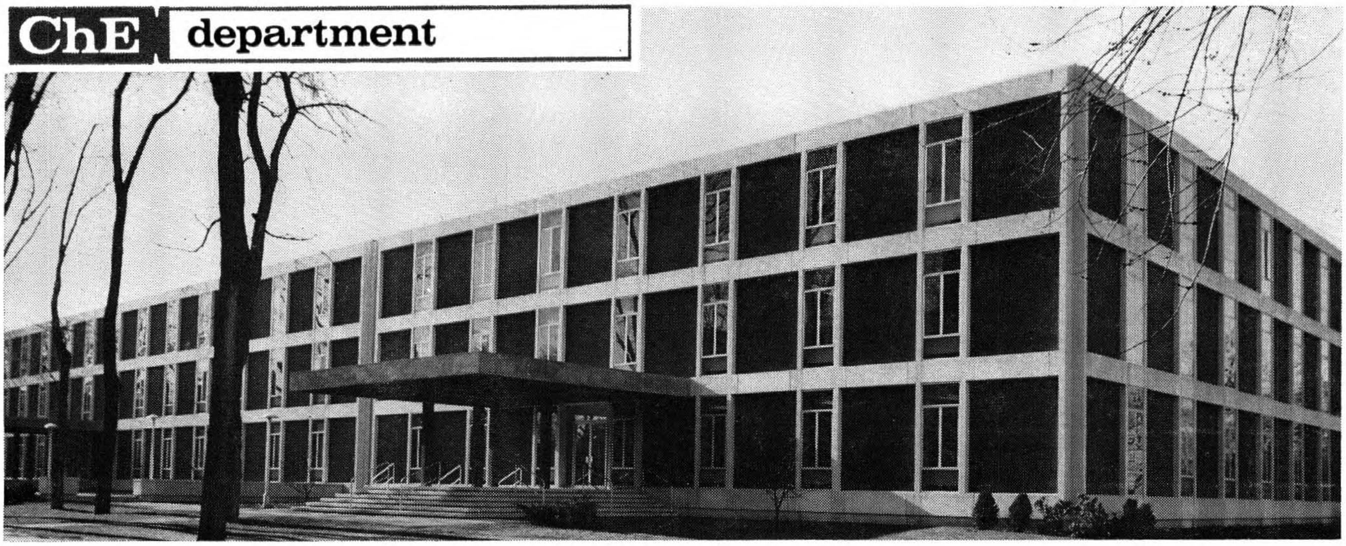
ChE department



RENSSELAER

CEE features a school which incorporates a new Master of Engineering degree into a dual administrative structure.

DAVID HANSEN
STEPHEN YERAZUNIS
Rensselaer Polytechnic Institute
Troy, New York

Chemical engineering education at Rensselaer has in recent years been strongly influenced by two major decisions of the School of Engineering. The first, taken in 1963, was to adopt a new structure for engineering education which departs significantly from the traditional pattern; while the second, taken in 1967, was to reorganize the administration of the School of Engineering.

In the educational structure, all engineering students pursue a pre-engineering program equivalent to three academic years during which emphasis is directed to the foundations of engineering by providing broad background in the natural sciences, mathematics, humanities, social sciences, engineering science and engineering. At the end of this phase the student may elect either to pursue a fourth year of study to a Bachelor of Science degree or to seek admission to the Professional School of Engineering and if qualified to undertake a coherent two year advanced study program to the Master of Engineering in a field of engineering. Students achieving either degree objective can continue their formal education either in engineering or in some other discipline or seek direct entry into a career.

The rationale of this educational structure originates with five principles: 1) the objective of a baccalaureate program should be basic education of a broad character, 2) professional engineering education should be based on a broad pre-engineering core, 3) the students' ability to resolve engineering problems must be developed and creativity should be fostered, 4) specialization in depth is necessary not only for career entry but also for developing ability to acquire new competence, and 5) programs must be flexible and responsive to individual needs.

These principles have not only influenced the educational programs but also played a fundamental role in the reorganization of the School of Engineering. The most pronounced feature of the new administrative structure is its dual character in that responsibility for research, advanced study and personnel administration is assigned to seven Divisions of Advanced Study while responsibility for all phases of programs up through the master's degrees is given to twelve Curriculum units, including the pre-engineering curriculum. Faculty members are associated with that division whose scope includes their individual fields and with those curriculum units reflecting their professional interests. From a curriculum point of view, this structure provides for an emphasis on educational development and makes available the whole faculty as a teaching resource.

THE PRE-ENGINEERING PROGRAM

The full implications of the pre-engineering program, Table 1, cannot be appreciated without an intimate awareness of the course content and philosophy. On the surface, it may seem to be a typical product of the trend towards unification of phases of engineering programs noted in recent years. However, such unification is frequently achieved as a lowest common denominator of the needs of all of the engineering specialties on which consensus can be obtained. In this instance, this program, which is under the direct control of the pre-engineering curriculum unit, is designed to provide the educational base upon which to superimpose professional study in depth without preoccupation with the specifics of the professional fields involved. In this context, subject matter represents not only a basis for further education of a professional nature but also a foundation for intellectual growth for a future whose details are in the main unperceived. The selection of knowledge must be based on appropriate criteria of value such as its longevity, range of application, contribution to future growth, relevance to the individual field of study and relevance to other subject areas. In addition, a balance must be obtained between prerequisites for areas of specialization, liberal education from a technical as well as nontechnical vantage point, and the opportunity for students to individualize their plans of study.

Two features of the program are worthy of note. First, the electives in the third year allow the student to plan a program suited to his interest subject to the limitation that his intended field of specialization may identify a maximum of two prerequisites. Most students oriented to chemical engineering elect a year of physical chemistry and courses in heat and mass transfer and thermodynamics emphasizing chemical and phase equilibrium. On the other hand, individual students can have unusual educational interests which may suggest rather different elective patterns and still meet the needs of the chemical engineering curricula either in the fourth year program or the two year Professional School program.

The second major feature is the engineering design stem which is a structured sequence of experiences intended to develop the student's perspective toward engineering,[1] The sequence is initiated with Engineering I,[2, 3] in which the elements of the engineering process, i.e. problem formulation, conceptualization, analysis and decision making, are developed through loosely defined engineering problems which will yield to analytical solutions under proper assumptions. The Engineering Laboratory courses continue this theme through engineering problems which require experimental information. The next stage occurs at the senior level or in the first year of the professional school program in an advanced course in which the students address more substantial problems oriented to their field of specialty and is concluded by an engineering project or thesis in the second year of the master's program. It should be observed that this sequence is aimed at developing the students' ability to resolve problems and to apply knowledge out of the context in which it has been learned. While a broad interdisciplinary flavor is maintained at the first two levels, a strong orientation in the specialty discipline can be obtained in the latter portion.

TABLE 1 — PRE-ENGINEERING CURRICULUM

Freshman Year	
Mathematics I	Mathematics II
Chemistry I	Chemistry II
Physics I	Physics II
Engineering Science I	Engineering Science II
Humanities Elective I	Humanities Elective II
Sophomore Year	
Mathematics III	Mathematics IV
Physics III	Physics IV
Engineering I	Thermodynamics I
Mechanics I	Mechanics II
Social Sciences Elective I	Social Sciences Elective II
Junior Year	
Fluid Mechanics	Materials
Circuit Theory	Engineering Laboratory II
Engineering Laboratory I	Mathematics Elective
*SES Elective 1	SES Elective 3
SES Elective 2	SES Elective 4
Humanities or Social Sci. Elective	Humanities or Social Sci. Elective

*Science or Engineering Science Elective

CHEMICAL ENGINEERING CURRICULA

The structure of the programs of specialization to be superimposed on the pre-engineering program was dictated by two major factors. First, of the students electing an engineering education, an increasing number have career objectives other than a direct commitment to engineering *per se*. For these students, an engineering education with its focus on technical and quantitative subjects can be a liberal education eminently suited for the diverse needs of our society so strongly influenced by and dependent on technology. Second, for those students who would practice engineering in a modern sense, an unusual degree of competence and flexibility to deal with problem areas not yet perceived using skills, tools and knowledge not yet discovered must be developed.

In order to meet these goals, the new educational pattern provides two curricula in each field or discipline, i.e. a one-year program to the Bachelor of Science degree and an integrated two year program to the Master of Engineering degree. In addition, since accreditation requirements as applied to the baccalaureate program would have severely limited flexibility, accreditation was obtained for the Master of Engineering as the first professional degree.

TABLE 2 — MASTER OF ENGINEERING

First Year	
Separation Process	Process Design
Organic Chemistry	Chemistry Elective
Chem. Engrg. Calculations	Chemical Engrg. Kinetics
Chemical Engineering Lab	Chem. Engineering Lab
Elective 1	Elective 3
Elective 2	Elective 4
Second Year	
Advanced Fluid Mechanics	Heat or Mass Transfer
Chemical Process Dynamics	Masters Project or Thesis
Master Project or Thesis	Elective 7
Elective 5	Elective 8
Elective 6	Elective 9

In addition to the requirements shown above, the students' plan of study must include a one-year sequence in Humanities or Social Science and courses in Thermodynamics and Engineering Economics.

For the Master's program, Table 2, course sequence and content is designed on the basis of an integrated two year program and some of the courses taken in the first year, including electives, are graduate courses. It may be noted that students apply for admission to the program in their junior year and are judged by the same admission criteria applied to graduate study. By allowing these students to take graduate courses during what would have been their senior year, in-depth study which can include advanced courses previously accessible only to doctoral students can be obtained. Although, the elective freedom is reduced by the general requirements of a one-year sequence in humanities or social science, courses in thermodynamics and engineering economics, and one year of physical chemistry if not taken in pre-engineering, this normally leaves the student with five electives which he can sequence in the first or second year to follow a diverse number of minors or specialty sequences such as transport phenomena, systems engineering, polymer science and engineering, management, etc.

The required courses in the program include the obvious topics for chemical engineers, namely, Separation Processes, Process Design, Kinetics and Engineering Economics. The remainder of the core, Chemical Engineering Calculations, Thermodynamics, Advanced Fluid Mechanics, Process Dynamics, and Heat or Mass Transfer, is a structured sequence of graduate level courses in which the topics are presented in a framework of modern mathematical analysis. The stage for this treatment is set by the Chemical Engineering Calculations course in which an intensive study of operational calculus is undertaken permitting this sequence to be focused on truly general and fundamental concepts. The overall core requirements are intended to develop the knowledge, understanding and skills required not only to initiate a career as a contributing member of an engineering group but also because of the depth of study to promote the students' potential for a creative engineering practice and to minimize the risk of obsolescence.

The Bachelor of Science curriculum for chemical engineering majors, Table 3, assigns approximately one-half of an academic year to the major field. In view of the elective opportunity in the junior and senior years, students wishing to emphasize subjects relating closely to chemical engoineering can follow plans very similar to strong traditional four-year programs. However, in the absence of accreditation requirements, students may use this elective opportunity to obtain educational experiences uniquely suited to advanced study outside of engineering or to a broad spectrum of careers for those who do not choose to practice chemical engineering *per se.*

TABLE 3 — BACHELOR OF SCIENCE

Separation Processes	Process Design
Organic Chemistry	Chemical Engrg. Kinetics
Chemical Engineering Laboratory	Engineering Economics
Humanity or Social Sci. Elective	Chemical Engineering Laboratory
Elective 1	Humanity or Social Sci. Elective
Elective 2	Elective 3

Because there is widespread concern that common core approaches tend to drive chemistry from engineering curricula, it is worth noting the following about the Rensselaer program. Every chemical engineering student takes a minimum of two years (4 courses) in chemistry beyond the general chemistry required of all engineering students. If he so chooses, and most chemical engineering students do, the student may elect additional chemistry. Indeed the flexibility of the curriculum permits a student to arrange a sequence in chemistry that would take him through to the most advanced graduate courses. Chemistry has not disappeared and is not disappearing from the programs of study of chemical engineering students at Rensselaer.

DISCUSSION

Although these brief descriptions of the program and organization can serve only to indicate some of the highlights, the experience to date suggests some conclusions.

The pre-engineering concept has focused the attention of the students, and the faculty involved with them, on their identity as engineers first and as specialists second. With subject matter that is in fact basic to engineering practice, a more enlightened and perceptive treatment is promoted. Engineering faculty members involved with this program have shown an increased awareness and concern for the rationale of course structuring, content and philosophy. The economics of providing new specialties is eased and a sound basic education is assured. With the pre-engineering curriculum recognized as an administrative entity, more viable and aggressive concern for the character and the quality of this phase of the program has been obtained.

From a chemical engineering point of view, the dual opportunity at the specialty level has increased significantly the ability of the student to follow a program particularly suited to his interests. Rather more diverse educational goals suited to the broad spectrum of career opportunities can be met. In addition, the integrated two year Master of Engineering program permits students to achieve considerably more advanced study in depth than under the alternative four plus one arrangement.

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LETTERS (Continued from page 55)

agreed with Professor Henley about the futility of advertising. . . .

At a high school Career Day recently, I sat next to a faculty man from the Physical Education department. "Hey kid," he said, "we have the highest paid college graduate this year — O. J. Simpson."

Professor Henley states that "we are not attracting the sons and daughters of college graduates." With only 3% unemployment in the United States, job opportunity is not much of an incentive to today's college student. But it has always been hard to attract rich kids to the more difficult curricula. The adage "shirtsleeves to shirtsleeves in three generations" has been around for a long time.

If Professor Henley encounters only "bread and butter types" among his students, I suggest that he is not getting across the glamour and importance of chemical engineering. And we can do without the "hippie types." The philosophy of the hippies, it seems to me, is to live only for today. The hippie takes whatever pleasures he desires when he wants it caring not a whit for the consequences of his actions on himself or on others. If he has any brainpower, he will addle it with "pot." Chemical engineering philosophy on the other hand, might well be defined as "leaving the world a little better than you found it."

Chemical engineers don't like to advertise. . . . The increase in enrollment is the result of advertising, pure and simple. Not meaningless platitudes, but getting the story to the high school students. Do you know what a high school Career Day is really like? Thirty to fifty different fields are represented and the most successful graduates are pictured as typical. The poor high school student can visit only three or four fields in the time available. At the last one I attended, Chemical Engineering got six visitors, Psychiatry got eighty-seven. When even the university president (ours) suggests that all BS degrees ought to contain the same number of credits and require the same number of courses, can you blame the high school kid for thinking that one BS degree is about as good as another and thus picking that which is the easiest?

Specifically, what do we do at Montana State? We give the widest possible publicity by means of poster announcements to all the State high schools to the industrial interest in chemical engineering as expressed by their forty-five $250 cash scholarships to freshmen. We follow this with newspaper publicity for each winner.

We show the students that chemical engineering does make a major contribution to man's problems. The population explosion and its accompanying pollution problems, if solved, will be done by "applied chemistry on a large scale." That's a pretty good definition of chemical engineering. We get to the high school girls the message that chemical engineering offers one of the few ways that a girl can get into the top 1% of women wage earners in only four years out of high school. We have sixteen girls enrolled in Chemical Engineering at Montana State.

Graduate Programs. I doubt that graduate programs have much to do with recruiting from the high schools. But recruiting has had a great deal to do with graduate programs. The decline in undergraduate enrollment in the last decade was accompanied by a large increase in the money available for university research. The faculty member found himself in the situation: no graduate student, no project. Some departments have seen graduate potential in a BS chemical engineer with a 2.3 cumulative grade point average. Any 1969 senior in Chemical Engineering with 3.5 GPA can get letters like this. "Pleased to offer you half-time research assistantship at $335 per month. You must pay resident tuition fees of $38 per month. We will award you an out-of-state travel allowance of $50. You would be expected to work from 15 to 20 hours per week on a research project of your choice, which would form the basis of your MS or PhD thesis research."

