ChE report

CHEMICAL ENGINEERING CURRICULA FOR THE FUTURE

Synopsis of Proceedings of a U.S.-India Conference, January, 1988

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THE GOVERNMENT OF India is committed to rapid industrial growth in which new technologies hold a prominent role, and it shares common concerns at the educational level and on curricular matters with chemical engineers from the United States. A seminar was held at Bangalore, India, in January of 1988, to deliberate curricular changes in undergraduate chemical engineering in view of emerging technologies. The International Division of the National Science Foundation provided grants which enabled several American delegates from chemical industries and academia to attend the seminar, which was also attended by Indian delegates from both industry and academia.

The seminar approached the issue of chemical engineering education by organizing a first session of presentations by industrial and academic personnel on specific areas of technology. In a second session, delegates debated various aspects of the undergraduate curriculum, including basic science and core courses, chemical engineering courses, and electives. After completion of the formal presentations and the discussions, individual committees deliberated on each of the foregoing curriculum components to arrive at a consensus of specific recommendations for the academic communities in the United States and India. In addition, a panel composed of delegates from industry and academia debated "The Emerging Technologies and the Role of Chemical Engineering in Them" in an open forum.

The proceedings of the seminar have been compiled into a Report to the National Science Foundation. The purpose of this summary is to provide a brief report on its results and recommendations.

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PERSPECTIVES ON EMERGING TECHNOLOGIES

The discussions on emerging areas of technology covered biotechnology, materials for structural, microelectronic, and catalytic applications, and new separations processes. In each of these areas, perspectives were presented by both industrial and academic personnel.

Biotechnology

Stanley I. Proctor and Walter Bauer (Monsanto) presented the areas of opportunity in biotechnology. Five categories (human health care, animal science, crop science, waste management, and miscellaneous products) were presented as the main areas of opportunity. Dr. Proctor emphasized that most of the unit operations in bioprocesses are the same as those used in classical chemical engineering, but distinctive elements of bioprocessing include special needs for sterile operating conditions for bioreactors, stringent control requirements for maintaining living systems, sophisticated separation techniques for dilute systems, *etc.* Scale-up methods for equipment operated at laboratory scale, such as chromatographic columns (*e.g.*, for the separation of proteins), were emphasized. Dr. Proctor also addressed the special needs of biotechnology and concluded that the training of chemical engineers to work in biotechnology should be handled as an option to the traditional program. He pointed out that although the biotechnology industry is a significant employer, it is not viewed as a major employer.

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He also encouraged joint appointments of life science trained faculty in chemical engineering and life science departments.

George T. Tsao (Purdue University) provided an academic view of opportunities in biotechnology and identified five basic components of biotechnology processing: reactor engineering, separation, genetic engineering, analysis and characterization, and post-treatment. The development of a suitable methodology to deal with each requires a cooperative effort with personnel in biochemistry, molecular genetics, chemistry, and microbiology. Professor Tsao also focused on the variety of products (foodstuffs, health products, specialty substances, bulk chemicals, waste utilization) arising from biotechnology processing and outlined several research areas of interest to chemical engineers. He emphasized the need for more background in general biological sciences, along with elective courses in bioreaction engineering and bioseparation, and outlined some general guidelines for their contents.

Material Engineering and Technology

There were five presentations (two by industrial delegates and three by academic delegates), and the topics covered polymers and their processing, ceramics, catalysts, and microelectronic materials. Presentations varied between those focusing on a class of materials for different applications (such as polymers, ceramics, and composites) and those that were geared to specific applications (such as catalysts and microelectronic devices). Robert Laurence (University of Massachusetts) and Sheldon Isakoff (Du Pont) presented surveys of the first type, while Lanny Schmidt (University of Minnesota) addressed catalyst materials specifically, and V. R. Raju (Bell Laboratories) and Tim Anderson (University of Florida) focused on microelectronic materials

Polymeric and Ceramic Materials-Composites: Professor Laurence provided an academic perspective on polymeric materials. He observed that the polymer industry, while maintaining its involvement with traditional commodity polymers such as polyolefins and PVC, has undergone a significant "restructuring" in its emphasis on new and advanced materials. In regard to newer applications he demanded broader understanding of polymer synthesis, electrochemical properties, morphology, and analytical methods. While the curriculum might include some in-depth courses in polymer science and engineering, he concluded that essential concepts of materials and polymers should also be incorporated in other core courses.

