CHEMICAL ENGINEERING
A Crisis of Maturity

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CHEMICAL ENGINEERING is a field in a state of transition. This is especially true for those of us who are involved in chemical engineering education and who wonder about the future and direction of our discipline. Ours is a relatively young branch of engineering and it seems to be in the midst of its first major transition. The optimists among us tend to call this transition "maturity," while the pessimists call it a "crisis." The truth is probably at neither extreme. I prefer to call it a crisis of maturity.

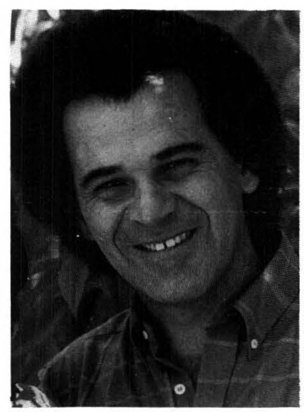
Chemical engineering is a mature field which stands on the solid foundation of physical chemistry, transport phenomena, kinetics, and reactor design. It emerged fifty years ago from the traditional field of industrial chemistry, and the consistent trend during all these years has been toward generalities, unified approaches, and fundamental studies. There are several examples of this trend. The originally different disciplines of fluid flow, heat transfer and mass transfer merged together into the unified field of transport phenomena. Unit operations such as distillation, absorption and extraction merged into stage operation. Even chemical kinetics and reactor design are now taught in a general form and rarely deviate from the general notation $A + B \rightarrow C$. This general approach was, and still is, very powerful. As a result chemical engineers became, and still are, extremely effective in solving problems and in designing plants. Twenty, or even ten, years ago most graduate research was devoted to topics such as diffusion, bubbles, falling film, and fluidized bed. There was no necessity for practical justification since it was considered basic chemical engineering—something which had to be done in order to establish the field. However, within the last few years things have changed considerably. The classical fundamentals are well established, and the research now done within chemical engineering departments is usually applied and is commonly evaluated on its relevance to current problems and needs.

The classical literature of chemical engineering is marked primarily by its simplicity. Transport phenomena and reactor design are examples where common sense, mathematics, and engineering are combined to solve practical and real problems in a simple way. However, recent trends in the chemical engineering literature suggest that there is a bias against simplicity. W. K. Grasman [*Interface*, **16**:2, 43-51, 1986] has pointed out a general trend, across all disciplines, toward publishing unnecessarily complex works. His "Joe's Theorem" can be applied to the literature of chemical engineering:

> ***Nothing is published in the area of chemical engineering science unless it is mathematically interesting. Nothing is applied in industry unless it is mathematically trivial. Since trivial results are not interesting and since results that cannot be applied are not useful, nothing useful will ever be published in the field of chemical engineering science.***

Though an exaggeration of the present state, this "theorem" points out the need for simplicity and relevance in academic research.

The direction of chemical engineering graduate research is changing. Fundamental topics are no longer appealing to the general population of graduate students who are mostly attracted to fields where jobs are currently available. Even in the academic job mar-



Jacob Jorne, professor of chemical engineering at the University of Rochester, received his PhD in chemical engineering from the University of California, Berkeley (1972). A native of Israel, he obtained a BSc and an MSc from the Technion-Israel Institute of Technology in 1963 and 1967, respectively. His research interests include electrochemical engineering, semiconductor processing, energy conversion and storage, and the theoretical biology of ecosystems. He has considerable industrial experience as a consultant. In 1979 he was named Chemical Engineer of the Year by the American Institute of Chemical Engineers, Detroit Section.

ket, the magic words of "biochemical engineering" and "semiconductor processing" can land a choice teaching job. It is interesting to note that these two attractive areas are at the core of the current transition within chemical engineering education.

MICROELECTRONICS—MISSED OPPORTUNITY

Chemical engineering missed the opportunity to make prime contributions to the microelectronic industry. Microelectronic devices are produced by a series of purely chemical processes such as chemical vapor deposition and etching. Nevertheless, the electronic industry emerged and matured virtually without the participation of chemical engineers. Though many chemical engineers are employed in the semiconductor industry, the contribution of their field, as a science and as a philosophy, is negligible. The amazing revolution toward miniaturization of devices and processes has occured over the last decade or two, yet chemical engineering is just starting to catch up with this trend. It might be too late. Had it been left to chemical engineers, the microelectronic industry would not be where it is now. The concept of carrying chemical reactions on a micron-size level, on a huge scale, and under absolutely clean conditions is foreign to the traditional chemical engineer who is educated to manufacture bulk chemicals within a profession dominated by the oil and chemical industries.

Chemical engineers must develop new processes, equipment, materials, and devices not currently envisioned. The possibility of packing chemical reactions into smaller and smaller volumes will begin to emerge through a better understanding of reaction mechanisms and networks, monolayer between phases, thin films, micro-sensors and microreactors, to name just a few. The trend should not be just an attempt to catch up with the microelectronic industry, but rather to develop a new field of microchemical engineering where we can combine and implement our unique knowledge and solid foundation and lead a new industry based on fields like molecular electronics, sensors and enzymes.

MICROCHEMICAL ENGINEERING

The idea of microchemical engineering is really not new, but it deserves new focus as a commonly denominating theme. Molecular thermodynamics is an example of a microscale research with macroscale applications. Similarly, recent works on interfacial phenomena, colloids, surface science, nucleation, microcirculation, and cell phenomena are all examples of chemical engineering science on a microscale.