When the several chemical engineering departments couldn't get enough U. S. citizens for our graduate programs, we turned to foreign sources. The Goals Committee seized on the upsurge in the percentage of MS and PhD being produced and said, "See, it's an undeniable trend. Face up to it and accept it." The trend extrapolates to 100% of the chemical engineers having advanced degrees in 20 years. It also extrapolates to the last chemical engineer in about 1990, and he will be a Ph.D. While industry complains that some departments have lost touch with reality (or practicality), it is not true that all have. Programs possessing considerable social significance in my department include — making Kraft paper plants more socially acceptable, recovering profitably the sulfur pollutants from metal smelters, converting sea water to fresh, removing the air pollutants from fossil fuels, contributing to the development of a cheaper artificial kidney. Why should we emulate the programs of the schools Professor Henley named? Except for Lehigh, Chemical Engineering does not bulk large on their campuses. Their production of chemical engineers compared to total enrollment was: Michigan State, 30/45,949; Michigan, 36/37,283; Northwestern, 20/15,766; Minnesota, 40/59,983; Ohio State, 18/38,300; Pennsylania, 21/18,173; Lehigh, 49/4,843. Perhaps the following have a better answer: Colorado Mines, 38/1,504; South Dakota Mines, 25/1,380; Montana State, 30/7,864.

The bulk of the chemical engineering educators are excellent teachers, researchers, scientists and/or mathematicians but very poor salesmen for their major product —the graduate. A salesman knows his product. Do you know by whom each of last year's graduates was hired, at what salary, for what job? Do you know what your alums are doing, all of them, not just a few whose accomplishments hit the newspaper? Do you know what companies can use women chemical engineers and in what kind of work? Do you know that there are three to ten times as many companies as graduates on your campus vying for the services of your graduates? Do you know that your top BS men have offers of up to $900/month; that your minimum 2.0 graduate has at least $825/month; that your new PhD grad commands up to $1375/month? Do you know that you are producing the highest priced BS grad on your campus (O. J. Simson excepted) or that your PhD's top any other field in earnings for seven years out of high school? Oh yes, but you and your students are not interested in grubby old money, only in serving humanity. Do you know that the population explosion is the most serious problem ever to face the human race and that it is going to be solved by famine, epidemic or catastrophic war — or the large scale application of chemistry. Have you had a drink of Moxie lately?

Lloyd Berg
Montana State University

Measurement of D

Sir: Having recently become interested in the measurement of diffusion coefficients utilizing axial dispersion techniques I read Professor Hudgins' article [CEE, 3, No. 1, 42-44 (1969)] with great interest. The advantage of using dispersional measurements is that the time required to determine a diffusion coefficient is much less than that of previous methods.

Recent developments, however, have shown that the entire profile need not be measured to determine a diffusion coefficient. Gill [AIChE Journal, 13, 801 (1967)] has given the following solution to the differential equation under slug input conditions

$$\theta_m = \tfrac{1}{2}\mathrm{erf}\left[\frac{\tfrac{1}{2}X_s - (X-\tfrac{1}{2}\tau)}{\sqrt{4K\tau}}\right] + \tfrac{1}{2}\mathrm{erf}\left[\frac{\tfrac{1}{2}X_s + (X-\tfrac{1}{2}\tau)}{\sqrt{4K\tau}}\right]$$

where $X = Dx/a^2U_0$, X_s is dimensionless slug length, $N_{Pe} = aU_0/D$, $\tau = Dt/2$, and K is the Taylor-Aris dispersion coefficient. Noting that the peak concentration will pass an anlysis point at the mean residence time $t = x/U_m$ this peak concentration is given by

$$\theta_{pm} = \mathrm{erf}\left[\frac{X_s}{4}\frac{1}{\sqrt{2KX}}\right]$$

The diffusion coefficient is then given by the following equation which is easily solvable

$$D^2 - \frac{x_s^2\, DU_m}{16x}\left(\frac{1}{\mathrm{erf}^{-1}(\theta_{pm})}\right)^2 + \frac{a^2U_m^2}{48} = 0$$

From this it can be seen that the diffusion coefficient can be solved for directly with knowledge only of the peak concentration, mean velocity, distance from the injection point and slug length.

The disparities in the step input results are indeed produced by natural convection effects induced by large density differences. This effect has been discussed by N. S. Reejhsinghani (AIChE Journal, 12, 916 (1966)) and is of great interest.

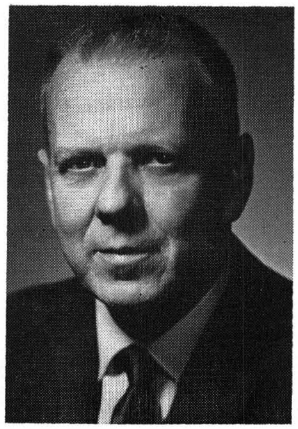
The article however does point out the great possibilities in the rapid determination of diffusion coefficients.

Charles J. Vadovic
University of Oklahoma

ChE views and opinions

THE PERSONALITY OF A PROFESSION*

CHARLES F. JONES, President
Humble Oil & Refining Company
Houston, Texas



President Jones holds BS, MS, and PhD degrees from the University of Texas. He joined Humble in 1937 and advanced through the technical service division to general manager of Humble's Central region. He was named President of Esso Research and Engineering Company in 1963. Promotion to President of Humble was announced in 1964. He received the University of Texas Distinguished Engineering Graduate Award in 1964, an honorary LLD from Austin College in 1965, and in 1966 President Johnson appointed him to serve on the National Science Board.

I am genuinely proud to be an engineer, and to be part of the engineering profession.

I want to make these attitudes clear at the very beginning. For it is precisely because I regard our profession so highly that I dwell on some of its shortcomings rather than on its accomplishments. There are flaws in the collective personality of our profession, and I would like to suggest some measures that might help to correct these deficiencies.

In the thirty years since I first entered engineering, I have seen our profession confronted with wholly unexpected responsibilities because of our command of a technology which developed with unexpected speed. In works that Shakespeare first made famous, engineers have had "greatness thrust upon them."

We have met the purely technological part of this challenge superbly. But I contend that the engineer of today is not providing a standard of guidance and leadership related to the human effects and social consequences of his technology, that is commensurate with the impact of his work and the importance of his profession.

By virtue of what he knows and his professional application of that knowledge, the engineer is a social force. By reason of the enduring effect of his work, the engineer bears a social responsibility to see that he does not, while solving a technical problem, create a human one.

Because of the increasing technical complexity of our problems the engineer is rapidly becoming someone who works on pieces of a puzzle, and if this trend is carried to its extreme he will ultimately find himself operating in a technological straightjacket—totally confined to executing the means, without being able to discern the ends. Coupled with this trend is the most unfortunate flaw in the engineer's professional personality—his repeatedly demonstrated reluctance to involve himself in the search for solutions to complicated, troublesome, politically oriented questions of public policy.

In my view the engineer is exhibiting a thoroughly disquieting tendency toward withdrawal from the total spectrum of public affairs. Though master of technology, the engineer seems to be willingly isolating himself from a view of the social consequences of his acts.

One of the engineers who took part in our survey commented on this disturbing trend quite bluntly:

> "Despite their training in solving problems," he said, "despite their ability to combine hard facts with intuitive judgments, despite their intelligence, engineers are generally ineffective in public affairs because they are not interested in people." Another remarked that many engineers "are living within a technical shell. They are afraid to live with people."

These are harsh works. Is it really true that engineers like numbers more than they like people? I think not; and I believe that the engineer's reluctance to come to grips with public problems as a citizen and leader—instead of serving solely as a technical consultant—is rooted in his own misconception of his proper function

*Presented to the Texas Society of Professional Engineers, San Antonio, Texas, June 21, 1968.

in society. Somehow the engineer has come to believe that professionalism and participation are mutually exclusive, and this attitude has been grafted onto the personality of our profession.

In his preoccupation with technology, and with the outward trappings of professionalism, I am afraid that the engineer is neglecting the one activity that, in the long run, will do the most to assure him unquestioned professional respect: *service* to his community, his city, his state and nation. One of our survey respondents put it this way:

> "Neither the public welfare nor the engineering profession can hope to benefit from a meager engineering participation in the public forums where vital government policy is developed, and where decisions are made that will affect our way of life for years to come."

Another problem is inherent in this hardening attitude of withdrawal into the narrow comforts of technical expertise. This is the distinct danger that the younger engineers now in the profession, and the next generation of engineers now in the colleges, will be led by example to believe in this idea of isolation from the ferment of society.

So I believe that we as professionals have a dual responsibility. First, we should guide the thrust of our profession's energies toward increased participation in public questions, so that engineers can be of increased service to society. Second, we should marshal our experience and our efforts in behalf of the coming generations of engineers so that they are well prepared for the demands of the profession, as well as being qualified in the tools of our trade.

To expose problem areas in our profession is one thing; to come up with solutions is quite another. Quite obviously I cannot recite the ultimate answers to these problems. But I do want to suggest some specifics which might point the way toward improvement.

• It is in the sphere of public service that I feel the Texas Society of Professional Engineers performs one of its most valuable functions. For example, there is TSPE's record of accomplishment in working with state boards and commissions. The activities of TSPE in helping formulate progressive state policies toward the use and conservation of water are well known. And I am most encouraged to hear that the Society is now putting together a group called "PERT"—an acronym for Professional Engineers Recommendations for Texas. As I understand it, "PERT" will be composed of engineers of the highest competence who will provide counsel and advice on broad public issues in the state.

Much has been made of the fact that few engineers run for public office, and more should be encouraged to do so. But an engineer does not have to be in public office to serve the public interest. Engineers should *take positions* on public issues, both as individuals and on an organized basis—either through their professional society, or in some other manner if that is not possible. And these positions should then be *communicated* to public officials and to the public at large. This will inevitably involve the utilization of publicity through mass communications media—an activity which many engineers seem to regard with horror. But publicity is a legitimate way to insure that the views of engineers are known to the public.

• It is of particular importance that the engineering profession take a more aggressive stance on issues which fall into our general area of expertise, such as mass transit, urban renewal, and city planning. Our most formidable problems today are in the cities; yet, perversely, it is here that the engineer's voice is becoming ever more faint.

With hardly a struggle the engineer has abandoned the field of city planning and urban renewal to a new group of planning consultants with different training and orientation. In so doing, he has become less and less a voice in the decision-making process. His influence is being consistently overshadowed in the deliberations where the future of the cities is being decided.

I am convinced that if these difficult urban problems are to be solved enduringly, and with the most effective utilization of our financial resources, the engineer must reassert his capabilities in a leading rather than a supporting role. We must re-establish in our profession the obligation of leadership on these—and other—public problems, and rediscover the concept of selfless service.

• This concept of service must embrace not only our own concerns; it must also look to the next generation of engineers as well. The lines of contact between the practicing professionals and the campuses should be even stronger than they are today.

• Time and again, the replies in our survey emphasized the need for more interchange between the practical and the academic. We had asked these experienced engineers to give us the benefit of their hindsight. Their words differed widely, but their ideas focused on two major areas which they deemed worthy of more emphasis in the engineering curriculum:

—Fundamentals of business management and business practices.

—Development of communications skills, both verbal and written, by the student engineer.

Measures should be taken to correct these deficiencies; steps that place emphasis on action. Why not, for example, have an interchange between an engineering professor and a practicing professional—have them actually switch jobs for a specified period ?

• There is growing evidence that many young engineers are already taking additional time to prepare themselves, by extending their education to the graduate level. A report by the ASEE states that only ten years from this date, two out of three bachelor's graduates will go on to a master's degree, and one in seven will go on to a doctorate.

The increasing number who go to the doctoral level may run afoul of what I feel is an anomaly in our system of engineering education. I refer to the preoccupation with research found in many advanced curricula. In no way do I demean the idea of research; but I do feel that the present emphasis on it is to some extent incompatible with the historical function of the engineer.

Throughout time, the engineer's role has remained essentially unchanged: he takes existing knowledge and does something useful with it for the benefit of society. In this process he often extends knowledge, or exposes blank areas where new knowledge is needed; but primarily he applies that which is known.

With this in mind, **I am convinced that there is need to restructure graduate programs so as to allow those who are not primarily research-oriented to obtain advanced training more suited to their field of interest.** Many engineers seeking advanced degrees are interested in preparation for such functions as design, development, and management; I think they deserve the opportunity to obtain such training. I do not suggest that we abandon the engineering laboratory; only that we redefine it. Where could there be more challenging laboratories than our great urban complexes, with their needs for imaginative and original engineering solutions?

• I suspect that we may also have to be prepared to redefine the word "engineer." It is becoming obvious that the traditional dividing lines of the educational disciplines are proving inadequate in producing people qualified to practice certain specialties. Recent developments combining engineering and medical skills are illustrative of this point. We may shortly be producing engineers of a hybrid nature—for example, a "social engineer" who applies engineering knowledge, systems analysis, and new tools such as the computer, telecommunications, and teaching machines to the solving of social problems.

I can envision the day when a student will go through three to four years of basic engineering training, and then will supplement this with two to three years of additional training in non-engineering fields to qualify him for a particular specialty. In such a way, for example, we might produce an "urbanologist" who combines knowledge in the basic sciences, the social sciences, and the humanities and uses this knowledge to cope with urban problems. Such an individual would combine some of the qualities of the engineer, the city planner, the educator, the sociologist—and, perhaps, the politician.

Obviously the field of engineering education, like the field of public service, offers endless challenges to the engineer. To anyone who takes these challenges seriously, it must seem at times as if the professional engineer is expected to be all things to all men.

We can't be, of course; but we can set ourselves the highest professional goals and work toward them. Where technology is concerned, we have remarkable new tools to work with. Our difficulties are likely to be nontechnical—as they are now—and within the realm of the intangible. We must reshape our professional personality so that we are more sensitive in the areas of human understanding and social awareness.

Early in these remarks I suggested that engineers have had "greatness thrust upon them." Those latter words, originally, were Shakespeare's, and the full quotation from his play *Twelfth Night* reads as follows: "Some are born great, some achieve greatness, and some have greatness thrust upon them."

I sincerely hope that subsequent events will prove that my choice of words was mistaken; that it can be said of the engineer, not that he is "born great," not that greatness is "thrust upon him," but that he is among those rare few who "achieve greatness."

DARTMOUTH'S Doctor of Engineering

GRAHAM B. WALLIS
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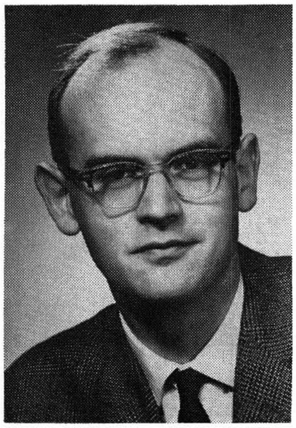


Graham B. Wallis is associate professor at Thayer School of Engineering. He was educated at Cambridge University, BS, MA, and PhD ('61) and at Massachusetts Institute of Technology, SM ('59). His research interests include heat transfer and two-phase flow. His book on "One-Dimensional Two-Phase Flow" will be published by McGraw-Hill Co.

The Doctor of Engineering program at Dartmouth qualifies as a "New Direction for Engineering" mostly because it stresses the practical side of engineering at a level which has traditionally been dominated by specialized, research-oriented programs. Its goal is the development of the student's ability to apply his technical knowledge creatively to satisfy some worthwhile need of society.