Dr. Isakoff focused mainly on structural materials. He covered the applications of various materials (advanced engineering plastics, structural composites, ceramic materials, *etc.*) and outlined the prevailing problems, avenues for their resolution, and areas where chemical engineers play a significant role. He stated that chemical engineers must be able to "speak the language" associated with advanced materials technology and believes this can be accomplished by offering special optional courses and minor specialization at the undergraduate level. He stated that examples from the new materials fields can be used in lectures, laboratories, and homework problems just as effectively as those from more conventional areas.

Catalysis and Materials: Professor Schmidt observed that the traditional scenario of "sequential" development of product-process combination in stages has given way to a situation requiring joint consideration of the entire process (reactor, catalyst, separations, feedstocks, by-products, and markets). A fundamental understanding of solid materials is necessary. He suggested that in order to understand the principles of crystal structure, phase behavior, electronic structure, and defects (all essential prerequisites to, and understanding of, catalysts), an introductory course in materials characterization techniques, such as X-ray diffraction, is necessary, and he pointed out that in pursuing the material aspects of catalysis one is concerned with issues very similar to those involved in processing procedures for microelectronic and ceramic materials.

Microelectronic Materials: Dr. Raju recounted chemical engineering principles encountered in the fabrication of optical fibers and integrated circuits, with special emphasis on the preparation of ultrapure glass preforms using the modified chemical vapor deposition process. He pointed out that the electronics industry uses a wide variety of processes (deposition, etching, diffusion, implantation, *etc.*) in which different types of chemical reactors are employed to carry out both homogeneous and heterogeneous reactions under precisely controlled conditions and that the necessary chemical engineering background has not been brought to bear on the optimal design of such chemical reactors. He also pointed to the need for an understanding of interfacial phenomena on a molecular level in developing processing techniques for manufacturing devices in which minute components are put together. Interfacial effects are extremely important in "thin film" deposition, controlled etching of microstructures, adhesive bonding, and in the realization of high performance organic materials as dielectrics in integrated circuits.

Tim Anderson presented an academic perspective of the opportunities for chemical engineers in electronic materials processing industries. He pointed out that these industries present many fundamental chemical engineering processes, with the major distinction between traditional chemical processing and EMP being the smallness of the scale of operation characterizing the latter. He outlined the various problems which can be tackled by chemical engineers, stressing that it is the unique coupling of process engineering with process chemistry that makes chemical engineering an integral part of electronic device manufacturing. He presented three different approaches for introducing electronic materials processing concepts to the undergraduate student and recounted in detail his experience with a specific senior elective course at the University of Florida.

New Separations Processes

E. N. Lightfoot (speaker) and M. C. M. Cockrem (both of the University of Wisconsin) presented an academic perspective on new separations processes. Using recovery from dilute solutions as an example, Professor Lightfoot illustrated the power of careful problem definition and application of transport phenomena in separations processes and equipment design. He pointed out that examination of crude economic data suggests that recovery of potentially valuable solutes from dilute solutions is dominated by the cost of processing large masses of unwanted material. This suggestion is confirmed by examination of the most widely used current processing techniques. He suggested a general strategy for reducing recovery costs.

Shivaji Sircar (Air Products and Chemicals, Inc.) concentrated on bulk separation of gas and liquid mixtures by adsorption and membrane technologies. He briefly described the process principles and their recent applications in the bulk separation of gas and liquid mixtures. In identifying research needs, Dr. Sircar pointed out that fundamental work towards understanding single and multicomponent fluid-solid adsorption interactions, both in terms of thermodynamic equilibria and interactive mass transport, was inadequate, and he added that some other areas in which fundamental work is needed include the transport of a fluid through solid membranes, durability of membranes under mechanical and thermal stresses, *etc.* He feels that the coverage of adsorption and membrane science technologies in texts on unit operations is inadequate and needs updating.