There are some objective reasons why the chemical industry and chemical engineers are so late in

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adopting the trend toward microscale processes and devices. Obviously, at the present time it is hard to envision miniaturization of heat exchangers, chemical reactors or distillation columns simply because heat and mass transfer need large interfacial areas and chemical reactions utilize space and time to achieve appreciable conversion. However, chemical engineering deals with a wide range of dimensions. The physical extent can vary over eight orders of magnitude. The megascopic systems are on the order of 1 meter and up ($>$ 1m). Macroscopic systems are usually within 10^{-3} to 1m. The microscopic and the submicroscopic systems are within the 10^{-6} to 10^{-4} m range, while the molecular scale is on the order of 10^{-8}m. Traditional chemical engineering deals mostly with megascopic systems whose fundamental mechanisms are within the macroscopic range. For example, heat exchangers and distillation columns are megascopic while heat and mass transfer boundary layers are within the macroscopic level.

We can rival the momentum of the microelectronic developments only by adopting new scientific discoveries and using our skills to bring them to commercial realization—a process we capitalized upon in the past. Our chemistry and industrial chemistry roots should be maintained as the most unique feature of our discipline, while the future of our profession depends entirely on the recent developments and advances made in chemistry, physics and, I must add, biology.

BIOCHEMICAL ENGINEERING

In addition to a dependence upon advances made in chemistry and physics, chemical engineering of the future will be increasingly dependent upon new biological knowledge. There is a shared conviction that biochemical engineering is destined to be a major force and most chemical engineering departments are looking for young faculty trained in this area. There is a danger in thinking that having one or two professors in each chemical engineering department who are doing some biological experiments will take us into the rosy future of genetic engineering and molecular biology. The challenge is much too great for such an approach. We must educate undergraduate students in biology, biochemistry, genetics, and molecular biology with the same intensity that we presently educate them in physical chemistry. For years we have been educating students and training them with the overall goal of preparing them to work for companies such as duPont and Standard Oil. This approach was very appropriate and extremely successful in the past. However, we must now prepare students for the unknown future and for imaginary employers which may include a genetic engineering company, space processing companies, and, maybe, molecular computer manufacturers. Courses such as distillation must be eliminated and replaced. This does not mean that distillation is a thing of the past. To the contrary, energy problems will be staying with us for a long, long time. However, teaching distillation is not a subject which increases the student's innovative capabilities nor does it provide basic science for the unknown future.

CONCLUDING REMARKS

I was always proud of chemical engineering, mainly because it was the only branch of engineering where science played a major role. As the field matured I sensed a departure from the fundamentals of science and the increasing reliance on applications. In order to regain the enthusiasm of the early years, and in order to establish new frontiers, we must rearrange our educational priorities and teach basic biochemistry, microbiology, genetics, solid state physics, and human factors engineering. We must undertake new courses as well, which teach innovative problem-solving and which encourage cross-disciplinary thinking. This is the only way we can preserve and revitalize chemical engineering, and it is the best insurance that we will establish new industries which promise to improve the quality of life.

The crisis of maturity confronting chemical engineering can be resolved with energy, courage, and foresight. The most important decisions will center on which traditions to maintain and which new approaches to establish. The question of whether we are in the midst of a crisis or are simply a matured profession is a debate we don't have time for. The lack of risk-taking, excitement and vision are the only relevant problems to be confronted. I am confident that wise deliberation will underscore our opportunities. □

THE WILLIAM H. CORCORAN OUTSTANDING PAPER AWARD

In the opinion of many, Bill Corcoran did more for the advancement of chemical engineering education and engineering education in general in the United States than any other person in recent decades. He shared his many talents selflessly, often working quietly behind the scenes, but more frequently in important positions of leadership. Recognition of Bill's many contributions through establishment of the William H. Corcoran Outstanding Paper Award allows the ASEE Chemical Engineering Division to, in Bill's own words, "pay back the debt we owe." Bill was describing his own dedication to his profession as a measure of his appreciation for the opportunities given him early in his career.

Bill Corcoran's excellence in teaching and his strong interest in students were recognized through his selection to receive the ASEE Western Electric Fund and Lamme Awards and the ABET L. E. Grinter Award. His comprehensive research on the nitrogen oxides predated the general recognition of the key role these substances play in environmental control. He pioneered the application of chemical engineering principles to biomedical engineering.

Singling out one area most noteworthy from the many in which Bill did so much is difficult, but many would agree that the area should be the technical literature. His own extensive list of publications includes three books and many widely read contributions to the technical literature and to contemporary thought about engineering education and practice. He was a member of the publications Board of *Chemical Engineering Education* from 1966 until his death, serving as its chairman in 1967-68 and again in 1975-77. At the national level in ASEE, he served on the Publications Policy Committee, Engineering Education Editorial Committee and ECRC Publications Committee. He held similar assignments in the American Chemical Society and in AIChE.

Bill is perhaps best known within ASEE for the landmark report resulting from the 1975-77 study of the Committee on Review of Engineering and Engineering Technology Studies which he chaired. His extensive service to AIChE led to his election as president in 1978; he was president-elect of ABET at the time of his death in 1982. He was elected to the National Academy of Engineering in 1980.

Through dedicated teaching, research, service and publications, Bill Corcoran was a positive force in engineering education. Just as Bill did throughout his career, the Corcoran Award will grow in stature over the years, beginning with its distinguished inauguration at the Cincinnati Annual Conference.

George Burnet
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