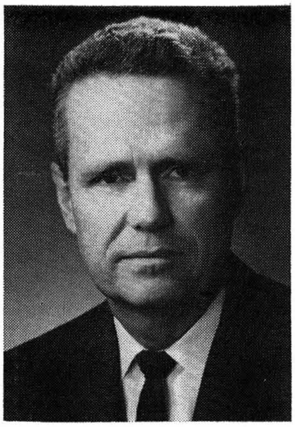
The basic philosophy and objectives of the program are not new at all. They have remained appreciably unchanged since the founding of the Thayer School of Engineering at Dartmouth College in 1871. Throughout the school's history the emphasis has been on the training of generalists in the profession of engineering. Students have been prepared at the Bachelor's level with a broad base of science and liberal learning from which they can continue to develop and cope with whatever engineering problems they may face in future years. We have believed that in practice a man who is well trained in the fundamentals seldom fails to fit himself (given a little time) to a special responsibility. The only "new" aspect of the present program is the extension of these principles to the doctoral level. In addition to requiring demonstrated competence in the conventional areas of engineering analysis the professional program emphasizes innovative design, economics, managerial and communication skills, and the effective use of resources. Students are taught how to develop knowledge on a need-to-know basis and, equally important, how to apply this knowledge.

The program is completely interdisciplinary and the degrees awarded are not designated as to any particular branch of engineering. Every attempt is made to involve the student in real-world, unsolved problems and to force him to make decisions in a professional manner. We are concerned not only with the knowledge that the student acquires but also with the development of his abilities and attitudes. These abilities include analysis of a vaguely-defined, practical problem, generation and evaluation of alternative solutions, completion of a convincing design, performing experimentation and testing (with a view to answering direct and relevant technical questions), and the managing of an engineering project. Individual programs are formulated according to the student's own aims and interests. There are no required courses; however, more than one discipine, or branch of engineering science, is usually involved in each student's program.

The *doctoral thesis* is the major piece of evidence which the student submits to show that he has developed the required abilities. Prior to this he is required to perform a *30-day design project*. In addition he may elect (or be firmly encouraged) to take the special course *"Internship in Engineering."* These latter features of the program are sufficiently unusual to warrant further explanation.

30-DAY DESIGN PROJECT

The student is required to demonstrate his ability to take an assignment in an unfamiliar field and produce a worthwhile contribution to the state of the art within a time limit of thirty days. The assistance of industry or government



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is usually needed because these design problems are selected from unsolved, real-life situations. For example, a student was recently asked to develop a method for making profitable use of city refuse. His proposal for producing ethyl alcohol from the 60% cellulose content of refuse is now under study for development by the U. S. Public Health Service and by at least one company.

The major purpose of the design project is to help the faculty and the student determine early in his graduate program his capability and motivation for the professional curriculum leading to the Doctor of Engineering degree. In other words, it is a qualifying exam. The student is judged on his ability to organize a project within a limited time, to apply scientific and technical fundamentals to the problem, to consider economic constraints and to present the results logically and coherently, both orally and in a written report.

INTERNSHIP IN ENGINEERING COURSE

The Internship in Engineering course is part of an attempt to provide the same service to engineering that the teaching hospital provides for medicine. The development of professional talents and their application to actual, present-day, technical problems are emphasized. The student obtains a realistic experience involving economic, social, political and legal factors as well as technical requirements. The problems are open-

The major purpose of the design project is to act as a qualifying exam. . . . The objective of the internship is to develop those abilities which are required by a professional engineer. . . . Industry provides a realistic background to the project.

ended and have no easy answers. They are volunteered by industrial and public organizations which also provide expertise and on-the-spot assistance to the students. Access to the client's proprietary information may be required and negotiations between him and the student are conducted on project planning, contracts, patents and dissemination of results.

The objective of the course is to develop just those abilities which are required by a professional engineer and which the student must demonstrate in order to get his DE degree.

The role of industry is to provide a realistic background to the project. By the involvement of industrial representatives in the course the student is made aware of the criteria by which his work will eventually be judged in the real world. Industrial attitudes often come as a surprise to the student who is conditioned to the usual, academic measures of success applied in most engineering courses.

INDUSTRIAL COOPERATION

Both the internship course and the 30-day design project depend for their realism and practical success on the participation and cooperation of industry and government. The Thayer School is actively establishing relationships with certain industries to foster an attitude and commitment of shared responsibility for the development of the professional program. Industries which become Partners or Associates in this program undertake to provide expert consultation, realistic design problems, critiques and discussions of student work and some financial assistance. Engineers are sent from industry to lecture, advise, learn and generally participate in the program. Special short courses and conferences are arranged periodically to provide an exchange of information and wisdom between these industries and the academic community. Typical subjects for these meetings include the management of research and development, decision-making, the design process, computer applications, technological contributions in the city environment, and the fostering of creativity in an industrial context.

AN ENVIRONMENTAL FOCUS FOR ENGINEERING EDUCATION*

SEYMOUR CALVERT
Dean, School of Engineering
University of California, Riverside

Dr. Seymour Calvert is Dean of Engineering at University of California (Riverside) and Director of the University of California Statewide Air Pollution Research Center. He has a BSChE degree from Michigan Technology University and MS and PhD degrees from the University of Michigan.

Dr. Calvert specializes in research on air and gas cleaning equipment (particulate and gas removal), research on air pollution system definition and analysis, design of industrial air pollution control equipment, and design of controlled environment systems.

For a number of reasons, historical and perceptual, educators are in a period of awakened concern for the world around us and for our relationships with it. Like the proverbial oversize suit that we would "grow into," the world is getting tight in spots and we can forsee its getting tighter. Unlike a suit of clothes, we cannot buy another world; we will have to live within what is available. The pressure upon educational institutions is indirectly through the needs implied by our environmental pinch and directly through the demands of students, the faculty, and even the educational process for relevance.

Many have written and spoken on the importance of environmental problems and desirability of universities giving attention to them. An important question is whether a university or one of its subdivisions will take up environmental problems in the same manner as it has approached others or whether a new pattern of approach should be used. As will be developed in the following discussion, my view is that a different approach is called for, consistent with a concern for both our environmental problem and the effectiveness of engineering education.

A starting point for this discussion might be to ask the question: "What would be the purpose and nature of an engineering school oriented toward problems of the environment?" In answering the question we should consider what environmental orientation means, what engineering education requires, and how the two can be joined.

Man and Environment

The meaning of environment in its broadest construction is all factors external to an organism which can have an influence upon it. Given that our concern is with man, what are the factors which comprise his environment? Commonly we think of the physical necessities — air and water — but we should also include food. On the negative side are hostile agents such as weather, radiation, disease producing organisms, pollutants, and predatory animals, including man. Acting through cognitive processes are the organizational or social influences and the singular or aesthetic factors. One can see that to understand man's environment is equivalent to understanding man; what he is and what he responds to.

There is a secondary group of factors which are the mechanisms of our responses to environmental demands and which in themselves become part of our environment. We need shelter to protect us from the weather and to provide suitable facilities for preparing and consuming food, for building devices, for resting, for dealing with disease, and many other functions. These shelters and work places — homes, offices, factories, stores — become forces which to some extent shape our patterns of activity and thought. Indeed, they usually are more immediate and continuous elements of the perceivable environment than the forces of nature.

Transportation is vital to every phase of life, enabling the movement of materials and people

*Presented at ASEE Meeting in Los Angeles, June 18, 1968.

and becoming a part of life's quality and scheme. Equally important and obvious are the roles of power and communication. At the base of all these factors are the natural resources whose magnitude is the ultimate limit of our capacity for sustaining life.

These factors are provided or controlled either by natural processes or by man's deliberate effort. Man's response to them in the past has been largely adaptive. He would seek a hospitable area for optimizing all needs or he would avoid the inhospitable. A measure of our progress has been our growing ability to change or destroy the inhospitable and to create hospitable factors — the ability to control our environment.

Orientation

A university which concerned itself with the environment would be characterized more by an orientation than by a catalog of its detailed activities. There is no such (sensible) thing as environmental mathematics, or literature, or history, or chemistry, or transport phenomena. What can be special are the use to which basic knowledge and methods can be put, and the motivation of learning and inquiry.

The general outlook of an environmentally oriented school would be directed toward our ability to live within the capabilities and resources of the earth. More specifically, it would be addressed to answering the broad questions:

1. Who and how many are we? What kind of people will populate the world, how will they be distributed, and in what numbers at various times in the future?

2. What are and will be our objectives? How will we accomplish them?

3. What do and will we need?

Consistent with the ramifying character of environmental considerations, the people working in this area must develop a personal sense of the contributions all disciplines can make. Management implies a multi-professional approach because of the necessity for resource allocation. In order to decide how to use the limited resources one must understand all of the competing claims upon them and all of the possible routes to their satisfaction. The old dilemma of "guns or butter" summons up the picture of this type of decision situation.

To expect that individuals can be educated to handle all aspects of an environmental problem is naive. The best engineering design will

What would be the purpose and nature of an engineering school oriented toward problems of the environment ?

be done by an engineer, economics by an economist, toxicology by a toxicologist, and so forth. Each of the professionals contributing to the solution of the problem must be in close touch with his professional colleagues and literature so that he may be expected to bring the best state of its practice to bear upon the problem. Yet he must be knowledgeable in all its aspects, probably to the point of being able to handle simple tasks in other disciplines, in order that he not overlook the need for assistance and possible interactions.

Another important element of the environmental orientation is the development of a sense of innovation; both of the need for change and the ability to accomplish it. An instant behind the question: "How does it work?" should be "How else can it be done?" It is difficult to state this as a unique characteristic of an environmental program — we would doubtless like to see it in any engineering education. Let us say that there is a greater need in the case where the present state of affairs is the result of a complex and non-intellectual evolution and where each man is very likely to be working alone rather than as a part of a technological hierarchy.

Rather than having his problems chosen and defined for him each person must possess an awareness of need. We might define this awareness as the ability to observe and speculate and to sense the opportunity or necessity for adaption. In that our reasoned approach to environmental management is at a primitive stage, we have no procedures and organization which relegate a bounded and fractional (small) role to each participant. It is still a wide-open, wild game and it calls for a perceptive entrepreneurial outlook and competence.

Method

A method for providing the special characteristics of an environmentally oriented school is as follows in outline:

- **Address the school to the question of our ability to live within the capabilities and resources of the earth.** This should be reflected in all functions, education-research-service, by their becoming specially competent in environmental planning and management. Simultaneously, strengths in basic disciplines are to be developed so as to permit a range of opportunity for their application. In terms of engineering education this means that design and applied problems used in basic core courses as well as systems designs will be related to our environmental needs.

- **Provide the structure and functions for an interdisciplinary approach.** Curricula should stem from a common core which will provide a real understanding of all disciplines and, further, will enable a significant mobility of students into any discipline. This is both economical of course offerings and essential to the student's preparation for continuous education in the future in order to accommodate new knowledge. Applied interdisciplinary projects can reinforce and multiply the conceptual links which each student has with areas outside his major as well as strengthening his concept of and capability to apply it. By drawing these projects from the surrounding real community we can provide the relevance and motivation the students (and faculty) need.

- **Use the campus itself for research and demonstration.** Educate and inspire by setting an imaginative example. This should involve not only the organized research activities but the actual campus-community context in the course work and research of the Engineering School.

Requirements for Engineering Education

Let us now turn our attention to the question of the ingredients of a good engineering education. The main emphasis will be on the undergraduate program as is consistent with the conviction that engineering education does have unique properties which must be incorporated into the entire college education of an engineer. The essence of this uniqueness is a motivational factor more than a substantive one. Engineers are distinguished by a desire to create and to control some component of the real world. This requires patterns of attitude and thought which are best developed at an early age.

To do a good job of engineering education one has to:

1. Present the basic physical, chemical, mathematical, biological sciences so that the student understands most of the important phenomena and has enough of a base so that he can continue to learn by self education if necessary.
2. Teach the basic engineering approaches which embody useful methods for problem solving and teach a method of intellectual approach to problems.
3. Confront theoretical predictions with reality to illustrate the usefulness and limits of both the theoretical and empirical approaches and to give experience with a broad range of reality.
4. Provide course sequences in the social sciences and humanities which will give the student knowledge of the history and nature of man, a base for future self-education, and understanding of contemporary social, political, and economic systems sufficient to illuminate the relationships between man, technology, and the world and to enable his conception of useful programs.
5. Teach the student to solve problems, to design, to think, to make use of acquired knowledge, to generalize, to fill blanks with reasonable assumptions.
6. Teach the scientific method and logic.
7. Provide for continuing education.

The methodology used to achieve the above goals in engineering education will have to satisfy several constraints. Some of these constraints are that the program has to incorporate:

1. Real problems which may involve a variety of disciplines and may not have a single "best" solution— to teach problem solving, design, the "engineering approach," and to provide links between the separate courses and the total practice of engineering.
2. Satisfaction of the student's desire to be involved in basic problems of society.
3. A means for more effective teaching of social sciences and humanities.
4. Better undergraduate teaching.
5. More effective research and professional activities for staff and students.
6. Better continuing education.
7. Independence from the danger of obsolescence accompanying preoccupation with current industrial technology.

Riverside Program

The Engineering school at the University of California, Riverside, is being established with a primary orientation toward problems of the environment. While there is no previous history of engineering at the UCR campus, there are several related activities which can be capitalized upon. There are capabilities on campus in air pollution, physical and biological sciences, agriculture, social sciences, dry land research, water resources, geology, and fire laboratory research. The data base in these related research areas provide a common body of knowledge for instruction in applied environmental engineering problems.

Students will be prepared for careers in industry, business, government, and education. They should have the option of taking employ-

The times now call . . . for a display of initiative by engineers. Increasingly the technological source of our productivity and wealth . . . of the quality of life have placed a bewildering burden on society's decision makers.

ment at the Bachelor of Science level or continuing with graduate school. They must, therefore, be employable (identifiable) in the present context where designated degrees are important and also be grounded in a primary professional discipline which is of enduring validity (and utility).

There will be three teaching divisions which will provide the basis for future growth and for present professional identification. While there will be a great deal of transference possible among divisions, they will each be distinguished by a strong orientation. They are:

Physical Division — dealing with mechanisms, structures, power, physical processes, and physical properties of materials.

Chemical and Biological Division — involving chemical and biological systems, properties, and processes.

Information and Computation Division — covering information properties, processing, and systems — including applied mathematics.

In addition to the three curricular core divisions there will be an **Advanced Projects Division** which will coordinate research, professional activities, continuing education, and various liaison relationships. This division will provide the mechanism for an optimization of the teaching-research combination by a redistribution in time of the available effort for each. Faculty assignments will be arranged so that the teaching and research periods will each be more intensive and effective. It is envisioned that faculty will devote nearly full time every third year to research or professional activities administered through the Advanced Project Division.

The teaching and research organizational structures will be separate and not identical. Research groupings will be consistent with specific objectives and will form, disperse, and reform as needs dictate. Teaching divisions will be permanent units, subject to future modification in the light of experience, and the faculty during their period of assignment to the division will be responsible and accountable for teaching. Division heads will be concerned with either teaching or research and professional activities and with coordination among the divisions. Thus the organization of the school is consistent with the concept of function wherein the engineer applies basic tools which have a relatively long life to special problems which are generally transient.

The major curricular challenge in engineering education is in the undergraduate level, graduate programs being largely tailor-made for the individual student. The UCR undergraduate curriculum is based on a very strong common core and is not organized around the traditional branches of engineering. This arrangement offers greater flexibility both for the student in choosing a curriculum to suit his interests and for the School in making modifications to meet changing demands. An outline of the curricular patterns is given below. In this system a student could elect a divisionally designated BS degree, a professionally designated degree (from those offered to meet sufficient demand), or an undesignated degree. A few courses required to augment a divisional curriculum enough to form a designated degree (such as Mechanical Engineering out of the Physical Core) would represent a small investment and could readily be added or deleted from the Engineering School offerings.