The foregoing presentations concluded the session in which specific technologies were discussed. Of particular interest in regard to education was the emphasis placed by several speakers on retaining the strong fundamental base of chemical engineering—some speakers warning against neglect of traditional areas and others warning against excessive introduction of technology at the expense of basic issues. The message came through that the problem is how to *enhance* the fundamental base of chemical engineering so that students will become literate in different areas of technology and be able to function efficiently in a multidisciplinary team of scientists and engineers.

EVALUATION OF CURRENT CURRICULA

In addressing the chemical engineering curriculum, four categories were identified: basic science courses, core courses, chemical engineering courses, and electives. Delegates from both sessions were present for the discussion, although the speakers in this session were entirely from academia.

Basic Science Courses

H. Ted Davis (University of Minnesota), J. M. Caruthers (Purdue University), and G. Padmanaban (Indian Institute of Science) covered different components of basic science requirements which are generally not covered in the present curricula.

Professor Davis made a strong plea for background in interface science and interfacial engineering, observing that the traditional background provided very little training in this area of increasing importance. He pointed out that interfacial processes impact a substantial part of a $150 billion U.S. industry because of its concern with products affected by interfacial engineering. The mixing of water, oil, and surfactants under suitable conditions produces applications of interfacial engineering in biotechnology, microelectronic and ceramic materials processing, *etc.* Professor Davis strongly recommended an elective course on the fundamentals of colloid and interface science which could also be taken by graduate students seeking specialization in this area.

Professor Caruthers pointed out that chemical engineers have a special role to play in advanced materials where the molecular/microscopic structure, manufacturing process, and ultimate product performance are intimately related. He feels that all chemical engineering students must have some familiarity with the solid state, but he ruled out the elective approach and instead proposed a required course in materials science taught (say) in the sophomore year. He presented topics that could be covered in the course, placing emphasis away from metals.

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Professor Padmanaban addressed the issue of a life science background for chemical engineers and warned against adherence to engineering methodology without sensitivity to biological complexities. He proposed a life science package of twenty-five credits in biology courses in a four-year bachelor's degree program in biochemical engineering. Since this requirement (which he believes is essential for good biochemical engineers) may be oversized, he suggested pruning the requirement down to 8-10 credits in the BS program, deferring the rest to a master's degree in biochemical engineering. He feels that not all chemical engineering institutions need to offer such a program. He also argued for biology courses to be taught by biologists, with special books to be written to suit chemical engineers.

Chemical Engineering Courses

The chemical engineering courses that were discussed were: thermodynamics, transport processes, chemical reaction engineering, process design, and process control. Discussion centered around how these courses can be modified in the light of newer requirements.

Thermodynamics: M. S. Ananth (Indian Institute of Technology, Madras) discussed thermodynamics as taught to chemical engineers and presented the outline of a course at IIT, Madras, much of which is "conventional" by design. He stated that changes are needed in the type of examples used and cited several examples with applications in biology and biochemistry, and in fuel cells and thermochemical cycles, as new areas of concern. He also emphasized the importance of computers in the teaching of thermodynamics, citing their impact in solving complex problems.

Transport Processes: R. A. Brown (Massachusetts Institute of Technology) argued that the need for understanding of transport processes was greater than ever before because in the new areas of application the focus is on fine-scale structural and chemical features of the product, and complex transport processes abound in the processing of the materials. He observed that a transport course must impart an understanding of transport processes and must provide a basic grasp of the key techniques of analysis. He provided arguments that the separation of techniques for analysis from applications was not necessary and presented an advanced undergraduate/graduate-level course in "Analysis of Transport Processes" in which the major emphasis is on teaching basic concepts in heat, species, and momentum transport and on the techniques for closed-form analysis of these processes. He presented the topics in detail and pointed out that examples from a variety of application areas could be easily incorporated by using the experiences of the lecturer and through text sources from these areas.

Process Control: Thomas F. Edgar (University of Texas, Austin) reviewed the developments in process control instruction and presented an outline for revision. He pointed out that in the coming years a process control course should not only cover analog controllers and continuous systems, but should also expose the student to digital control and discrete systems concepts. Hands-on experience in distributed control with industrial grade equipment would be helpful, and the availability of computer-aided instruction software with graphics would greatly enhance teaching effectiveness. Such software could also expose the student to plantwide control concepts as opposed to analyzing only single loop systems.