The undergraduate educational elements are listed below:

- An environmental orientation is effected largely through design and applied problems in the following areas: air, water, food, shelter, transportation, natural resources, community systems, social interactions, and long range planning and management. These enter at all levels of the undergraduate program.
- All students take a General Core which accounts for 55% of the undergraduate credits. Subject areas are: Mathematics, Physics, Chemistry, Biology, Earth Science, Social Sciences, Humanities, and Economics.
- All students take an Engineering Core which accounts for 20% of the credits and includes: Mechanics, Transport Phenomena, Thermodynamics, Dynamic Systems, Materials, Systems Design and Optimization.
- Students may elect a Divisional Core or an undesignated program which accounts for the remaining 25% of the undergraduate credits. When there is sufficient demand there may also be designated degree options within the Divisions of utilizing perhaps one-third of the Divisional Core credits. Subject matter will be:

1. Chemical and Biological Division Core — Chemistry, Biology and Chemical and Biological Systems.
2. Physical Division Core — Mathematics, Physics, and Mechanical Systems.
3. Information and Computation Division Core — Mathematics, Computation, and Systems Analysis.

THE ANSWERS TO YOUR

FUEL CELLS

John O'M. Bockris, University of Pennsylvania, and **S. Srinivasan,** State University of New York, Downstate Medical Center. Available Spring

Sets forth the theoretical basis of electrochemical energy conversion. Unlike other books, this work considers the basic electrode kinetics of the fuel cell.

HEAT TRANSFER, Second Edition

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Revision of a standard text for undergraduate courses. Contains new material on thermal contact conductance, radiation network analysis, conduction shape factors, an analytical model for liquid metal heat transfer, and many other topics.

THERMODYNAMICS

Jack P. Holman, Southern Methodist University. Available Spring

Offers a brief, broad coverage of **all** aspects of thermodynamics for undergraduate introductory courses. The emphasis is on simplicity, clarity, and teachability, and the coverage includes both macroscopic and microscopic thermodynamics with an introduction to transport gases. Conventional power cycle applications and introductory material on direct energy conversion schemes are also presented.

ENGINEERING DIFFERENTIAL SYSTEMS

Robert D. Kersten, Florida Technological University. 224 pages, $13.00.

The first book of its kind to treat both analytical methods in engineering — the classical continuous approach and the "discrete" approach usually associated with numerical methods. It proceeds from the typical cases, which can be mathematically treated by the classical approach, to the more difficult cases, which must be handled by some numerical technique.

MASS TRANSFER OPERATIONS, Second Edition

Robert E. Treybal, New York University. **McGraw-Hill Series in Chemical Engineering.** 688 pages, $15.75

Provides a vehicle for teaching the characteristics, principles, and techniques of design of equipment for mass transfer operations. Theoretical principles are applied to the practical problems of equipment design.

Air Pollution

One of the difficult environmental problems facing us is air pollution and we can gain insight into the role any environmental problem may play in education by reviewing some recent experiences with air pollution as an educational focus. The following section is drawn from the author's experience in establishing an interdisciplinary air pollution training program at Pennsylvania State University. Let us first review the nature of the air pollution problem and then the specific pedagogical device — the focal project.

In their beginning and in their significance air pollution problems are sociological (political) problems; they involve interrelationships between individuals and groups in society. While their phenomenological substance presents questions in science and engineering, their meaning to society is in terms of the various planes of man's life and thought. As individuals we react to physiological factors ranging from subtle influence to gross insult and to psychological (or aesthetic) factors ranging between comparable limits. In groups of all sizes from neighborhood association to national and international bodies we work to recognize, identify, understand, and control environmental factors. When decisions are needed the plane of economics serves as one of our principal bases for evaluation of alternative courses of action. **In general we can see that as a social-political problem air pollution has much in common with the multitude of questions that face the community.**

To consider the phenomenon itself, we may use the simple picture of the air pollution as a chain of "source-transport-effect." To understand air pollution we need knowledge of all three links of the chain but we note that transport and effect follow inevitably (offer no opportunity for control) from the fact of emission by a source. Control must therefore be upon the source and is in its specific nature an engineering problem. The kind and degree of control required depend on cause-effect relationships which are established through study of atmospheric dispersion, reactions during the dispersion period, and effect on man, animals, vegetation, and materials.

Changes in manufacturing processes, fuel availability, technology, population concentration, transportation, etc., will influence the specifics of air pollution. We can expect new problems to develop, some of the old ones to disappear and others of the old ones to grow. It is clear that the field of air pollution is not only broad but is also reflective of the dynamics of society. Significant progress on the problems of air pollution will require the depth of competence of professionals of many kinds who can turn their attention to new problems as they arise.

Focal Project

Teaching interdisciplinary subject matter to a multi-disciplinary group is one of the large unsolved problems in university education. We are in general not set up structurally or philosophically to handle such problems. They are not neatly organized, capable of closed definition or final correct solution; they are design problems. They require the application of all sorts of knowledge and it is nearly impossible to set prerequisite requirements which can be met by all of the mixed group of students who must represent the needed spectrum of skills. Professors who insist on highly organized courses requiring several stages of prerequisite preparation are likely to feel that interdisciplinary courses are not graduate level or even upper division undergraduate level.

It is enigmatic that a problem which is one of the very difficult ones for society is not considered difficult enough to be worthy of the attention of regular courses in our universities. We need a way of dealing with real problems and still do whatever it is that universities feel is a compulsive expression of their scholarly character. One approach is the focal project described here.

The focal problem was a single problem which received the attention of the class for a period of preferably one year. This sequence related to air pollution in the community and the individual problems were the study of the total situation in a city. Seminars, applied problems, field trips, and some research were to a large extent referred to the focal problem. Staff members and students were assigned to study and define the various (scientific, political, sociological, economic, engineering, public information, health, plant damage) aspects of the problems. They prepared and presented the study plan and source material for the seminar and for student projects. People representing industry, control agencies, municipal government, citizens' groups, news media and others were involved in the study and were brought in to address the seminar.

As a pedogogical device this provides the student with a familiar ideological framework to which he can relate new ideas. Likewise it provides people from different disciplines with a common reference structure and a secure starting point for the development of mutual understanding. This sequence supplements thesis research and will ensure a breadth of coverage of the field which does not result from work on specialized research.

Some of the term projects which were assigned to small groups of students are as follows:

1. Survey of effects of air pollution on the insect populations in Greater John Doe town.
2. Meteorology study. Apply standard diffusion equations to sources in the Greater John Doe town area and calculate pollution movement. Develop a proposed sampling grid for Greater John Doe town including location of samplers with respect to air flow, bridges, etc.; power supply, public places, etc.

Experience with the focal projects over a three-year period was encouraging and generally comparable to what we had encountered at Case Institute of Technology in chemical plant design and process development projects which were done in cooperation with industry.

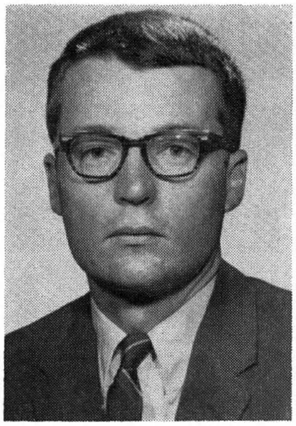
Conclusion

Engineering education has been evolving through a series of stages in which it has related to rather specific activities which were the occupation of engineers. Its programs have been responsive to the needs of industrial, civil, or military activities until recent years when disappointments in various national enterprises have moved us to seek an independently directed method. An attempt to follow the example of the physical scientists by fixing the program on a basic research focus has not led to a useful mechanism for educating the undergraduate and has not provided any sense of direction for engineering.

The times now call for something different, for a display of initiative by engineers. Increasingly the technological source of our productivity and wealth, of power generation, of communication mechanisms, of the quality of life have placed a bewildering burden on society's decision makers. Political leadership has filled this role in the past but it is sporadic and becomes less accessible to the politician's competence as the issues become more technical. The posture of engineers have been responsive, "Ask me a technical question and 'll give you a technical answer." Who is going to ask the proper questions, recognize the emerging issues, pose the alternative possibilities, provide the visionary leadership?

EDUCATION FOR A NEW ENVIRONMENT: BIOMEDICAL ENGINEERING*

RICHARD C. SEAGRAVE
Iowa State University
Ames, Iowa



Richard C. Seagrave received his BS in ChE from the University of Rhode Island in 1957, and his PhD from Iowa State University in 1961. After four years on the faculty of the ChE Laboratory at Cal Tech, he joined the faculty at Iowa State as an associate professor with a joint appointment in Chemical Engineering and Biomedical Engineering. His research interests have been in the areas of transport phenomena in flow systems, and in the simulation of chemical reactor systems. He is currently directing research in these areas, and participating in the research and teaching activities of the Biomedical Engineering program at Iowa State.

INTRODUCTION

During the last third of the twentieth century, engineers will become increasingly involved in two relatively new phenomena of enormous social, scientific, and economic consequence. **The first of these phenomena, increasingly evident in recent years, is the emergence of the interdisciplinary approach — the exploitation of historically separated talents to solve new problems.** Whereas the major scientific and engineering advances of this and the previous century have been wrought by intradisciplinarians such as Planck, Einstein, Gibbs, Westinghouse, and von Karman, the increasing complexity and communication capability inherent in the modern world is thrusting together scientists, engineers, and many other practitioners of widely varying professional and disciplinary training, making in many cases strange bedfellows by necessity, and reuniting in some cases disciplines separated since the 19th century. The emergence of entirely new areas of activity are becoming almost an annual phenomenon, and while perhaps the lifetimes and eventual relevance of many of these new activities may still be in doubt, it is becoming more obvious that the engineer and scientist of tomorrow will to an increasing degree be an interdisciplinarian in his professional activities. While the need for rigorously trained specialists in very narrow disciplines will undoubtedly continue, the important scientific discoveries and engineering developments of social significance in the next 30 years will most probably be affected by teams of interdisciplinarians rather than by teams within existing disciplines or by individuals.

The second, and probably the more significant phenomena, is the invasion by the engineer, with his tools and talents, of hostile and unexplored environments. During this century, we have for the most part carried out our activities at a macroscopic level on the surface of the earth, concerning ourselves with ideal gases and Newtonian fluids, dealing with the corrosive effects of our relatively friendly atmosphere, and to a large degree extrapolating and interpolating the efforts of our ingenious professional predecessors. Certainly the engineer has made enormous contributions to the welfare of his fellow man, although as we look into the atmospheres near our large cities, to our stockpiles of incredible weaponry, and to our highway systems, we occasionally notice some interesting and somewhat worrisome side effects of our rampant and fulminating technology. Here at the two-thirds point in this century, we now find ourselves, as a consequence of these advances in science and technology, stimulated by a myriad of political, social, and economic factors, on the thresholds of entirely new environments, for which we possess the tools and capabilities of entrance. The foremost examples are those of the reaches of interplanetary space and the unexplored and unexploited depths of the oceans. *But perhaps the most interesting of these new environments, the most hostile, the most complicated, the most studied and the least understood, and the one most urgently calling for engineering attention, is the environment found within the human body.* The popular press, as well as the

*Presented at the Los Angeles meeting of ASEE, June 17-20, 1968.

technical press, bears daily witness to the impact that cooperative efforts between engineers and physicians will have on our lives in the future.

The problems faced on entering this new environment are formidable indeed, and they require the fervent cooperative efforts of the life scientist, the physical scientist, and the engineer, not to mention the lawyer and the theologian.

Biomedical Engineering

It has often been observed that prior to the middle of the 19th century there was little to distinguish the methodology of the physical scientist and that of the life scientist. The landmark efforts of the French physician Poiseuille concerning the flow of blood in capillaries, resulting in a basic engineering equation, is a good example of the quantitative approach employed by life scientists at that time. When the hypercomplexity of living systems became increasingly apparent due to the development of better observational tools, the life scientist by necessity chose to resort to a more qualitative or descriptive approach, while the physical scientists continued along more quantitative or analytical paths, concerning themselves with simpler systems. *In recent years, we have witnessed the slow but steady re-convergence of the methodologies, and once again life scientists are employing quantitative techniques based on a growing understanding of the physical and chemical processes which take place in living systems. The physical scientist, in turn, is extending his quantitative and analytical methods to the study of more complicated systems.*

Meanwhile, the engineer, born of the needs of society to translate the results of the physical sciences into practical terms, has also been historically separated from the life scientist and his counterpart "engineer", the physician. As the sophistication of both of these professions has increased, as major developments in techniques of instrumentation and fabrication of materials have been made, and as the needs of an educated and complex society have mushroomed, communication between the disciplines has increased, and cooperative interdisciplinary programs have appeared worldwide, to the point where new educational and research programs bearing names such as "Biomedical Engineering" are currently being developed on many campuses across the country and indeed around the world.

I submit that no discipline or profession is better equipped to promote this reunion and this entry into a new environment for engineering, and to indeed benefit from it, than is chemical engineering. The chemical engineer was the first truly interdisciplinary engineer. He combines an engineering mentality and training with the pure sciences of chemistry and physics, and out of necessity has had to be conversant with the other "lesser species" of engineer as well as with the physical scientist. Many of us now believe that the chemical engineer can, and in fact must, become equally involved in the life sciences and their engineering application, and in fact is splendidly prepared to do so. **It comes as no surprise to a chemical engineer, for instance, that examples of almost every classical unit operation can be found within the confines of the human body.** The applications of chemical engineering thermodynamics and transport phenomena in the study of physiology and in the design and operation of artificial organs are legion. The concept of the body as a mobile, reproducible aggregation of isothermal chemical plants has a validity far beyond that of a tongue-in-cheek lecture device.

I hasten to point out that while the chemical engineering principles required for the design and operation of artificial organs encompasses almost the entire breadth of our training, the converse is of course not nearly true. That is, the breadth of our training naturally falls far short of the skills and background that are required for the design of such devices. We must not only rely heavily on communication with our colleagues who are experts in the environment, but we must also be prepared to speak an entirely new language. We must be prepared to hold our patience when encountering the maddening maze of descriptive jargon which we would instinctively replace with equations and graphs. And finally, we must also be prepared to play "second fiddle" in many respects to those who must bear the public responsibility for our joint efforts. But above all, we must be expert chemical engineers. We must be strong enough in our parent discipline, interdisciplinary as it is, to become an expert member of a team possessing a myriad of skills, and to be able to make unique and sound engineering contributions. This is perhaps the most important part of this discussion. It is vitally important for us to realize that chemical engineering can be broad enough in its content to accomplish this.

There are few things more personally distressing to me than hearing that a graduate chemical engineer has decided to go to medical school. Although a chemical engineering background is excellent preparation for a professional medical education, it appears to me that the real contributions in this new arena of interdisciplinary activity will be made by experts who can communicate, and who can understand the environment, rather than by people with piecemeal or hodgepodge training who are likely to be masters of no trade. The standard medical school program represents and extraordinarily inefficient and time consuming way for a graduate engineer, with six or eight years already invested in his professional education, to learn to communicate and to understand the environment. However, there is another factor at work here. *There unfortunately exists in many of us a professional "second class citizenship" mentality which makes many feel that somehow an engineer is professionally inferior to a physician.* This is undoubtedly stimulated somewhat by the enormous difference in mean income, and by consequences arising from the fact that a physician's effectiveness is often critically dependent on his public image. Any fair comparison of a graduate program in engineering and the program of studies leading to an MD degree should quickly modify this image problem. While the MD usually interacts directly with his "customer" and hence bears a special kind of responsibility the engineer while usually operating behind the scenes, bears a different kind of responsibility and by no means has to be considered as a "second class citizen" on the team.

Education for Biomedical Activities

At this juncture we should consider some facets of the education and training which would be desirable for a chemical engineer who wants to participate in biomedical activities during his professional life. While we cannot anticipate all of the developments and discoveries of the next thirty years, there does appear a fair number of guideposts in the form of current research problems to indicate the direction in which we need to move.

If we look at the current research areas at the interface between engineering and medicine, the single and most immediate deficiency that we seem to face is the need for new materials suitable for use in this new environment. For example, about 5000 people per year in the United States need to have part of their face removed, either as the result of injury or disease. At the present time no completely suitable material for facial prostheses exists which meets the structural, mechanical, biological, and cosmetic requirements of this application. The search for biologically suitable materials for many similar applications has proceeded along very empirical lines. Most probably, this search process has been duplicated for many other engineering and processing problems. One gets the feeling that somewhere a tremendous amount of technological information about materials must be accumulating. The person that many feel should be aware of and familiar with this technological information, and who should be able to produce or predict these results, is the chemical engineer. We somehow need to increase the emphasis in our curricula on problems of materials — possibly as a start at the graduate level — and to develop some understanding and appreciation in our students of problems in this vitally important area.

We easily could spice our regular coursework with selected examples of a biomedical nature.

We easily could, and certainly should, spice our regular undergraduate and graduate coursework with selected examples and problems of a biomedical nature. For example, let the thermo student compute how long it takes to freeze to death, or explain why fever must accompany chills. Let the unit operations student compute how much area is needed in the blood oxygenator or in an artificial kidney. Our sophomores could perform their material balance calculations on the lung and the kidney. We need to convince our students (it won't be difficult) that the application of chemical engineering principles in the body are often quite interesting and easily understandable. The necessary qualitative and descriptive material, once the physical and chemical principles are understood, can be picked up quite easily. I hasten to point out that at this level only enough understanding of the living system to remove fear and stimulate interest is required, and the student should be made to realize the degree of the oversimplification with which he is presented. There is certainly good precedent for this pedagogical trick in chemical engineering education.

In the study of simulation and process con-


They're already planning to mine oil instead of pump it.
Isn't that the kind of company you'd like to work for?

trol, there are many good examples and applications in the body which chemical engineering students would find challenging and interesting. The student can undoubtedly feel more personally involved in a problem of respiratory feedback control than in a constructed problem involving some hypothetical process.

In the study of typical chemical processes or of the process industries, we might include selected topics such as the artificial kidney to illustrate the application of chemical separation techniques in a fascinating context. I know of at least one chemical engineering department which devoted an entire one term course in the sophomore year to this topic as a means of introducing chemical engineering.

What I am saying is that to a large degree our present curricula, inoculated with a medium of selected examples, represents an excellent technical preparation for further interdisciplinary study. One of the fringe benefits of such a strategy might be an improvement in the public image of our curricula. **Chemical engineers, like all engineers, suffer somewhat these days from a public relations problem.** This is continually manifested by the problem of stagnating engineering enrollments, and by the fact that recognition of or acknowledgement for engineering accomplishment is rare in the public press. If we could demonstrate that our professional curricula contains considerations of these apparently more relevant aspects, perhaps our role would become more fully realized and even appreciated. Of course, we should continually stress the relevance of the things we study to all aspects of modern technology, as well as to the area of biomedicine.

Chemical engineers, like all engineers, suffer somewhat these days from a public relations problem.

Some R and D Problems

Perhaps some examples of current research and development problems in which chemical engineers are participating could serve to illustrate this point. These examples have been selected with no particular criteria except as interesting examples involving among other things direct application of principles presented in undergraduate chemical engineering curricula.

The problem of carefully heating a premature infant that has underdeveloped thermal autoregulation is a complicated heat transfer and control problem involving all three classical modes of heat transfer as well as elements of some rather sophisticated control system. Current research on this problem involves measurement of the newborn's skin temperature in the period shortly following delivery. A simple energy balance computation will show that a nude, wet newborn will lose 2 degrees of body temperature per minute unless preventive measures are taken to drastically reduce thermal losses.

Another interesting heat transfer problem involves the apparent use by the body of a countercurrent heat exchanger using facial venous blood to control the temperature of arterial blood leading to the brain, and hence the operating temperature of the brain. **The brain produces 15% of the body's total heat yet while it is encased in a thick skull covered with hair, it apparently operates nearly isothermally under wide environmental conditions.** Current research involves temperature and flow rate measurements around the heat exchanger in the nose and facial regions of dogs and horses to determine the actual operating characteristics of the heat exchange system.

Increased mass transfer efficiency of devices such as the artificial kidney and the membrane blood oxygenator continues to be a subject of much attention among biomedical engineers. More recently, efforts are being extended to the development of miniature oxygenators suitable for pediatric use in the treatment of cardiac and respiratory disorders in newborns. The delicate physical and chemical nature of the working fluid and the difficult fluid mechanics problem of forming stable thin flowing films continues to impede development in this area.

The transient relationships between pressure, volume, flow, and compliance in the extracorporeal space during heart-lung bypass procedures is an interesting problem involving elements of fluid mechanics and process control. **The changes which occur in the vascular system during surgery have a complicated and profound effect on the distribution of blood inside and outside of the subject, and on the "holdup" in the bypass system.** Current research on this problem is directed to determine the effects of various drugs used during surgery on the operation of the bypass system to optimize the blood distribution in the system.

. . . the field of interaction between engineering and medicine is presently crying out for leadership.

The problem of optimally managing subjects during post-operative recovery can be aided by knowledge of the material and energy balance relationships in effect. Work is being done to develop instrumentation and computational procedures to aid in gathering this type of data.

A classical problem involving many elements of chemical engineering is the simulation of the behavior of the human respiratory system during obstructive lung disorders or circulatory abnormalities. The system of equations required to describe this situation represents a challenging problem which when solved can hopefully be used to provide insight for the clinician as well as the physiologist. Current research in this area is directed to developing models which can account for the variations in the mass transfer capability at the blood-gas interface as well as mis-matching of the streams due to flow anomalies.

Educational Trends

One of the trends that seems to be evident is that following the experiences of our colleagues in electrical engineering, our activities are going to become increasingly more microscopic. That is, we will spend a higher and higher percentage of our time dealing with systems and with problems which are related to smaller and smaller spaces, and as a consequence, we must continue to insure that our students are exposed to the physical and chemical principles which can be used to describe these systems.

The most important of our educational tasks, however, in my opinion, is one that we often overlook. It is especially critical with regard to this new environment which we have been discussing. We need to instill and to develop in our students and in our graduates some feelings about the social responsibilities of an engineer. As indicated earlier, we need only look around us to realize how delinquent we as a group have been in providing the social leadership necessary for the balanced good of society. **The concept of an engineer as a technical member of a team who produces a service for a fee without regard for its social or moral consequences is outmoded.** Engineers must provide leadership in this area, and the field of interaction between engineering and medicine is presently crying out for such leadership. Few professional people who have the influence required to control the course of things are presently concerned with the overall impact on our society that unbridled advances in areas such as artificial organ technology will have. We can see around us — too late in many cases — the undesirable side effects which could have been avoided by a combination of engineering and social concern. The overdevelopment of the American automobile is perhaps the clearest (or most obvious to our senses) on a smoggy day. Somehow we need to educate the chemical engineers of tomorrow in an atmosphere that promotes the consideration of responsibility to society before the fact, instead of after.

Conclusions

In summary, the following points have been offered.

- **Advances in science and technology along with an increased awareness among scientists and engineers of their mutual needs and similarities have stimulated the phenomena of the interdisciplinary team.**
- **Engineers are concerning themselves with new and unexplored environments, a noteable example being living systems, particularly the human body.**
- **It is important to realize that a chemical engineering background is well suited for many current problems in biomedicine.**
- **Chemical engineers working in this area must maintain their identity, and in fact must be unusually well grounded in chemical engineering principles to make maximum contribution. It is probably inefficient to undertake a formal educational professional program in the life sciences.**
- **The problem of finding suitable materials for biomedical applications is presently critical, and represents a logical stamping ground for chemical engineers.**
- **Examples of current research problems in medical areas involving chemical engineering demonstrate interesting applications of principles presented in undergraduate chemical engineering curricula.**
- **Chemical engineering education can exploit these new phenomena by making curricula more attractive and more relevant. By spicing fundamental courses with problems and examples taken from physiology and medicine the student can become more conscious of the breadth of chemical engineering.**
- **It appears that our activities will become increasingly more microscopic, and we need to insure that our future students can continue to handle these new and smaller systems.**
- **We somehow need to give our students more appreciation of the social responsibilities of an engineer, so that they can provide leadership in many of the complex situations of the future, which will continue to evolve from these interfacial activities, and expanding technology, and the exploration and exploitation of new environments.**

OCEAN ENGINEERING

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The United States is losing a space race. We are losing to Russia, to Japan, even to Peru. The race is to occupy, control, and exploit the vast resources of "inner space" represented by the oceans. We have hardly begun to develop the technological base which will be necessary to meet this challenge although the need is now generally recognized and activity is vigorous. One vitally important element in this effort will be the development of educational programs which combine not only the best marine science but the best modern engineering science to educate men with the capacity to cope with the strange new world of the sea.

A PhD program in Applied Marine Sciences has been initiated at the University of California at San Diego by Scripps Institute of Oceanography and the Aerospace and Mechanical Engineering Sciences Department in response to the growing demand for individuals with such training and research experience.

THE RESOURCES OF THE SEAS

Athough 70% of the surface of the earth is covered by oceans containing most of its animal and plant life, man extracts relatively little knowedge and material of value from water areas compared to land areas. Less is known of the geography of the deep ocean than is known of the back surface of the moon. Only about 1% of man's food is extracted from the 400 billion tons of organic matter produced in the oceans every year, yet men go hungry. Some 25% of the earth's oil lies underwater, yet recently the value of sand and gravel mined near the shore was greater than the value of the oil pumped from underwater. Billions of dollars are lost each year in ruined crops, lost construction time and damaged property because of our inability to accurately predict, let alone control weather conditions dominated by oceanic transport phenomena. In spite of these facts, our total national oceanographic program just ten years ago was less than $10 million annually. This amount has since risen dramatically: President Johnson proposes $462 million for the next fiscal year.

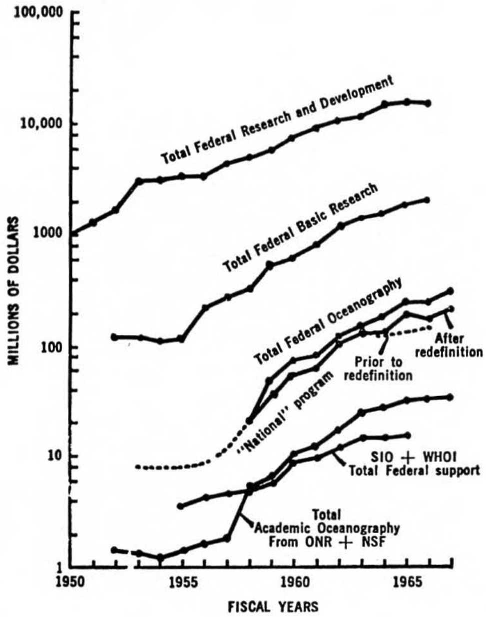

Fig. 1. Growth of Federal support for marine science and technology.

A significant fraction of the ocean bottom is not in deep water. An area about the size of Africa is in water less than 200 meters deep forming the so-called continental shelves. An intenational Convention on the Continental Shelves in Geneva reached an agreement in 1964 giving sovereign jurisdiction to the natural resources of the sea bed and subsoil of this land adjacent to coastal nations. In this way, the United States acquired 850,000 square miles of adjacent sea bottom or an increase in our territory of 25%. Clearly it is this land which can be expected to yield the first economic benefits.

THE NATIONAL OCEANOGRAPHIC PROGRAM

Appreciation of these vast resources has been awakening. From 1958 to 1965 Federal support to oceanography increased 11 fold as shown in Fig. 1 taken from the Panel on Oceanography of the President's Science Advisory Committee report[1] "Effective use of the Sea". This Panel recommended giving further expansion of the national oceanography program highest priority. They recommended a general increase of the nondefense component of the program from the 1966 level of $120 million to $210 million by fiscal year 1971 and an increase in basic research and education support from $15 million to at least $25 million in the same period.

*Presented at the Los Angeles ASEE Meeting June 17-20, 1968.

An important step forward in assuring a coordinated long-range national program for the effective use of the sea was the enactment of the Marine Resources and Engineering Development Act of 1966[1]. The Act established a Cabinet level National Council on Marine Resources and Engineering Development, headed by the Vice President, and a Commission on Marine Science. The Act also established as national policy "the advancement of education and training in marine science". Such legislation was motivated by the widespread impression that the nation's marine interests were not being adequately pursued because of organizational fragmentation of Federal responsibility for oceanography and due to lack of a sufficiently high level advocate for ocean science and technology in the administration.[1]

For whatever reasons, the United States is slipping behind in important areas of marine technology. Between 1954 and 1964 our annual fish catch actually decreased slightly from 6.13 to 5.82 billions pounds, while Peru's catch increased by nearly a factor of 50 to put her in first place with 20.2 billion pounds. Four other countries besides Peru lead us in this area. Lagging technology and obsolete equipment are certainly contributing factors. Our average medium-sized trawler in the Atlantic is 24 years old. Many segments of our maritime industry are struggling to stay alive. Japan leads the world in the development of "aquaculture" while this field is practically nonexistant in the United States, even though it has been estimated[2] that areas suitable for oyster production in the United States could produce more than the total fish catch of the world using modern methods of aquaculture developed in Japan. Three years after the loss of the submarine Thresher we still would probably not be abe to recover the Scorpion along most of its route across the Atlantic, even if we could find it. *All of these examples illustrate our past neglect of ocean engineering.*

Estimates of future world population growth indicate that conventional methods of food production will be hard pressed to meet either caloric needs or the critical problem of animal protein deficiency. Chronic protein deficiency is the leading cause of death for children between weaning and five years of age in all countries of the equatorial zone, accounting for as high as 50% of such deaths[1] as well as blighted health at all ages. Marine protein concentrate extracted from various species of hake can provide adequate protein to supplement one child's diet at a cost of only $2.00 per year using presently available technology. The "food-from-the-sea" program has been given the highest priority by the Marine Science Council.[3]

EDUCATION IN OCEAN ENGINEERING

The incredible efficiency developed by our agriculture is recognized as a key factor which permitted the economic success of this country. Many attribute this rapid development of agriculture to the stimulus provided by the Land Grant College system and the associated State Agricultural Experiment Stations which followed. When President Lincoln signed the Land-Grant Act in 1862 hardly a college in the country was equipped for laboratory teaching or research. The familiar pattern today of teaching and graduate research was an idea vigorously debated during the formative years of the land grant college system. In fact, a previous version of the Land Grant Act had been vetoed 4 years earlier by President Buchanan. The Land Grant Colleges brought major changes in the philosophy of higher education. Instead of teaching a narrow curriculum of philosophy, theology, dead languages and mathematics, the function of a university was expanded to include both the seeking and dissemination of new knowledge as well as teaching of the old. Since the inception of the Land Grant Colleges, the efficiency of the farmer has increased over 700%. Today, research-based increases in agricultural efficiency are estimated to save this country over $7 billion each year.[2]

In contrast to the seven fold productivity increase of the farmer, the productivity of U. S. fisherman has increased only 33% in the same period according to Senator Claiborne Pell,[2] author of the National Sea-Grant Colege and Program Act. The Sea-Grant College concept was inspired by the success of Land Grant Colleges, and was first suggested by Dean Athelstan Spilhaus of the University of Minnesota.