Professor Edgar feels that a lack of fundamental understanding is preventing the development of closed-loop control strategies and mentioned two specific examples—one in solid-state device processing and the other in batch and fed-batch bioreactors. As improved understanding of such processes develops, it would be worthwhile to include examples built around them in the course on process control. Professor Edgar also presented an outline of a futuristic (in the year 2000) course on process control which focuses on discrete control systems concepts.

Chemical Engineering Electives

In addition to the elective courses discussed below, the course on interfacial science and engineering proposed by Professor Davis during the discussion on science courses, and the course in electronic material processing discussed by Professor Anderson in Session I must also be regarded as recommended electives.

Biochemical Engineering: H. C. Lim (University of California, Irvine) feels that the scientific base of chemical engineers must be broadened to include life sciences, and he pointed out that life science concepts can be incorporated into traditional courses (*i.e.*, one can cover life science examples in a kinetics and reactor design course). He also asked that the undergraduate curriculum be flexible enough to allow specialization through carefully planned elective courses and that students opting for biochemical engineering be advised to take life science courses in their sophomore and junior years. He argued that with a strong life science background, the application-oriented courses can focus more on the engineering aspects of emerging technologies. He also feels the need for flexibility in the rules of accreditation in order to provide for more strength in life sciences and biochemical engineering.

Polymer Science and Engineering: S. K. Gupta (Indian Institute of Technology, Kanpur) observed that incorporating polymer background into the chemical engineering curricula has been slow. In discussing an elective course in polymer science and engineering, Professor Gupta asked for integration of the fundamental concepts from the polymer field into the core courses. He illustrated polymer topics that can be absorbed into the basic courses in chemistry (mechanics, thermodynamics, reaction and reactor engineering, transport phenomena, and process control and optimization), and he pointed out the scarcity of textbooks in this vein. He argues that many of the topics currently covered in polymer electives can actually be covered in the core courses, leaving newer material for an elective course. He outlined the contents of such a course, and although the list of topics is application-oriented, the treatment of the topics itself is fundamental. Heavy emphasis is placed on biopolymers, which he believes offer considerable scope for contributions by macromolecular engineers.

Artificial Intelligence: Venkat Venkatasubramanian (Purdue University) presented an elective course in artificial intelligence (AI). He argued that AI and knowledge-based systems provide an important framework for the modeling and solution of several classes of problems in process engineering, and he observed that training in these approaches will better prepare chemical engineers to cope with the demands and changes of the industrial environment. From his personal experience in teaching a course on AI, he feels that the proper way to educate students about AI is to teach it from a process engineering perspective. Students were taught the interdisciplinary area of AI and process engineering by using examples and exercises from process engineering. He feels that this approach is more appropriate and meaningful than learning from a computer science point of view. The lack of a suitable text will be remedied in the future by a series of monographs on AI in process engineering to be published by CACHE Corporation, an affiliate of the AIChE.

Colloids and Interfaces: R. Rajagopalan (University of Houston) presented an elective course in colloids and interfaces. He asked for integrating basic concepts of colloid and interface science into the core courses and listed several topics that could be included in material and energy balances, transport phenomena, thermodynamics, and separation processes. Although many examples from high technology were cited as motivation for the topics discussed, Professor Rajagopalan echoed the warnings of others that "high-tech" is not a panacea, stating that advances in high technology often cannot wait for systematic research while at the same time academic research and education cannot afford to keep switching directions based purely on the forces of the market.

The Chemical Engineering Laboratory

M. M. Sharma (Bombay University) began with the observation that the conventional chemical engineering laboratory course does not realize its stated objectives. He discussed various remedial measures to correct this situation, including the use of large-size equipment, open-ended experiments, demonstration experiments, and equipment study experiments. He emphasized open-ended experiments and suggested a regular turn-over from a "bank" of experiments. He proposed the inclusion of an experimental design project in which the student would be required to suggest an aim, the equipment required, and the measurements to be made for achieving the aim. He also proposed demonstration experiments chosen to satisfy well-defined criteria.

DISCUSSIONS AND RECOMMENDATIONS

Each presentation was followed by a discussion period in which all delegates participated, and committees were formed to discuss the various components of the chemical engineering curriculum. The chairmen of the individual committees then presented the committee recommendations to the entire group of delegates. An article by Watters, Laukhuf, and Plank (University of Louisville) has examined the committee recommendations in light of ABET requirements and has concluded that implementation is possible. Generally, the organizers feel that accreditation requirements must be softened to accomodate future curricular needs.

In addressing curricular changes, the diversity of existing curricula makes a universal formula impossible. The seminar was designed as an intellectual discourse on curricular changes in the light of emerging technologies, with the hope of evolving some general guidelines. The following sections outline those guidelines.

Science Courses: The science group, headed by Professor Davis, felt that the science core should be taught by scientists and that the chemical engineering faculty must persuade physical chemists and material scientists to include concepts and examples related to emerging technologies in the core courses. More specifically, examples must include solids, polymers, catalysts, interfaces, colloids, bioreactions, *etc.* They further recommended a course on computational methods after the completion of the core math courses, and that chemical engineering students be allowed to substitute one life science course for one core chemistry course (the most logical option being the second organic chemistry course). No changes were recommended for the physics courses.

Engineering Core Courses: This group, led by Professor Gandhi, outlined the topics to be dealt with in thermodynamics and transport processes. Although their outline showed no changes in the list of topics currently covered in chemical engineering curricula, they suggested that a special effort be made to include new examples from the emerging technologies. Another recommendation was to include discussion of the solid state with respect to deformation, transport of energy and mass, and chemical reaction, with examples of applications to the newer technologies of materials and microelectronic devices.

Chemical Engineering Courses: Arvind Varma (Notre Dame) headed the group which presented observations and recommendations on chemical engineering courses such as chemical reaction engineering, separations, design, control, and laboratory. The group stressed fundamentals with inclusion of examples from both traditional and emerging technologies. Since textbooks on the newer technologies are not yet available, they recommended that examples be commissioned and circulated to chemical engineering departments in a package. They encouraged the use of realistic problems, with liberal use of computer software focusing away from numerical methods. They also recommended that in addition to the two-semester laboratory course, demonstration experiments and video tapes should be used to firm up concepts and even to introduce new course material.

Electives: This group, headed by J. M. Caruthers (Purdue University), classified electives in the new technology areas as microelectronics, biochemical, interfacial, AI, and polymers, and in the traditional technology areas as environmental, petroleum, process metallurgy, and food. A third category was termed "Advanced Core" and included transport, thermodynamics, optimization, and control. The group felt that electives in the new technologies should not eliminate electives in either the traditional technologies or the advanced core. They observed that it is not necessary for each department to offer a complete package in every area.

CONCLUSIONS

The broad conclusions which can be drawn from this four-day seminar are:

1. Chemical engineering must retain its traditional interests, but at the same time must expand its fundamental base to include applications in the new areas of technology. In particular, background in states of matter other than the bulk fluid state (such as solids, thin films, interfaces, microstructured materials, *etc.*) was emphasized.

2. In view of the interdisciplinary nature of the newer areas and the essentially transient nature of technological developments, a fundamental background is necessary to provide a healthy appreciation of the issues involved in the new fields. Thus, chemical engineering expertise on process systems design in such areas must function within the framework of a collaborating team of scientists and engineers of various backgrounds.

3. Curricular modifications must entertain two elements. First, fundamental information must go into the science and engineering core courses, with examples to illustrate the new applications, and chemical engineering courses must be oriented similarly wherever possible (*e.g.*, chemical reaction engineering, separations, control). Second, more detailed involvement with the newer areas of technology must be accomplished through elective courses. ☐

REVIEW: Buoyancy

Continued from page 181.

neering science point of view. They focus on the formulation of appropriate forms of the transport equations in the boundary region and on the development of similarity or perturbation solutions. Hence, their book complements the book by Joseph *(Stability of Fluid Motions)* where more mathematical aspects of buoyancy-induced convection are discussed.

This book is clearly written and the material is presented in an orderly fashion. The book should serve as a valuable and comprehensive reference source for anyone interested in the engineering aspects of natural convection. Engineers and scientists doing research in this field will certainly want to own a copy of this book. ☐