Dean Spilhaus envisions more than simply increased support to research and teaching in ocean engineering in the Sea Grant Colleges. He sees the same sort of educational extension work applied in marine technology as was developed in American agriculture: "county agents in hip boots" are even a part of his prescription for the propagation of new discoveries in ocean technology.

In 1963-64 the total U. S. oceanographic science staff was about 3000 including 500-600 PhD's. The growth in the numbers of students and degrees in oceanography or marine science is shown in Fig. 2. At present there are some 1000 students enrolled in over 50 marine science curriculums.[3] It has been increasingly apparent, however, that much less effort and support has been expended in training ocean engineers. Only 17 curricula in ocean engineering or technology were listed by the Interagency Committee on Oceanography in 1967-68[4] It is this situation which the Sea Grant College Act is intended to alleviate by its particular emphasis on ocean exploitation and applied research.

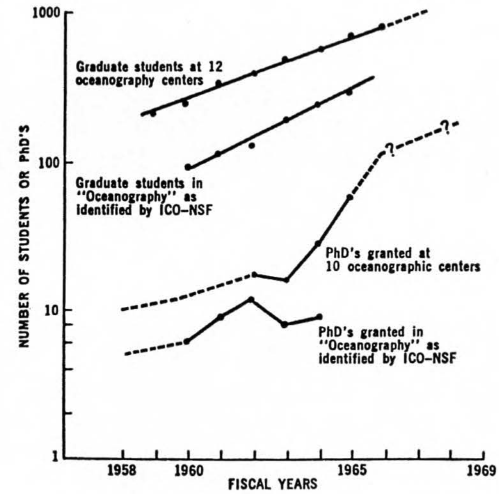

Fig. 2. Growth of students and degrees in oceanography.

APPLIED MARINE SCIENCES AT UCSD

At La Jolla, the development of ocean engineering has been rather opposite to that expected by the Sea Grant College Act, although the end result may be similar. Instead of starting oceanic studies in an existing university, an existing center of marine science has started a new university. As described by Professor William Nierenberg, director of Scripps Institution on Oceanography in his testimony at the Sea Grant Colleges Hearings in 1966[2]:

> "For the past 10 years the oceanographers at Scripps have carried on continuous study and discussion of the best way to contribute further to the advance of ocean-related sciences. The first result and the principal one was the establishment of a new campus of the University of California at San Diego. It was agreed that a school of oceanography could not flourish unless it were closely associated with a university that had first-rate departments in the basic sciences and engineering. A school of marine science that is isolated from a first-rate campus is a poor concept in this day and age . . . the area of formal education in applied ocean science, sometime called ocean engineering . . . we hope to establish on a broad an surer basis in cooperation with our department of engineering, headed by Professor S. Penner."

The first college of the new San Diego campus is named for one of these oceanographers: Roger Revelle, former director of Scripps and a leader of the successful effort to establish a branch of the University of California at San Diego.

At present the joint Applied Marine Sciences curriculum between the Aerospace and Mechanical Engineering Science Department and the Department of Oceanography is operating on an ad hoc basis, with perhaps half a dozen PhD candidates taking courses in both departments although considerable expansion is expected in the near future. Ten faculty members in AMES have expressed interest in the program, with backgrounds covering engineering physics and geophysics, mechanical, electrical, chemical, aeronautical and bioengineering, applied mathematics and mechanics, system dynamics and control, pathology and physiology. Among the thirty typical thesis topics which were suggested are:

- Laboratory studies of wind generated waves
- Turbulent transport phenomena at the air-sea interface and in stratified media
- Noise models for analyses of undersea communication and detection, application of Kalman filtering and Folker-Planck-Kolmogoroff equations
- Determination of wave heights by satellite
- Structure of waterspouts, maelstroms and tsunamis

Because of the unusual breadth required of an applied marine scientist, it was agreed that the course material requirements for participation in the program should be substantially higher than the curricular requirements of either department for its candidates, totalling at least the material in 20 quarter courses and commonly more. Although there is clearly a need for individuals trained at all levels in ocean technology, it was concluded that only a PhD program would be consistent with the function of the University and the high level of competence in both fields of modern engineering science and oceanography which will be required of those individuals who can supply leadership in expanding application of marine science.

Recent developments have been the expansion of the interdepartmental ocean technology program to include the Medical School and Applied Electrophysics Department, the estabishment of a curricular group by Professor Warren S. Wooster, Chairman of the Scripps Graduate Department, to design the curriculum and initiate new courses which may be appropriate, and the selection of the University of California at San Diego for a Sea Grant College program.

SUMMARY

Greater efforts are needed in the development of applied marine science if the United States is to take full advantage of the potentially valuable resources of the oceans. Education will play a vital role in establishing the technological base, and the federal government has moved to assist the development of ocean engineering, especially through the Sea Grant College Act. The University of California at San Diego is developing a PhD program in Applied Marine Sciences in response to the awakening national awareness of the need to harvest the wealth as well as the knowedge of the sea.

ACKNOWLEDGMENT

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1968 Award Lecture

FLOW and TRANSFER at FLUID INTERFACES*

Part III - Convective Diffusion

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LET US CONSIDER steady, two-dimensional cases of the three classes of basic flow represented in Figures 2 and 6. These are parallel flow, in which surface dilation is absent; nearly parallel flow, in which there is mild surface dilation of "rejuvenation"; and irrotational stagnation flow, in which there is strong surface dilation and concomitantly the effect of convection normal to the interface completely overshadows that of convection parallel to the interface. The appropriately specialized versions of the convective diffusion equation are tabluated in Figure 11. Note that in the first two categories diffusion parallel to the interface can be neglected in comparison with convection in that direction. The boundary conditions in every case are a uniform and constant equilibrium concentration at the fluid interface and an unchanging concentration at great depths.

The leading convective diffusion solution for parallel flow is that of Leveque (1928), rederived by Elser (1949) and Kramers and Kreyger (1956); approximate solutions for some other instances of parallel flow have been computed by Beek and Bakker (1967) and Byers and King (1967). Perhaps the most useful exact solution will be that obtained recently by my coworker Majoch and described in Figure 12; although the

*Based on the main part of the 1968 Annual Lecture to the Chemical Engineering Division, ASEE at the University of California at Los Angeles June 18, 1968, sponsored by the 3M Company.

Parallel Flow $$0 + v_z(x)\frac{\partial c}{\partial z} = \mathcal{D}\left[\frac{\partial^2 c}{\partial x^2} + \underbrace{\cancel{\frac{\partial^2 c}{\partial z^2}}}_{\to 0}\right]$$

Nearly Parallel Flow $$v_x(x,z)\frac{\partial c}{\partial x} + v_z(z)\frac{\partial c}{\partial z} = \mathcal{D}\left[\frac{\partial^2 c}{\partial x^2} + \underbrace{\cancel{\frac{\partial^2 c}{\partial z^2}}}_{\to 0}\right]$$

$$v_x = -\int(\partial v_z/\partial z)\,dx$$

Stagnation Flow $$\frac{\partial c}{\partial t} + v_x(x)\frac{\partial c}{\partial x} + v_z(z)\frac{\partial c}{\partial z} = \mathcal{D}\left[\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial z^2}\right]$$

$$v_x = ax \quad , \quad v_z = -az$$

Fig. 11.—Convection Diffusion Equations.

Leveque solution is the special case $n = 1$ (i.e., $v_z = ax$) the range $n>1$ corresponds to vanishing shear stress at the interface and is more relevant to flow and transfer at free surfaces. The solution conveys the very important lesson that convection and diffusion are not additive processes

$$ax^n\frac{\partial c}{\partial z} = \mathcal{D}\frac{\partial^2 c}{\partial x^2}, \qquad c(x,0) = c(\infty,z) = c_o, \qquad c(0,z) = c_e$$

Similarity transformation $\eta = xf(z)$:

$$-(n+2)\eta^{n+1}\frac{dc}{d\eta} = \frac{d^2c}{d\eta^2} \quad \text{provided} \quad f^{n+1}\frac{df}{dz} = \frac{(n+2)\mathcal{D}}{a}$$

$$\frac{c-c_o}{c_e-c_o} = \frac{n+2}{\Gamma(1/n+2)}\int_0^\eta \exp(-y^{n+2})dy \quad \text{if} \quad f(z) = \left[\frac{(n+2)^2\mathcal{D}z}{a}\right]^{\frac{1}{n+2}}$$

Fig. 12.—Steady Transfer—Parallel Flow. (Majoch & Scriven 1968).

(with the trivial, inconsequential exception of rigid-body motion parallel to a concentration gradient). Convection affects diffusion by tilting and sharpening or dulling concentration gradients, and it can do this even when flow is perpendicular to the overall concentration difference. This fundamental feature of the convective diffusion process was scarcely known in the era of Lewis and Whitman and Higbie, nor has it gotten enough attention from those following in Danckwerts' steps. Whether relative motion of liquid at different depths close beneath an interface may safely be neglected depends very much on the nature of that motion.

The most informative convective diffusion solution for nearly parallel flow is, in my opinion, one I published with R. L. Pigford in 1959 as part of a study of flow and transfer in laminar liquid jets. It was rediscovered in a somewhat different context by Angelo, Lightfoot, and Howard (1966). It rests on an approximation valid insofar as the streamwise varying tangential component of velocity is substantially independent of depth within the zone penetrated by convective diffusion (Figure 13); equivalently, it

By continuity $$v_x = -\int_0^x(\partial v_x/\partial z)dx \simeq -x\frac{dv_s}{dz}$$

Hence $$-x\left(\frac{dv_s}{dx}\right)\frac{\partial c}{\partial x} + v_s(z)\frac{\partial c}{\partial z} \simeq \mathcal{D}\frac{\partial^2 c}{\partial x^2}$$

Approximate solutions by the "integral method" led to the similarity transformation $\eta = xf(z)$ and exact solution.

Fig. 13.—Steady Transfer—Nearly Parallel Flow (1).

holds in the zone where flow is so dominated by boundary conditions that the normal component of velocity is proportional to distance from the interface (as we saw at the outset). The solution, interestingly derivable in different ways, again illustrates the merging of convection and

$$-2\eta\frac{dc}{d\eta} = \frac{d^2c}{d\eta^2} \quad \text{provided} \quad \frac{v_s}{f^3}\frac{df}{dz} - \frac{1}{f^2}\frac{dv_s}{dz} = -2\mathcal{D}$$

$$\frac{c-c_o}{c_e-c_o} = \operatorname{erfc}\eta \quad \text{provided} \quad f(z) = \frac{v_s(z)}{\sqrt{B + 4\mathcal{D}\int_0^z v_s(\zeta)d\zeta}}$$

$$\eta = xf(z)\,, \qquad B \text{ from b.c. @ } z = 0$$

Fig. 14.—Steady Transfer—Nearly Parallel Flow (2). (Scriven & Pigford 1956, 1959).

diffusion into a single process (Figure 14). The corresponding flux formula (not shown) confirms that a velocity component toward the interface, hence $dv_s/dx>0$, enhances interphase transfer even though the velocity component vanishes *at* the interface; conversely a normal component away from the interface, hence $dv_s/dz>0$, reduces the rate of interphase transfer —though not in the same proportion, generally. These phenomena stand out in the next class of flow.

Because velocity normal to the interface has the greatest effect on interphase transfer, it is logical to seek the class of flows that most fully typifies normal motion and still leaves the convective diffusion equation tractable. Chan selected two-dimensional and axisymmetric, irrotational stagnation flows, which nearly fulfill the Navier-Stokes equation, do satisfy the kinematic and tangential traction boundary conditions at free surfaces, and epitomize the fact that relative normal velocity near free interfaces increases linearly with depth (v_z=-az; cf. Figure 11). The history of convective diffusion solutions is interesting. By separation of variables and series

$$\frac{\partial c}{\partial t} + a(t)x\frac{\partial c}{\partial x} - a(t)z\frac{\partial c}{\partial z} = \mathcal{D}\left[\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial z^2}\right] \quad \text{and i.c. + b.c.'s}$$

$$\text{Invariant under} \quad x \longrightarrow x' = x - A\exp\left[\int_0^t a(t)dt\right]$$

$$\text{Therefore} \quad c(x + dA,\ z,\ t) = c(x,\ z,\ t) \quad \text{and} \quad \partial c/\partial x = 0$$

$$\frac{\partial c}{\partial t} - a(t)z\frac{\partial c}{\partial z} = \mathcal{D}\frac{\partial^2 c}{\partial z^2}$$

Fig. 15.—Unsteady Transfer—Unsteady Irrotational Stagnation Flow (1).

expansions Chan in 1963 obtained a formal solution of great generality and little practicality, except that he very shrewdly identified the particular series for flux at the interface in the case of main interest (1964). Simultaneously a coworker, B. A. Finlayson, obtained close approximations by weighted-residual methods. Within a a month my former colleague, C. V. Sternling, pointed out privately that a transformation of variables leads to a closed-form solution in the case of main interest. Within another month Chan (1964) justified this solution by a symmetry argument (Figure 15) and rederived it by the similarity transformation technique to which nearly parallel flow had yielded earlier. More recently we have identified Sternling's variables as material coordinates and a curiously warped time (Figure 16). From the Daliesque point of view these variables provide, the convective diffusion process appears as though it were pure diffusion (unsteady diffusion equation in Figure 16), which is remarkable — and a subject of current investigation.

$$\textbf{Material coordinates:} \quad \xi = x\exp\left(-\int_0^t a(t)dt\right), \quad \zeta = z\exp\left(\int_0^t a(t)dt\right)$$

$$\textbf{Warped time:} \quad \tau = \int_0^t \exp\left[2\int_0^{t'} a(t'')dt''\right]dt'$$

$$\frac{\partial c}{\partial \tau} = \frac{\partial^2 c}{\partial \zeta^2}, \qquad c(\zeta, 0) = c(\infty, \tau) = c_o, \qquad c(0, \tau) = c_3$$

$$\frac{c - c_o}{c_e - c_o} = \operatorname{erfc}\left[\frac{\zeta}{\sqrt{4\mathcal{D}\tau}}\right] = \operatorname{erfc}\left[\frac{z}{\sqrt{\frac{2\mathcal{D}}{a}[1 - \exp(-2at)]}}\right] \quad \text{steady flow}$$

Fig. 16.—Unsteady Transfer—Unsteady Irrotational Stagnation Flow (2).

The convective diffusion solution for steady, irrotational stagnation flows yields the formula for flux at the interface shown in Figure 17 and graphed in Figures 18 and 19. Study reveals that so long as the exposure time is no longer than it takes fluid particles to move 20% closer to or farther from the interface, the simpler formula for penetration solely by diffusion is a fair approximation; one also finds that there is no

$$\text{Stagnation-flow model:} \quad j = (c_e - c_o)\sqrt{\frac{\mathcal{D}}{\pi t}} \cdot \sqrt{\frac{2at}{1 - e^{-2at}}}$$

$$\text{Penetration model:} \quad j_* = (c_e - c_o)\sqrt{\frac{\mathcal{D}}{\pi t}}$$

$$\boxed{\frac{k}{k_*} = \frac{j}{j_*} = \sqrt{\frac{2at}{1 - e^{-2at}}}}$$

Fig. 17.—Instantaneous Mass Flux.

natural length scale with which to compare a purely diffusive penetration depth $\sqrt{Dt}$. At longer exposure times, flow toward the interface (a>0) steepens the concentration gradient at the interface appreciably and therefore the formula indicates increased transfer rates; conversely, transfer rates and concentration gradients are reduced by flow away from the interface

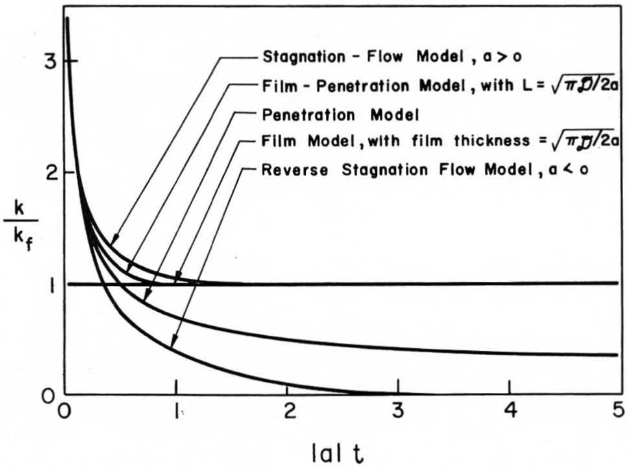


Fig. 18.—Instantaneous Transfer Coefficients vs. Time (Dimensionless Forms).

(a<0, "reverse stagnation flow"). At very long exposure times, the flux in stagnation flow asymptotically approaches a *constant* value, which is also characteristic of film models of flow and transfer (Figure 18). On the other hand the flux in reverse stagnation flow asymptotically approaches zero, as does the flux in the penetration model; but the former diminishes so rapidly with time that the total amount transferred approaches a finite asymptote, whereas the total transferred increases without bond in the penetration model (Figure 19). Normal convection away from the interface eventually brings the concentration at all finite depths to the interfacial value, effectively saturating the liquid and leaving its equivalent to a "stagnant pocket" of the sort suggested by Perlmutter (1961).

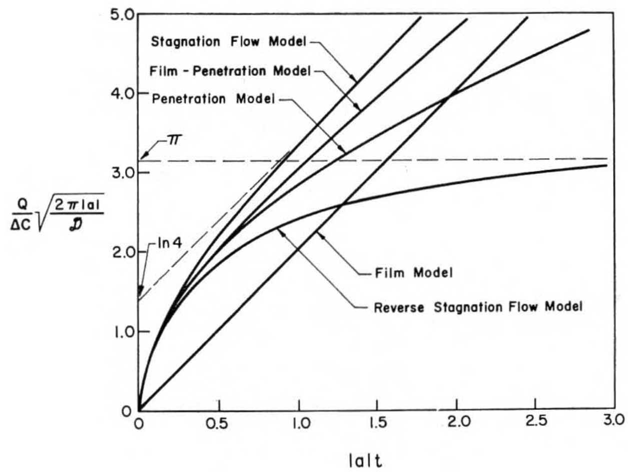


Fig. 19.—Total Transfer vs. Time of Exposure (Dimensionless Forms).

THE SIMPLE STAGNATION FLOW model accounts for the greatest effect convection can have on diffusion in transfer at fluid interfaces. In its functional behavior it spans the film model, the penetration model, and even an undeveloped stagnant-pocket model. Populations of stagnation flows of different flow strengths ($a>0$, $a=0$, $a<0$) can match the transfer performance of the various and sundry combinations, elaborations, and populations of less realistic microflow elements that we reviewed earlier. The stagnation flow model is the first to build convection right into the basic transfer process in the microflow element, and the result is a "master equation" that clarifies why each of the earlier models yields a functional form of mass transfer coefficient that may be useful in one or another range of practical circumstances.

Furthermore, the convective diffusion solutions for *unsteady* stagnation flows might permit more accurate modeling of turbulent action, in that they can account for development periods of microflow elements, i.e., the interruptive events need not be taken as instantaneous. What's more, populations of stagnation flows can be mixed with populations of other types of microflow elements to give even more versatile correlating formulas for transfer rates. I do not believe, though, that these are directions in which to push research, although comparative studies of the sensitivity of final working formulas to microflow elements and distribution functions probably would be widely instructive. Before turning to what I think is needed more, I should comment on one feature by which certain models can be differentiated.

This distinguishing feature is the way in

$$\boxed{k \propto \mathcal{D}^n}$$

Fictitious film	$n = 1$	Film-penetration	$1/2 \le n \le 1$
Penetration models	$n = 1/2$	Subsurface sweep (Beek & Bakker)	$1/2 \le n \le 2/3$
Surface rejuvenation Stagnation flows	$n = 1/2$	Subsurface sweep (Majoch)	$1/2 \le n \le 1$

Fig. 20.—Diffusivity Dependence of Mass Transfer Coefficient.

which mass transfer coefficient depends on the coefficient of molecular diffusion. The models we have been considering are contrasted in Figure 20; in all of them the mass transfer coefficient varies as the diffusivity raised to a power of from one-half to one, which is the range encompassing most experimental results. Yet there are a few data in the literature which indicate a weaker dependence on diffusivity, even no dependence at all. To account for such data several correlating formulas have been put forward: see Figure 21. Kishinevski's arguments are unconvincing but I suspect the data and his formula can be rationalized in terms of *time-averaged* convective flux by chaotic motions back and forth across the *mean* position of the fluid interface — a subject of further investigation. King has explored possibilities inherent in an empirical "eddy diffusivity" for scalar transport in free boundary turbulence, and has noted that were eddy diffusivity to increase linearly with distance from the interface (measured in a frame of reference moving with the interface, presumably), the average transfer coefficient would be proportional to the square-root of molecular diffusivity in the first instant of exposure and would become progressively less dependent as exposure time increased. But as Majoch recently pointed out at Minnesota, such an eddy diffusivity corresponds to a mean normal component of relative velocity everywhere including *at* the interface (cf. Figure 21), and while this would amount to a convective mechanism quite independent of molecular diffusivity, it does violate the elementary kinematic boundary condition of

Kishinevskii (1949, 1954): $j = \text{"}v_n c\text{"} \doteq \overline{v_n c}\,, \qquad \therefore\ n = 0$

Davies (1963): $j = \text{"}v_n \Delta c\text{"} + \Delta c\sqrt{\mathcal{D}/\pi t}\,, \qquad \therefore\ 0 \le n \le 1/2$

King (1966): $\dfrac{\partial \bar{c}}{\partial t} = \dfrac{\partial}{\partial z}\left[(\mathcal{D} + \text{"}\epsilon\text{"})\dfrac{\partial \bar{c}}{\partial z}\right], \ \epsilon = az \implies 0 \le n \le 1/2$

But $\epsilon = az \implies \dfrac{\partial \bar{c}}{\partial t} - \underbrace{a\dfrac{\partial \bar{c}}{\partial z}} = (\mathcal{D} + az)\dfrac{\partial^2 \bar{c}}{\partial z^2}, \ \therefore\ 0 \le n \le 1/2$

N.B. $\epsilon = az^2 \implies \dfrac{\partial \bar{c}}{\partial t} - \underbrace{2az\dfrac{\partial \bar{c}}{\partial z}} = (\mathcal{D} + az^2)\dfrac{\partial^2 \bar{c}}{\partial z^2}, \ \therefore\ n = 1/2$

Fig. 21.—Correlating Formulas for Weak Diffusivity Dependence.

. . . a "vorton" arriving at glancing incidence at a fluid interface is "scattered" . . . the toroidal eddy arrives . . . pushes along the surface briefly as it tips forward and then, parting company from the "ripplons" it has raised, it descends somewhat less energetically back into the bulk phase.

hydrodynamics. The lesson here is that such crude concepts as eddy diffusivity are poor substitutes nowadays for experimental and theoretical fluid mechanics together with the instantaneous and time-average convective diffusion equations. Nevertheless it does happen that an eddy diffusivity that increased as the *square* of distance from the interface would come very close to producing the same concentration field and mass transfer coefficient as a certain stagnation flow (Figure 21). And a *negative* eddy diffusivity that decreased in the same way would nearly match the corresponding reverse stagnation flow in its effect!

IN OUR ONGOING PROGRAM at Minnesota for understanding flow and transfer at fluid interfaces the question of greatest current interest is how periodic motions, such as accompany progressive and standing surface waves, affect diffusion. While we have some partial answers the state of the results is still such that they are more easily sketched in lecture than in writing. They and the further questions they raise do not point toward an eventually comprehensive theory of convective diffusion fields.

Vortex rings are the simplest experimental models of the "eddies" that according to surface renewal, surface replacement, or surface rejuvenation notions are responsible for interrupting quiescent interludes of diffusion at interfaces. In a preliminary to observing turbulent interfaces carefully, we have watched the encounters of dye-marked vortex rings with water-air and water-benzene interfaces. That this is edifying is plain from the motion-picture record, but it is difficult to summarize all of the wonderful things one sees. It will have to suffice here to report that under certain circumstances a "vorton" arriving at glancing incidence at a fluid interface is "scattered"; in other words the toroidal eddy arrives from the bulk phase, pushes along the surface briefly as it tips forward and then, parting company from the "ripplons" it has raised, it descends somewhat less energetically back into the bulk phase. Vortons arriving at rigid surfaces are invariably annihilated, incidentally—another contrast between the boundary conditions at rigid walls and fluid interfaces.

Beyond these sorts of studies, what I think is needed is research on the mechanics of fluid interfaces under turbulent bombardment, research designed to shed light on such matters as when populations of microflow elements are appropriate and how to relate the parameters of the elements and of their distribution functions to fundamental parameters of the turbulence — which is to say, to parameters in a turbulence theory that is not yet well in hand.

Not everyone would agree. In closing let me call your attention to the viewpoint of someone in closer touch with the practical problem past and present. P. V. Danckwerts evidently never returned to the hydrodynamic issues that he acknowledged but left unexplored in his well-known 1951 paper. At the Twentieth Congress on Theoretical and Applied Chemistry in Moscow fourteen years later, according to the twice-translated version in the first issue of *Theoretical Foundations of Chemical Engineering,* he said,

> "The problem of the absorption of gases, from the industrial aspect, has an essentially practical character and our approach to it must be pragmatic. This does not mean the negation of the role which the scientific understanding of the phenomenon plays but it must be understood that the contemporary state of applied sciences at times makes us overemphasize the value of analytical methods and that, in the case of too great expenditures of time in clarifying the mechanism of processes, the substance of the practical problem may fall from view."

ChE news

OPPORTUNITIES FOR DISADVANTAGED YOUTH AT BERKELEY

The Chemical Engineering Department of the University of California at Berkeley has obtained funds to support a limited number of minority-group students in both its undergraduate and graduate programs. At the graduate level a student without formal training in chemical engineering may apply if he has a degree in chemistry or another related field.

Although several black students have received degrees in chemical engineering at Berkeley in recent years the vast majority of them have been from foreign countries. The desire to see them take advantage of the excellent opportunities offered by the chemical engineering profession has led the faculty at Berkeley to start campaigning actively to recruit students from among the minority groups in this country. While some waiver of normal entrance requirements is being made to get this program started, the degree requirements will be unchanged.

Students and faculty from other schools who wish to receive additional information about this program may write to Scott Lynn, in care of the Department at Berkeley, California, 94720.

EDUCATIONAL FILMS

Two films on phase behavior have been produced by the University of Utah and the Chevron Oilfield Research Co., with the financial support of the National Science Foundation. Part 1 shows the phase changes in a single component system and Part 2 shows the phase changes in binary and multicomponent systems. The films were produced, written, and narrated by Noel de Nevers, ChE Department, University of Utah. Copies of the films may be purchased ($250 each) or rented ($5 each) from Educational Media Center, University of Utah, Salt Lake City, Utah 84110.

PRAIRIE VIEW — IOWA STATE PROGRAM

A group of administrators from Iowa State University including George Burnet, professor and head of chemical engineering, are continuing work on a cooperative program between Iowa State and Prairie View to develop a record-keeping data processing service and to establish a program in chemical engineering there. George Burnet explained that the first goal has been realized and it is hoped that the proposal for the chemical engineering program will be approved by the Texas Board of Regents in time for the 1969-1970 academic year.

Prairie View A and M, a predominantly Negro college, was established as a land-grant college in 1876. The college is located 46 miles NW of Houston and provides its 4,000-plus enrollment with training in agriculture, arts and sciences, engineering, home economics, industrial education, and nursing. The School of Engineering, established in 1952, has departments of architecture, mechanical, civil, and electrical engineering.

This continuing cooperative program is one of five programs begun in 1966 under the auspices of the ASEE to develop five predominantly Negro institutions in the South. ASEE and a number of industrial firms are providing funds to support the five programs. The other programs are: Virginia Polytechnic Institute and University of Wisconsin are aiding A and T of North Carolina; University of Illinois and Tulane are aiding Southern University; Vanderbilt is aiding Tennessee A and I; and University of Michigan and Auburn are aiding Tuskegee.

OUTSTANDING TEACHER AWARD

Dr. John D. Stevens, professor of chemical engineering, recently received an "Outstanding Teacher Award" along with three other members of the Iowa State University faculty. Each award consists of a plaque and $500 made possible by a grant from the Standard Oil Foundation to recognize superior teachers. In 1966, Stevens received the first annual H. A. Webber Teaching Award in the chemical engineering department at Iowa State.

ENGINEER OF THE YEAR

In recognition of outstanding contributions to engineering, Dr. Albert L .Babb, chairman of the Department of Nuclear Engineering at the University of Washington, has been named "Engineer of the Year" by the Washington Society of Professional Engineers.

He received a plaque and citation at a recent meeting of the association from Rolf Lux, president of the Seattle chapter. Dr. Babb was cited for "his untiring efforts on behalf of the engineering profession and for his unselfish services for the good of humanity."

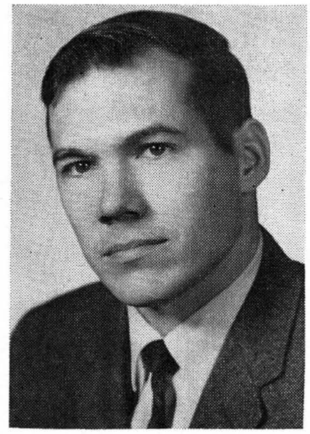
Dr. Babb has conducted significant research on the processing of irradiated nuclear fuel elements. Working with members of the medical profession, he also has helped to develop a new technique for the early detection of cystic fibrosis and was a member of a bioengineering team that designed improvements for components for the artificial kidney.

In 1968, he received a citation from the Washington State Legislative Joint Committee on Nuclear Energy for his contributions to the peaceful use of nuclear energy in medicine.

ChE classroom

POLLUTION CONTROL TECHNOLOGY

GARY POEHLEIN
Lehigh University
Bethlehem, Penn. 18015



Gary Poehlein received the BS, MS, and PhD ('66) degrees in chemical engineering from Purdue University. His industrial experience was gained with The Procter and Gamble Co. and with The Humble Oil Co. His interests include polymer chemistry, applied rheology, heat transfer, and environmental sciences.

All of us are aware that environmental pollution has become a major social-political problem in many parts of the world. Governmental regulations and public pressure have had and will continue to have a significant economic impact on the chemical industry. These facts have resulted in larger allocations of capital for pollution research by industry and governmental agencies. This, in turn, has resulted in formal instruction in pollution control technology within some chemical engineering departments.

A course in pollution control technology can be a constructive part of nearly any engineering curriculum. This great flexibility results because of the large number of potential lecture topics and because of many possible organization schemes. Our course is not monolithic but depends strongly upon the teacher. We have tried instruction based on (a) in-depth studies of a few problems or processes and (b) brief introductory study of many processes and related topics. Both approaches have been readily accepted by our students; however, I believe that course organization is more important than the selection of study topics. The course is organized to teach the fundamentals of processes for pollution control while, at the same time, preserving the tremendous motivation generated among students by their concern for the problems of our society.

The major objectives of our elective course offered at Lehigh University for advanced undergraduates and graduate students are:

- To illustrate the magnitude of the pollution problems facing this country.
- To teach the fundamentals of the processes of importance in the design of facilities for air and water pollution control.
- To provide an opportunity for the study of real pollution problems in local industry.

These objectives were achieved through several types of study. Formal lectures were given on a number of topics listed in Table 1. Several of the lectures were presented by outside speakers who were experts in areas such as; water ecology, air pollution control regulations, thermal pollution, etc. Field trips to a local municipal treatment plant and the research laboratories of a large company were a very successful part of the course. More field trips will probably be included in the future.

TABLE 1. LECTURE TOPICS

1. Sources and Characteristics of Industrial Wastewaters
2. Air Pollution Detection and Measurement Problems
3. Sedimentation
4. Ecology
5. Flocculation and Flotation
6. Aeration and Gas Transfer
7. Biological Treatment Processes
   a. BOD and COD; Significance and Measurement
   b. Natural and Aerated Lagoons
   c. Trickling Filters
   d. Activated Sludge Processes
   e. Sludge Disposal Processes
8. Adsorption in Air and Water Treatment
9. Oil Refinery Problems
10. Liquid Scrubbing of Gas Streams
11. Thermal Pollution and Cooling Tower Design
12. Mathematical Modelling of Rivers
13. Ion Exchange
14. Water Chemistry Topics
15. Pollution Problems in the Steel Industry
16. Foam separation

The course presents the fundamentals of processes for pollution control while preserving the tremendous motivation generated among students by their concern for the problems of our society. . . . It can be a constructive part of nearly any engineering curriculum.

In addition to formal lectures and homework assignments, all students were required to submit a term report covering an in-depth study of a pollution topic of their choice. Graduate students were expected to suggest potential areas for future research. This activity was especially important when lectures were restricted to brief treatments of important topics. The term paper provided a mechanism for more complete study of a significant problem and it helped to illustrate the importance of current literature in a rapidly developing field.

The third major course objective was achieved with the assistance of local industry. During the summer prior to our last course offering I decided to ask a number of local corporations to assist me in teaching pollution control technology by allowing a group of 3 or 4 students to study a specific problem within their plant. At first I had doubts that such a program could be arranged because of the sensitive nature of the subject. Much to my surprise nearly all companies responded favorably to initial correspondence. Suitable projects were outlined for the complete undergraduate enrollment of 21 seniors.

These industrial problems were, without question, the most satisfying and successful part of the course. They served as an ideal laboratory experience and, equally as important, generated motivation among the students for learning the lecture material.

The industrial problems were chosen because I felt the students would be able to contribute to their solution. Brief descriptions of some of the more successful experiences are outlined below.

- **Meat Packing Plant.** A total plant water survey was conducted on a medium size (3,000 hogs/day) meat packing plant. The plant technical staff was minimal and concerned primarily with day-to-day operation.

The student group measured solids (mostly fat particles valued at 4¢/lb) content and BOD of effluent streams. They determined the value of lost fat at about $130,000/yr. They then obtained bids for screening equipment to recover this fat from vendors who had worked on similar problems in other packing plants. The total installed cost of the solids recovery system was estimated to be $40,000; not a bad investment (certainly better than continuing to dump this material into surface waters).

- **Small Inorganic Chemical Plant.** A plant wastewater survey was conducted. The plant technical staff were well trained but pollution control activity was minimal.

Sample analysis indicated that the major problem involved two highly acidic streams which were currently discharged into an earthen hole about 75 yards from a river. A plant process-water well, located between the hole and the river, was no longer in operation due to acid pollution.

The student group suggested the installation of a limestone acid neutralization pit. Detailed construction drawings for this pit were provided.

- **Organic-Inorganic Plant.** This plant was of medium size with full-time staff assigned to pollution control activities. The student group worked on an alkaline wastewater problem under the supervision of plant professionals. Plant laboratory facilities were available to the students for sample analysis.

This type of arrangement is attractive because in-plant personnel are well acquainted with economic restrictions. In this case an acid neutralization proved to be the best solution. The plant discussed above was too far away for the ideal solution of stream combination, but the students did think of this possibility.

SUMMARY

Formal instruction in pollution control technology will undoubtably increase markedly over the next several years. Such instruction may take the form of a course such as I have outlined in this paper or it may involve the use of pollution control problems as examples in other courses. Either approach will be well received by students. Our course has demonstrated one meaningful way to involve industry in the academic process. No one can doubt that a few experiences such as those cited above will help to "turn on" our students. Similar programs, especially if they could occur earlier, may help to attract more students to the study of engineering.

ChE book reviews

Nonlinear Differential Equations of Chemically Reacting Systems, G. R. Gavalas.

Springer-Verlag New York Inc., (1968), ix, 107 pp. $8.50.

This is an important monograph in the field of the mathematical theory of chemically reacting systems — a field of increasing activity in recent years. The study of chemical reactions and reactors is central to the profession of chemical engineering. This field is of great importance since some reactions are not exceedingly fast, and there may be competing reactions leading to undesired products.

Despite its central importance, the quantitative study of chemical reactions and reactors did not receive much attention until the end of World War II. Gradually, we have built up the classical theoretical models of chemical reactions and reactors that are still the principal ones used today, such as the Langmuir-Hinshelwood-Hougen-Watson kinetics, the cascade of stirred tank reactors, the dispersion model and the stochastic model of reactors, and the diffusion model of a pellet. In the last ten years, we have seen increased use of mathematics to study the *consequences* of these fundamental models. With the coming of high-speed electronic competers, many models have been studied and solutions for particular sets of variable values can be computed to a great deal of accuracy. Another line of development is concerned, for a range of values, with the *properties* of these solutions such as: the existence and multiplicity of solutions, the a priori bounds of the solutions, the stability and transient behavior of these solutions. This monograph represents one of the most important contributions in this direction.

This book is of primary interest to theoretical engineers in research and in teaching. It represents the research results of the author on three specific systems: the batch reactor, the stirred tank reactor and the catalyst pellet. He used the concepts of topology and functional analysis with exceptional skill. His theorems are rigorously derived, but contain few surprises. The short-term impact of this monograph on chemical technology is likely to be small, since it is addressed to the specialist in academic research rather than to the engineers facing current problems. The main pleasure in reading this book is to see many questions settled with authority and economy.

There is a danger of a growing divergence of terminology between the chemist and the chemical engineer. The concept of "mechanism" to a chemist represents more than the stoichiometry of an elemental reaction, it includes also a stereochemical description of the molecules as they unfold and break apart. It is quite conceivable that many different mechanisms could lead to the same kinetic expression, which describes the rate of chemical reaction as a function of concentrations, temperatures, pressures, amounts of catalyst, etc. Two reactions are said to be "independent" to a chemist if they proceed by different mechanisms, for example a hydrocarbon molecule may crack into two smaller molecules by a thermal mechanism or a catalytic mechanism by way of a carbonium ion. The overall stoichiometry of these two reactions could be identical, but to a chemist they clearly belong to two different mechanisms and are independent of each other. With a little care, a chemical engineer can refer to those two reactions as "linearly dependent" but "mechanistically independent." The chemist and the chemical engineer must remain on speaking terms for many years to come, and it would be preferable if they speak the same language.

JAMES WEI
Mobil Oil Corporation

ACKNOWLEDGMENTS:

Industrial Institutions

In lieu of advertising, the following have donated funds for the support of **CHEMICAL ENGINEERING EDUCATION:**

C. F. Braun & Co
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Standard Oil (Indiana) Foundation
The Stauffer Chemical Company

ACKNOWLEDGMENTS: Educational Institutions (New)

In addition to **eighty** institutions listed in the Winter 1969 Issue, the following have donated funds for the support of **CHEMICAL ENGINEERING EDUCATION:**

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South Dakota School of Mines and Technology
University of Southwestern Louisiana
University of Texas
Texas A & M University
Villanova University
University of West Virginia
University of Wisconsin

CHEMICAL ENGINEERING DIVISION ACTIVITIES

The annual ASEE meeting will be held at Pennsylvania State University, University Park, Pa. on June 23 - 26, 1969. The ChE Program Chairman for the meeting is Dr. Kenneth B. Bischoff, University of Maryland, College Park, Md. 20742. The program follows:

Monday, June 23

12:00 - 1.30 P.M. **Business Luncheon, Executive Session**
Presiding: W. H. Corcoran

Tuesday, June 24

10:00-11:45 A.M. **Annual Lectureship Award** (sponsored by the Minnesota Mining and Manufacturing Co.)
Presiding: W. H. Corcoran
Distinguished Lecturer: C. J. Pings, Cal. Tech
Topic.: "A Chemical Engineer Looks at the Physics of Simple Liquids

12:00-1:30 P.M. **Annual Business Meeting**/Luncheon
Presiding: W. H. Corcoran

1:45-5:30 P.M. **Panel Discussion**
"Educational Directions for Problems of Society: Urban Affairs"
Presiding: J. M. Marchello
Co-Moderator: K. B. Bischoff
Panelists: J. B. Coulter,R. A. Gaska, E. Lindvalt, J. O'Grady, C. D. Prater, J. R. Sheaffer

Wednesday, June 25

8:00-11:45 A.M. **Conference and Panel Discussion** (Joint with Biomedical Engineering Committee)
Educational Directions for Problems of Society: Bioengineering
Presiding: R. L. Dedrick
Speakers: R. L. Dedrick, Introduction; A. E. Humphrey, Biochemical Engineering: Applications of Single Cells — Food and Enzymes; D. I. C. Wang, Large-Scale Tissue Culture; E. S. K. Chian, G. Moore, R. P. de Filippi, Separation Processes in Bioengineering; K. B. Bischoff, Biomedical Engineering.
Panel Discussion: Bischoff, Dedrick, de Filippi, Humphrey, Wang

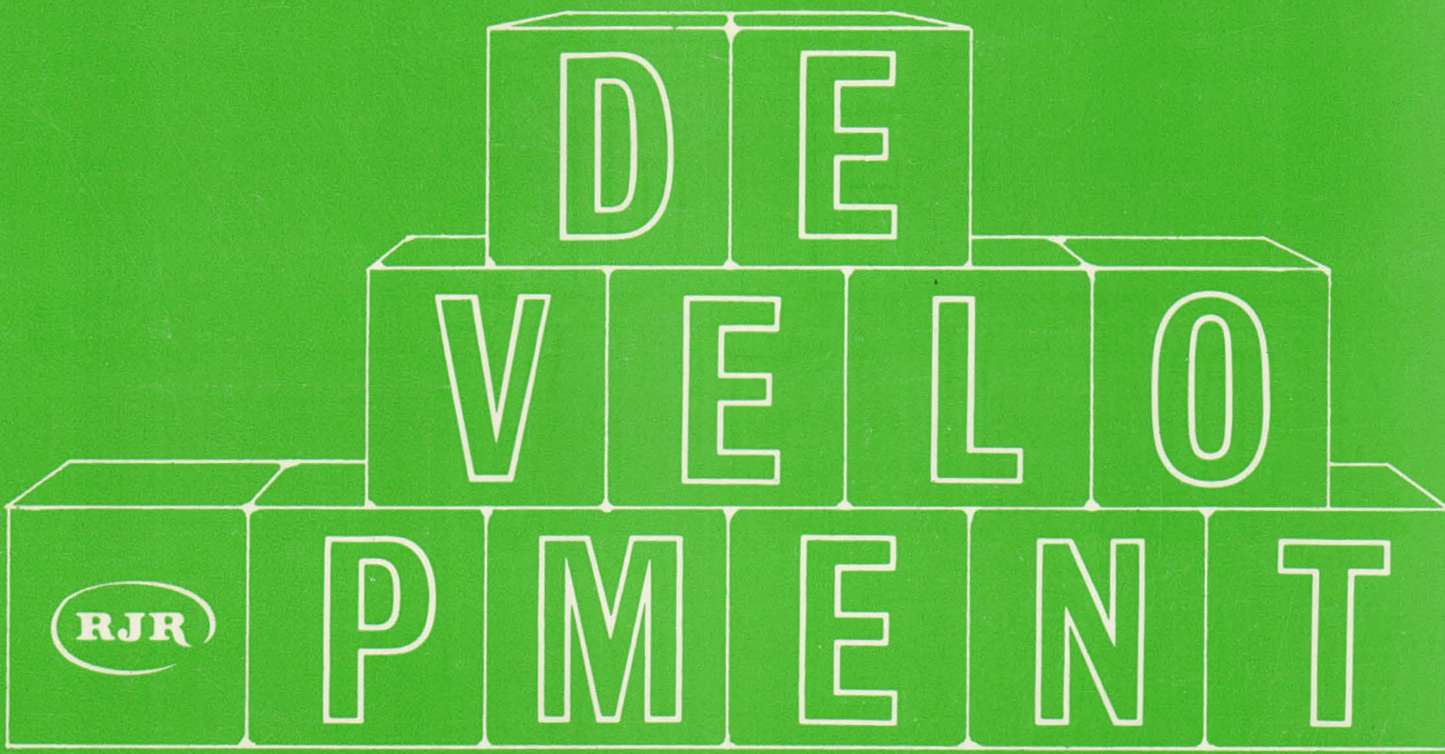
10:00-11:45 P.M. **Panel Discussion** (Joint with Electrical and Industrial Engineering Divisions)
Interdisciplinary Foundations for Systems Engineering
Presiding: R. N. Lehrer
Speakers: Systems Theory: Does It, or Will It, As it Develops, Provide a Common Basis for Interdisciplinary Developments in Systems Engineering?; Industrial Dynamics: What Does it Offer for Systems Engineering?; How Are Social and Human Aspects Integrated into Interdisciplinary Systems Engineering?; How Does Systems Analysis Integrate with Systems Engineering?

1:45-3:30 P.M. **Business Meeting/Department Heads**
Presiding: E. B. Christiansen

1:45-3:30 P.M. **Conference** (Joint with Energy Conversion Committee)
New Energy Sources
Presiding: Manfred Altman
Speakers: Howard Wilcox, Under-Water Power Sources; S. W. Gouse, Jr., New Externally Heated Engines; Donald Friedman, New Automotive Power Sources; J. B. Dicks, Large Scale Power Developments; Arvin Smith, New Developments in Space Power; Royal Rostenbach, Energy Conversion and Universities.

1:45-3:30 P.M. **Panel Discussion** (Joint with Electrical and Industrial Engineering Divisions)
Interdisciplinary Foundation for Systems Engineering
Presiding: R. N. Lehrer, Georgia Institute of Technology, continuation of 10:00-11:45 A.M. event.

6:30 P.M. **Annual Banquet**
Presiding: W. H. Corcoran
Speaker: R. E. Balzhiser, University of Michigan
Topic: "A Technologist in Government"



R. J. Reynolds Tobacco Company has one of the country's best Development Centers . . . and we want CHEMICAL ENGINEERS!

We have immediate openings for CHEMICAL ENGINEERS in the Tobacco Products Division of the Product Development Department.

Our Product Development Department is relatively new, being established in 1965 primarily due to the Company's expanding diversification program.

The Product Development Department has the responsibility for formulating, developing and evaluating products for existing, as well as potential markets in the areas of foods, allied packaging products and tobacco.

CHEMICAL ENGINEERS at RJR develop existing lines in the Company's food and tobacco products and work on new product lines in a variety of fields.

These include such leaders as; HAWAIIAN PUNCH, CHUN KING, PATIO, COLLEGE INN and FILLER SNACKS in the food line and WINSTON, SALEM, CAMEL, PRINCE ALBERT and MADEIRA MIXTURE in the tobacco line.

The challenge, the growth and the future are unlimited for CHEMICAL ENGINEERS at R. J. Reynolds Tobacco Company, Winston-Salem, N. C.